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World Agricultural Production, Resource Use, and Productivity, 1961–2020

Keith O. Fuglie, Stephen Morgan, Jeremy Jelliffe

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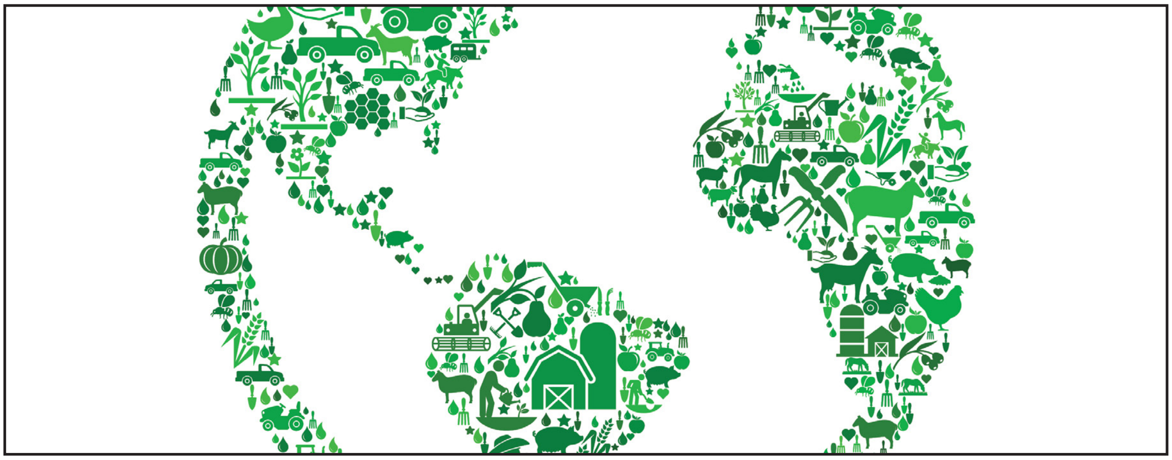

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Abstract

Over the past six decades, the role of agriculture has undergone a vast transformation in the world economy. Agricultural output increased nearly fourfold, while the global population grew by 2.6 times, leading to a 53-percent increase in agricultural output per capita between 1961 and 2020. Real food prices declined relative to the general price level, supplying more affordable and diverse diets. Most of the growth in agricultural production was achieved by raising productivity rather than expanding resource use. There was a pronounced and sustained shift in the location of production to the Global South (developing countries), which between 1961 and 2020 increased their share of global agricultural output from 44 to 73 percent. The composition of world agricultural production, however, remained generally stable, changing slightly to include a larger share of oil crops, nonruminant livestock products, and aquaculture. Global agricultural land area increased by 8 percent to 4.76 billion hectares, or 32 percent of the world's land area. The total number of people working on farms peaked in 2003 at just over 1 billion and then declined to 841 million by 2020, working on approximately 600 million farms. Major technological developments included the spread of Green Revolution crop genetic improvements, increased fertilizer use in the Global South, and the development of biotechnology and genetically modified crops offering pest and disease resistance. Further, aquaculture was developed as an important food source. However, by the decade of the 2010s, the pace of output and productivity growth in world agriculture slowed, food prices rose in real terms, the number of food-insecure people increased, and pressure to expand the use of natural resources to produce food intensified.

Keywords: Total factor productivity, family farms, capital-labor substitution, food security, environmental resources, agricultural land, irrigation, Green Revolution, genetically modified crops, agricultural technical change, agricultural research and development, agricultural extension

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Errata
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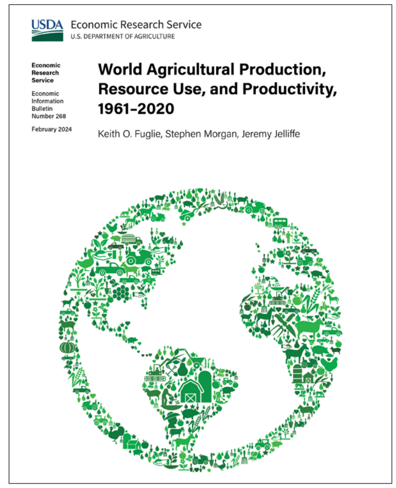
A report summary from the Economic Research Service *February 2024*

World Agricultural Production, Resource Use, and Productivity, 1961–2020

Keith O. Fuglie, Stephen Morgan, and Jeremy Jelliffe



What Is the Issue?

World agriculture has undergone significant transformation over the past six decades. Over this period, most regions of the world transitioned from a natural resource-dependent to a productivity-led growth path, made possible by the development and adoption of new technologies and farming practices. This USDA, Economic Research (ERS) report documents those changes, providing insights into shifting patterns of agricultural production and resource use worldwide. It also shows the evolution of agricultural growth over time and discusses the implications of these dynamics for sustainable use of natural resources and global food security.

What Did the Study Find?

This report shows trends in world agricultural production, resource use, and productivity over the past 60 years (1961–2020). Over this period:

- World production of crop, livestock, and aquaculture commodities grew fourfold, from a gross value of $1.1 trillion to $4.3 trillion dollars (at constant 2015 commodity prices).
- The global share of agricultural production in the Global South increased from 44 percent in 1961 to 73 percent in 2020.
- The composition of global agricultural output gradually adjusted to meet changes in demand, with modestly increasing output shares for oil crops, nonruminant livestock, vegetables, fruits, nuts, and aquaculture and declining output shares for root and tuber crops, cereal grains, and beef cattle.
- Land in global agriculture increased by 8 percent, from 4.43 billion hectares to 4.76 billion hectares. Agricultural land in the Global North declined by 260 million hectares, whereas it increased by 597 million hectares in the Global South, for a net gain of 336 million hectares.
- Irrigated area grew by a factor of 2.3 times between 1961 and 2020 to 343 million hectares; water use in agriculture now accounts for about 70 percent of total global freshwater withdrawals.

- Labor employed on farms worldwide peaked at 1.06 billion people in 2003 but subsequently declined to 841 million people by 2020, working on approximately 600 million farms.
- The use of synthetic fertilizers, especially nitrogen, expanded rapidly during the 1960s through the 1980s; since the 1990s, it has increased at about the same rate as agricultural output.
- The use of feed concentrates, especially protein dense oil crops and meals, became an increasingly important source of animal nutrition and the major feedstuff for nonruminant livestock, poultry, and farm raised fish.
- Agricultural total factor productivity (TFP) measures total output of a sector relative to the total inputs of land, labor, capital, and materials. The world agricultural TFP growth rate increased over the decades from 1961 to 2010, rising from less than 0.1 percent per year in 1961–70 to nearly 2.0 percent per year on average by 2001–10. Agricultural TFP growth then slowed to an average of 1.1 percent per year over 2011–20.
- Increases in agricultural TFP reduced the intensity of natural resource use in agriculture; between 1990 and 2020, the global average amount of land used and greenhouse gasses emitted per unit of agricultural output fell by half or more.
- Sub-Saharan Africa has lagged behind the rest of the world in agricultural productivity; underinvestment in agricultural research and development, limited access by farmers to new technologies and markets, and weak agricultural extension systems are a few of the major constraints to improving farm productivity in this region.

How Was the Study Conducted?

The study drew heavily on USDA, ERS's International Agricultural Productivity data product, which documents the outputs and inputs used in world agriculture and constructs country and regional indices of agricultural total factor productivity (TFP) over the 1961–2020 period. Selected information from other sources help illustrate and explain major developments in world agricultural production and resource use and the linkages between agricultural productivity growth, use of natural and environmental resources, and global food security. Supplementary materials to the report describe the sources of data and the methodology for constructing the TFP indices and estimates of global capacities in public agricultural extension.

World Agricultural Production, Resource Use, and Productivity, 1961–2020

Forces Shaping World Agriculture

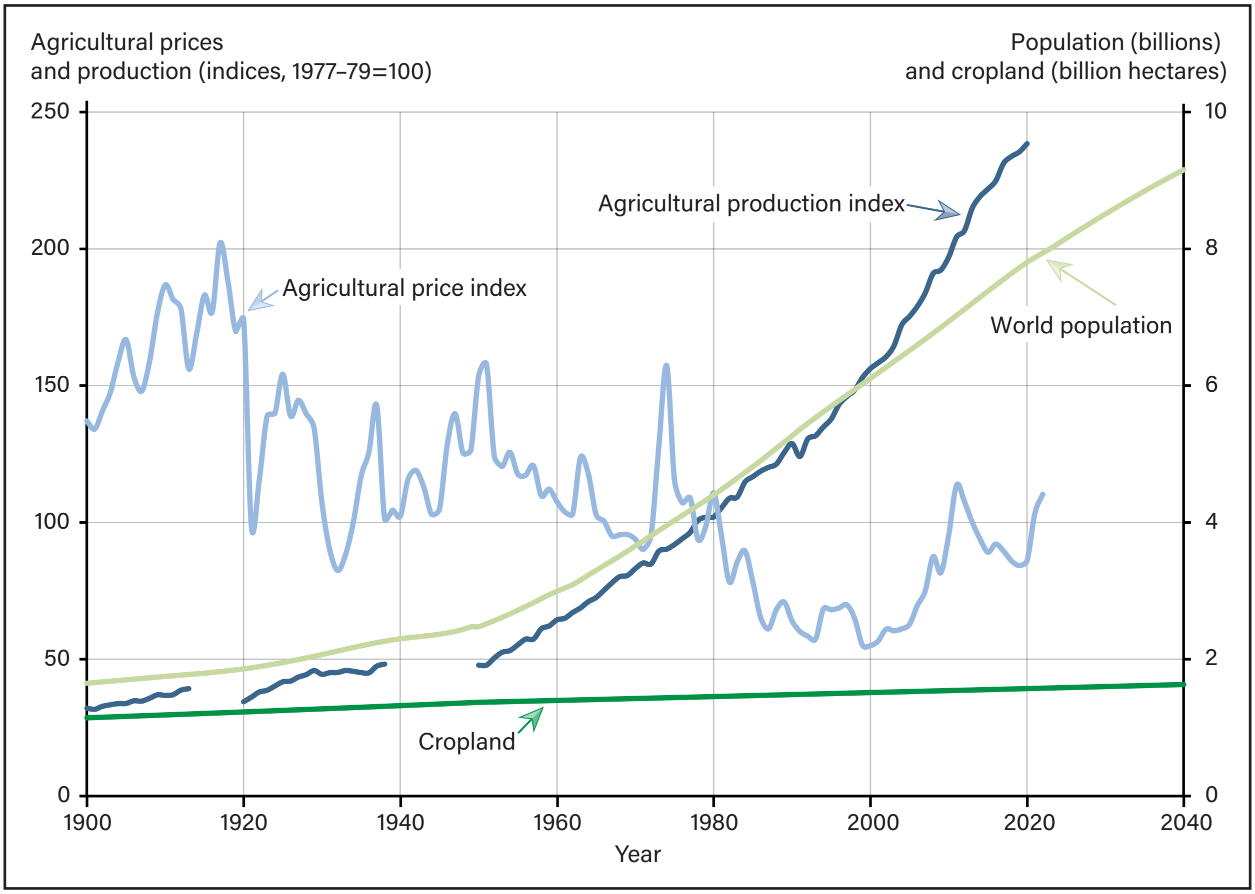
The 20th century witnessed unprecedented increases in both global population and food production. The fact that agricultural production was able to expand to meet the growing world demand for food and other agricultural products was a remarkable achievement. We are now in the third decade of the 21st century and face the significant challenge of meeting food demands for a world population projected to reach 10 billion by 2060 (United Nations, 2022), and doing so in a way that is environmentally sustainable and can successfully adapt to a changing climate.

This report reviews major developments in world agricultural production and resource use over the six decades from 1961 to 2020. A recurring theme in the report is the important role that agricultural productivity—particularly total factor productivity (TFP)—has played in increasing output while reducing reliance on natural resources. TFP is a measure that compares the total volume of output produced from the combined set of land, labor, capital, and material inputs used in a sector. It is a broad measure of economic efficiency and performance, of the ability to produce more with less. It is usually achieved through the application of improved technologies and farming practices, specialization in the commodities and farming systems that make the best use of local resources, and other ways of raising the efficiency with which farmers produce crops and livestock. With improvements in TFP, farmers can produce commodities at lower unit cost since fewer inputs are required for each unit of output. This can make farms more profitable while also keeping prices relatively low for consumers. In fact, it is likely that over time a large part of the productivity gains in agriculture have been passed on to consumers in the form of lower food prices. Farms that successfully raise their productivity stay profitable even in the face of lower prices, but farms that do not may see their profitability and incomes gradually decline.

Figure 1 illustrates long-term trends in global agricultural output, prices, and cropland, as well as in world population, over the 120 years from 1900 to 2020, along with population and cropland projections to 2040. The global population increased from 1.65 billion in 1900 to surpass 8 billion by 2023, and it is projected to reach 9 billion by the late 2030s. Cropland, on the other hand, has increased at a much slower pace, from 1.14 billion hectares in 1900 to 1.57 billion hectares in 2020. Global agricultural production, by volume of total crop and livestock products harvested, increased more than sevenfold over this 120-year period. Agricultural commodity prices, expressed as a composite index relative to the price of manufactured goods, were on a declining trend through the 20th century (1900–2000) but rose significantly during the first part of the 21st century (2000–2022). The nearly 60-percent decline in real agricultural prices in the 20th century reflected a dramatic increase in the efficiency of the world agrifood system due to the adoption of improved technologies and widening trade that enabled efficiencies from specialization, where regions and farms produce the commodities they are best at producing. The increase in agricultural prices over the past two decades is likely due to a number of factors, including rapidly growing demand for richer and more diverse diets in low- and middle-income countries, the growing use of commodities for biofuel, a slowing pace of technological innovations, and the effects of climate change (Morgan et al., 2022).

The purpose of this report is to describe major global trends in world agricultural output and resource use over the six decades from 1961 to 2020. The report underscores the important role of agricultural productivity for global food and environmental security. The report is mainly descriptive and draws heavily upon the publicly available USDA, Economic Research Service (ERS) data product, International Agricultural Productivity (for more information, see Box 1 and the International Agricultural Productivity data product on the USDA, ERS website). This data product reports annual data on agricultural output, input, and productivity trends for each country and region of the world over these 60 years. Outputs include crop, livestock, and aquaculture products, whereas inputs include land, labor, capital, and material inputs such as fertilizer and animal feed. A key feature of this data product are indices of agricultural TFP for each country and region of the world. TFP is simply a ratio of total output to total input. It is a broad measure of the efficiency with which farmers transform resources into commodities. If TFP is growing, it indicates that fewer inputs are needed to produce a given amount of output. Under constant input and output prices, every 1-percent growth in TFP implies a 1-percent decline in the unit cost of production.

Figure 1
World agricultural output, price, cropland, and population since 1900



Note: The right axis measures the size of the world population and the amount of cropland worldwide, in billions of people and hectares, respectively. Production data for 1914–19 and 1939–49 are missing due to disruptions caused by World War I and World War II.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, International Agricultural Productivity data; Federico, G. (2005). *Feeding the world: An economic history of agriculture, 1800–2000*. Princeton University Press; United Nations. (2022). *World population prospects 2022*. United Nations, Department of Economic and Social Affairs, Population Division; Oxford University. (2017). *World population growth, our world data*. Oxford University; and Pfaffenzeller, S., Newbold, P., & Rayner, A. (2007). A short note on updating the Grilli and Yang commodity price index. *The World Bank Economic Review, 21*(1), 151–163.

International Comparisons of Agricultural Total Factor Productivity in Global Agriculture

The USDA, Economic Research Service (ERS) data product on International Agricultural Productivity publishes annual indices of agricultural total factor productivity (TFP) for 179 countries and territories, as well as regional and global aggregates. This data product was first published in 2013 and is updated annually. This report uses the October 2022 version of the data product, which contains data from 1961 to 2020.

TFP is a broad measure of agricultural productivity. It compares the whole set of farm outputs (crop, livestock, and aquaculture commodities) with the combined set of land, labor, capital, and intermediate inputs used to produce them. Higher TFP reflects greater efficiency with which the inputs are employed to produce outputs. Growth in TFP occurs when farmers adopt new technologies and practices, achieve economies of scale, reallocate inputs to produce commodities of higher value, and/or concentrate production on the most fertile areas while retiring lower quality resources.

The USDA, ERS International Agricultural Productivity data product measures agricultural TFP as an index with a base year of 2015 = 100 for each county and region. Changes in the index value indicate growth or decline in agricultural TFP relative to the base year. For example, if a country's agricultural TFP index is 105 in the year 2020, it means TFP had grown by 5 percent since 2015, or by about 1 percent per year. Since each country's TFP is set to 100 in the year 2015, international comparisons of TFP are only possible for the rate of TFP growth; the indices do not compare TFP levels across countries.

To measure the rate of TFP growth (and the values of the annual index), USDA, ERS first calculates the rates of growth in total agricultural outputs and total agricultural inputs. The rate of growth in TFP is then the difference between the total output and total input growth rates. If output is growing faster than inputs, it means a given set of inputs is producing more output (or, equally, the same amount of output is being produced with fewer inputs), and therefore that TFP has increased.

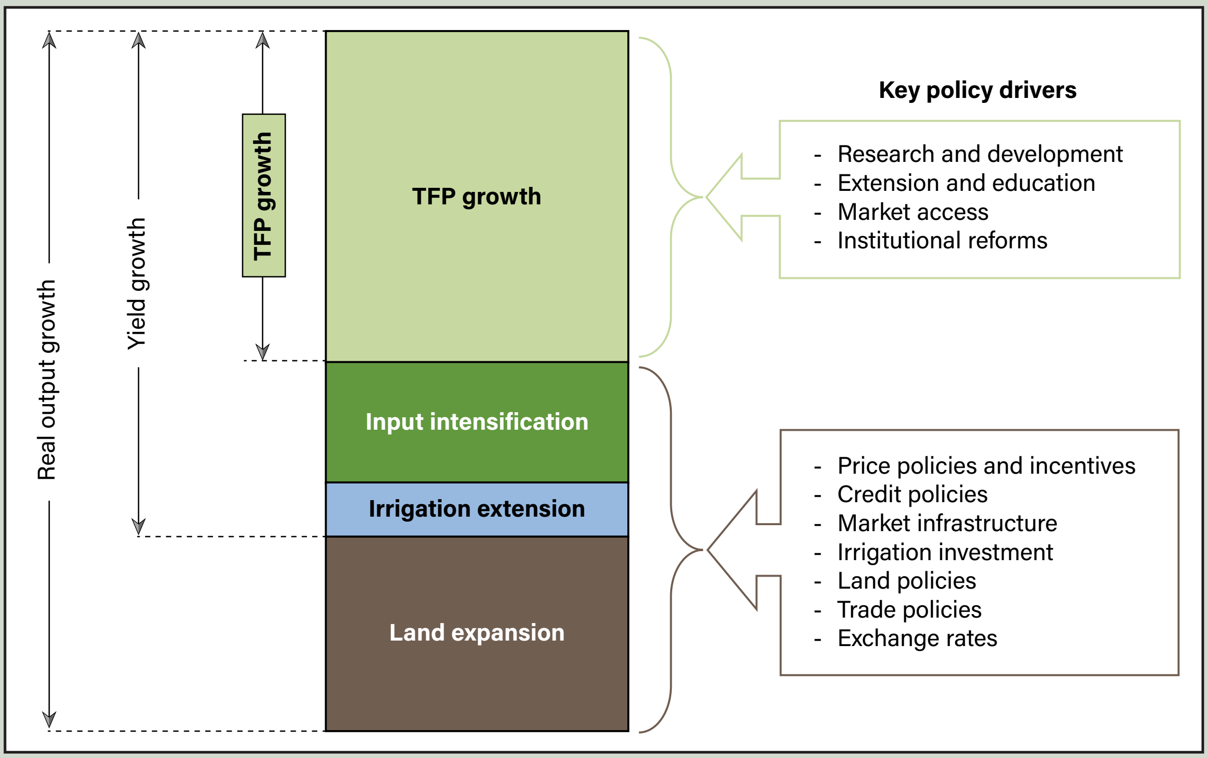
Agricultural output is the aggregation of 199 agricultural commodities, including 160 crops, 31 animal products, and 8 aquaculture products. Outputs are aggregated using a fixed set of prices (i.e., global average farm-gate prices from 2014–16 estimated by the Food and Agriculture Organization of the United Nations FAOSTAT database measured in 2015 dollars per metric ton (FAO, 2023a)). Since prices are held fixed over time, aggregate output is a volume measure. For example, an increase in output from $1 trillion to $2 trillion means the quantity volume of output doubled. Country-level output quantities of crop and livestock commodities for each country are from FAO (2023a), while quantities of aquaculture products are from the FAO's Fishery and Aquaculture statistics FISHSTAT (FAO, 2023b).

Agricultural inputs are the amounts of land, labor, capital, and intermediate inputs employed in production. Agricultural land is a quality-adjusted measure of "rainfed cropland equivalent" hectares, composed of rainfed cropland, irrigated cropland, and permanent pastures and rangeland, where each type is weighted by its relative yield. Agricultural labor is the number of economically active adults whose primary sector of employment is agriculture. Agricultural capital is the accumulated value of investment in structures, machinery, breeding stock, and crop trees, discounted for depreciation as capital ages. Intermediate inputs include agricultural fertilizers and chemicals, seeds, feeds, animal health products, fuel, and electricity. Due to incomplete data, the quantity measure of intermediate inputs consists of inorganic and organic fertilizers (i.e., metric tons of nitrogen (N), phosphate (P_2O_5) and potassium (K) nutrients), and animal feeds from grains, oilseeds, roots and tubers, byproducts from crop processing, and animal and fish meals (measured in kilocalories of feed energy). The primary sources of input data are FAO (2023a) for agricultural land, capital, and fertilizer and the International Labor Organization's ILOSTAT database for agricultural labor, while animal feed quantities are derived from the commodity balance sheets in FAO (2023a) and the USDA, Foreign Agricultural Service's *Production, Supply and Distribution* database.

Input quantities are aggregated into a composite input index using a cost-accounting procedure that is the growth rate in total inputs is the weighted average of the growth in each factor input, where the weights are factor cost shares. Factor shares for agricultural land, labor, capital, and intermediate inputs are assembled for each country and region from multiple sources (Fuglie, 2015).

This methodology allows output growth to be decomposed into the share of new output coming from changes in the quantities of the various inputs (or combination of inputs) and the share coming from increases in TFP. Figure B1 illustrates one way of decomposing sources of output growth: It allocates an increase in output between any two periods to (1) an increase in agricultural land area, holding other inputs fixed; (2) extending irrigation to cropland; (3) increasing the amount of labor, capital, and intermediate inputs per hectare of agricultural land; and (4) growth in TFP. Key policy drivers of TFP-led growth include investments in innovation, such as agricultural research and development, extension, farmer education, and other institutional and policy factors that improve incentives and market access for producers.

Figure B1
Agricultural growth comes from increasing the use of land and other resources and from raising the productivity of those resources



TFP = Total factor productivity.

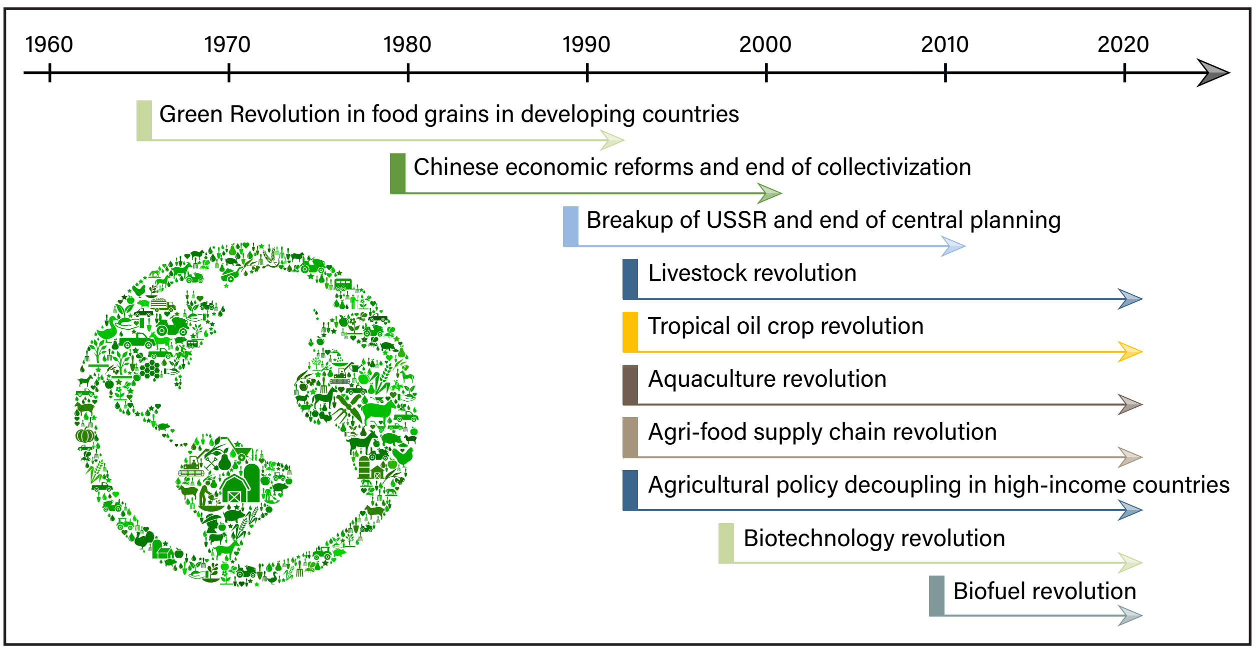
Source: USDA, Economic Research Service (ERS) using USDA, ERS, International Agricultural Productivity data.

In addition to conventional inputs like land, labor, and capital, the report also describes some of agriculture's demands on environmental resources—particularly water for irrigation, nutrient loadings to the environment (the excess of nitrogen and phosphate nutrients applied to fields from all sources net of the amount removed by crop harvests), and greenhouse gas emissions. The authors constructed measures of resource intensity (i.e., the amount of environmental resource used to produce a unit of output) or its inverse, resource-use efficiency (i.e., the amount of output per unit of environmental resource used) and compare outcomes over time and across countries.

But first, the authors identified a number of major developments that helped shape world agricultural production and resource use since the 1960s (figure 2). Although subjective and not comprehensive, the items on this list stand out for their influence on global agriculture over these decades. Some of these developments, such as the Green Revolution and biotechnology revolution, were primarily supply shocks, which were directly affecting farm productivity, whereas others, such as the livestock and biofuel revolutions, were primarily demand shocks, which were expanding the use of farm commodities and the prices consumers were willing to pay for them. This list of developments also contains some institutional and policy reforms that significantly affected the economic incentives faced by farmers.

- **World Population Growth**
  The fundamental driver of the growth in food demand and thus agricultural expansion from 1961–2020 was rising world population, which increased from 3.0 billion to 7.8 billion over these years. More than 90 percent of the increase of 4.8 billion people occurred in the Global South (developing countries). Even though the annual population growth slowed from around 2 percent in the 1960s to about 1 percent by 2020, the world still added 80 million people to the global population in 2020 (versus about 64 million per year in the 1960s). The United Nations projects that world population will reach 9 billion by the late 2030s but that the annual rate of growth will continue to fall throughout the rest of the 21st century. (For more information, see *World Population Prospects 2022*, United Nations, 2022).

Figure 2
Major developments affecting world agriculture since 1961



Agri-food = agricultural and food; USSR = Union of Soviet Socialist Republics.

Source: USDA, Economic Research Service.

- **The Green Revolution**
  Crop yields began to increase rapidly in North America and Western Europe after World War II but remained stagnant in most developing countries. Then, the onset of the Green Revolution in the mid-1960s brought major yield gains to cereal staples in the Global South, especially for rice and wheat in Asia, as farmers adopted improved varieties, increased fertilizer applications, and made more extensive use of irrigation (Evenson & Gollin, 2003). One study estimated that by the year 2000 the productivity gains from improved crop genetics alone lowered global food prices by 18–21 percent (Evenson & Rosegrant, 2003). A major driving force behind the Green Revolution was the establishment of a system of international agricultural research centers in developing nations. Today this system is known as CGIAR (formerly the Consultative Group for International Agricultural Research). Initially focused on improving productivity of cereal grains, the system later expanded its research and development (R&D) portfolio to include a broader array of food crops, livestock, natural resources, and food policy, among other topics. CGIAR has continued to produce innovations that raise farm productivity, and by 2020, CGIAR-related crop technologies were estimated to have been adopted on more than 220 million hectares in the Global South (Fuglie & Echeverria, 2024).

- **The End of Farm Collectivization**
  In the 1960s and 1970s, formerly Communist nations in Asia experienced severe agricultural crises: China had a major famine during 1960–62 when an estimated 30 million people died of starvation; in the late 1970s and early 1980s Vietnam experienced several years of poor crops and serious food shortages. Both of these countries had departed from the family farm model that characterizes the great majority of world agriculture and had opted for large collectivized farms. This model of farm organization offered poor rewards to farmers for their labor and initiative. In 1978, China began to abandon its collectives, instead leasing land to individual families through a household responsibility system. Vietnam followed suit with similar Doi Moi (or renovation) reforms in the 1980s. Gradual reforms were also introduced into markets, improving the prices received by farmers for their products. As a result of these reforms, agricultural output and productivity rose rapidly and helped lift millions of people out of poverty (Rozelle & Swinnen, 2004). Other countries (e.g., Algeria and Ethiopia) that experimented with collectivization eventually abandoned this model as well. For a broad look at the failures of 20th-century experiments with farm collectivization, see Pryor (1992).

- **End of Central Planning in the Former Soviet Union and Central Europe**
  Following the fall of the Berlin Wall in 1989, major agricultural reforms were implemented in former Communist countries of Central and Eastern Europe. These mostly former Soviet Union countries had adopted a mix of large state-managed farms, farm collectives, as well as some family-run farms or individually-managed plots. The farm sector was under the direction of central planning and received large subsidies in an effort to boost production. The end of central planning meant the privatization of farms and markets and a reduction in agricultural subsidies, but the pace and nature of reforms differed widely among the 28 independent nations that emerged out of the former Soviet Union and its Central European satellites. Following reforms, agricultural output in most of these countries sharply contracted, collectively falling by 35 percent between 1989 and 1999. Even by 2020, their aggregate agricultural output was still slightly below 1989 levels, although it was being produced more efficiently, with significantly less land, labor, and capital employed. For a review and synthesis of agricultural reforms and their impacts in transition economics of Europe and East Asia, see Rozelle and Swinnen (2004).

- **The Livestock Revolution**
  Rising population, per capita income, and urbanization in low- and middle-income countries increased demand for more diverse foodstuffs, especially for livestock products such as meat, milk, and eggs. Over the past 25 years, diets in many low- and middle-income countries have especially shifted away

from staple foods like grains and root crops to instead rely on an increasing share of calories from livestock products. In turn, the growth in livestock demand has shifted the use of cereal grains from food consumption to animal feed. Although the Green Revolution was supply driven by the adoption of improved technologies, the Livestock Revolution was demand driven. One of the first studies to highlight the emerging importance of livestock in the Global South is Delgado et al. (1999). For a more recent evaluation of the economic and environmental implications of global livestock, see Steinfeld et al. (2006).

- **The Tropical Oil Crop Revolution**
  Another demand-driven force shaping world agriculture has been a rapid expansion of oil crop area and production in tropical regions, especially soybean in South America and oil palm in Southeast Asia. When processed, oil crops produce two main products: vegetable oils and oil crop meals or cakes. The same forces driving demand for animal products have driven the demand for animal feeds. New uses have also emerged for vegetable oils, such as for biodiesel. Between 2000 and 2020, world utilization of vegetable oils for biodiesel increased from under 1 billion liters to more than 48 billion liters, according to data from the Organization for Economic Cooperation and Development (OECD) and Food and Agriculture Organization of the United Nations (FAO) (2021). The value chains created around the tropical oil crop revolution expanded trade and created jobs, but they also contributed to deforestation and loss of natural grasslands. For an indepth look at the drivers and impacts of the growth of tropical oil crops, see Byerlee et al. (2017).

- **The Aquaculture Revolution**
  Aquaculture is one of the fastest growing segments of the global agri-food system. World production of farm raised fish and shellfish increased from 13.7 million metric tons in 1990 to 86.4 million metric tons in 2020 (FAO, 2023b), surpassing the world quantity of beef produced by 2012 (FAO, 2023a). In addition, in 2020 aquaculture produced 35 million metric tons of seaweed, more than seven times the 1990 figure, for food, feed, and industrial purposes. Aquaculture has been a technologically dynamic sector, using R&D to domesticate wild species of fish and through selective breeding to improve yield, feed efficiency, and fish nutrition. Technological advances in plant-based feeds have helped to reduce dependence on feed made from wild fish catch. Management of pests, diseases, and natural resources remains a significant challenge for the industry. For a 20-year retrospective review of the growth of global aquaculture, see Naylor et al. (2021).

- **Agri-Food Supply Chain Transformation**
  Agri-food value-chains (AVCs), or the wholesaling, retailing, and processing of agricultural commodities into food products, has undergone rapid transformation in many countries of the Global South over the past several decades (Barrett et al., 2022). One notable feature of this transformation has been the growing market share of supermarkets in food retail (Reardon et al., 2003; Reardon et al., 2007). The growth in per capita income, urbanization, participation of women in the labor force, access to home refrigerators, and transportation services have increased demand for greater food variety, convenience, and quality, and changed the way households procure and shop for food. On the supply side, economies of scale, scope, and size as well as policies favorable to Foreign Direct Investment (FDI) have encouraged expansion by multinational food companies.

  The AVC revolution has had significant implications for farmers. Multinational companies are positioned to source agricultural commodities where they can be produced most efficiently and manufacture food products at scale. These practices are contributing to efficiency gains in global agri-food markets. At the same time, food companies often use various forms of vertical coordination to secure farm commodities and enforce their food safety and quality standards. The extent to which smallholder farmers and farm laborers participate or are excluded from high value AVCs has garnered considerable attention as, generally, food companies have preferred coordinating with larger farm producers. In cases where smallholder farms have participated in AVCs, they appeared to have shared in the economic benefits that AVCs have produced. For a recent indepth assessment of AVC transformation, see Barrett et al. (2022).

- **Decoupling Policy Reforms in High-Income Countries**
  Governments intervene in agriculture to promote growth, enhance food security, support farm incomes, and conserve natural resources, among other reasons. Across 54 OECD and emerging market economies, government subsidies for agriculture were estimated to be $815 billion in 2020, the highest recorded by the OECD (OECD, 2022). In the 1970s and 1980s, agricultural subsidies to individual producers were largely tied to production (with larger producers receiving more subsidy), which led to supply-demand imbalances and costly supply management policies (Johnson, 1991). In the 1990s, several OECD countries implemented policy reforms that partially decoupled subsidies from production, providing direct income support to producers instead. The United States' 1996 Freedom to Farm Act, the European Union (EU) Common Agricultural Policy's 1992 MacSharry Reforms, and the 2003 EU Single Farm Payment program all served to reduce market distortions in agricultural policies (OECD, 2017). Between the 1986–88 period and 2020, the share of total farm subsidies tied to commodity output by these countries fell from 81 percent to 39 percent (OECD, 2022). The evolution of government support for agriculture in OECD countries is detailed in the OECD's annual report series, Agricultural Policy Monitoring and Evaluation.

- **The Biotechnology Revolution**
  Scientific advances in plant and animal genetics have led to the widespread application of biotechnology to agriculture. Agricultural biotechnologies, including genetic engineering, molecular markers, tissue culture, and most recently gene editing, have given agricultural scientists more tools to improve crops for yield and resilience in the face of diseases, pests, and environmental pressures. Transgenics is one kind of biotechnology, where the transfer of genetics from one species to another is done to produce a desired trait that would not otherwise be possible through traditional breeding methods alone. In modern agriculture, transgenics has been used to create a number of genetically modified (GM) crop varieties. The first GM crops became commercially available in the mid-1990s, and by 2019 nearly 187 million hectares were planted to GM crops worldwide, or about 12 percent of total global crop area harvested (International Service for the Acquisition of Agri-biotech Applications (ISAAA), 2019). The crops with the largest area in GM varieties are corn, soybean, cotton, and canola, and the most common GM traits that have been inserted into these crops are insect resistance and herbicide tolerance. Adoption of GM crops has resulted in significant economic and environmental benefits, increasing crop yield and farm profits, and reducing pesticide use and food prices for consumers (Brookes, 2022; Brookes & Barfoot, 2020; Klümper & Qaim, 2014). However, public reservation to the use of GM traits in agriculture have led to a complex systems of regulations, which in many countries have slowed or restricted their use (Qaim, 2009).

- **The Biofuel Revolution**
  Between 2005 and 2020, the use of crops to manufacture biofuels surged. Cereal grains, sugar, and starchy root crops were used to produce ethanol that was blended with gasoline, while vegetable oils were used to produce biodiesel. By 2020, global production of ethanol exceeded 118 billion liters and biodiesel production reached nearly 48 billion liters; biofuel manufacturing used about 6.6 percent of world cereal grains, 16 percent of vegetable oils, and 19 percent of sugar produced worldwide (OECD & FAO, 2022). The growth in biofuels was heavily influenced by government policies as well as rising prices of fossil fuels. Many countries promoted the use of biofuels as a means of achieving

environmental and energy security goals as well as reducing reliance on imported fossil fuels and the associated greenhouse gas emissions. Some countries offered subsidies to biofuel manufacturers and/or enacted regulations requiring bio-ethanol and biodiesel be blended into commercial fuels. The growth in the use of biofuels contributed to rising commodity prices and stimulated cropland expansion in some countries. OECD and FAO (2023) projects biofuel consumption and production to grow at a slower pace during the next decade due to changing support policies in developed countries. For an assessment of the global economic and environmental impacts of the first decade of biofuel use, see Timilsina and Zilberman (2014). A comprehensive review and reassessment of the effects of biofuel policies in the United States is given in Taheripour et al. (2022). Ramsey et al. (2023) project global fuel ethanol demand in international markets through 2030.

This selective list of some of the major forces that have shaped the evolution of world agriculture over the past decades, including the growth and changing composition of world agricultural outputs; the land, labor, capital, and material inputs employed in their production; and the central contribution of productivity improvement to the sustainable use of resources to meet the growing global demand for agricultural commodities helps to contextualize this report.

Because of the international focus of this report, quantities are reported in metric units (i.e., hectares for area, and metric tons and liters for quantities). Aggregate output is reported in purchasing-power-parity dollars using a constant set of prices from 2014–16. Thus, gross agricultural output is expressed in "constant 2015 purchasing-power-parity dollars." Because prices are held fixed, changes in the gross value of output over the 1961–2020 period reflect changes in the quantities of commodities produced and not changes in their prices. The report uses the term Global North to refer to more economically developed regions of the world and the Global South to refer to less economically developed regions of the world. Box 2 contains further information on how the report defines and measures agricultural output and how countries and territories are grouped into regions for expository purposes.

Measuring Global Agricultural Production and Resource Use

What is Produced on Farms

This report describes the quantity of agricultural production and the amounts of land, labor, capital, and material resources used to produce that output over the six decades from 1961 to 2020. Agricultural output is the aggregation of 200 crop, animal, and aquaculture commodities harvested annually from farms. To add up different kinds of products, each commodity is valued using a constant set of prices from 2014 to 2016 from the Food and Agriculture Organization of the United Nations FAOSTAT database (FAO, 2023a). FAO (2023a) uses the Geary-Khamis method to estimate global average prices for this period in purchasing-power-parity dollars per metric ton (Rao, 1993). Holding these prices fixed and allowing the quantities to vary over time provides a volume measure of gross agricultural output. See the Supplementary Materials on the USDA, ERS web page to this report for further details and data sources.

The 200 commodities include 162 crops, 30 animal products, and 8 types of aquaculture products:

- Cereal grains (rice, wheat, barley, maize, millet, sorghum, and others);
- Roots and tubers (potatoes, sweet potatoes, cassava, yams, taro, and others);
- Oil crops (soybean, groundnuts, oil palm, coconut, cotton, sunflower, rape, and others);
- Field beans and pulses (beans, cowpeas, chickpeas, lentils, and others);
- Vegetables, melons, and tree fruits and nuts;
- Fiber crops and rubber (jute, hemp, sisal, and cotton, which is also an oil crop);
- Specialty crops (coffee, cocoa, tea, pepper, spices, and others);
- Meat from cattle, buffalo, camelids, equines, pigs, poultry, rabbits, and snails;
- Milk from large and small ruminants;
- Other animal products (eggs, wool, raw silk, honey, and others); and
- Aquaculture (freshwater fish, marine fishes, diadromous fishes, crustaceans, mollusks, aquatic plant, and two classes of miscellaneous products).

Not included in agricultural output are harvests of fodder crops, hay, flowers, and other ornamentals.

This measure of gross agricultural output differs from another common measure, agricultural value-added, or Gross Domestic Product (GDP). For example, the World Bank's World Development Indicators report agricultural value-added by country in current and constant U.S. dollars. This is based on national-level current prices adjusted for inflation by a national general price index and then converted to U.S. dollars at the official exchange rate. Thus, agricultural GDP is influenced by market prices, exchange rate fluctuations, and agricultural and trade polices (which influence local prices), whereas the gross output measure used in this report only changes when quantities harvested change. Moreover, the same price is applied to each metric ton of output, regardless of where it is grown.

Where It Is Grown

This report provides details on changes in world and regional agricultural production over time. Figure B2 shows how countries and territories are assigned to various regions. Regions are grouped into the Global South and the Global North. These generally coincide with countries thought of as developing or least developed and developed or industrialized, respectively, although each contains countries at different stages of development. In particular, the Global South contains some high-income countries and emerging economies, as well as low-income countries. Africa is split across two regions, and Europe and Asia are further divided into some subregions:

The Global South:

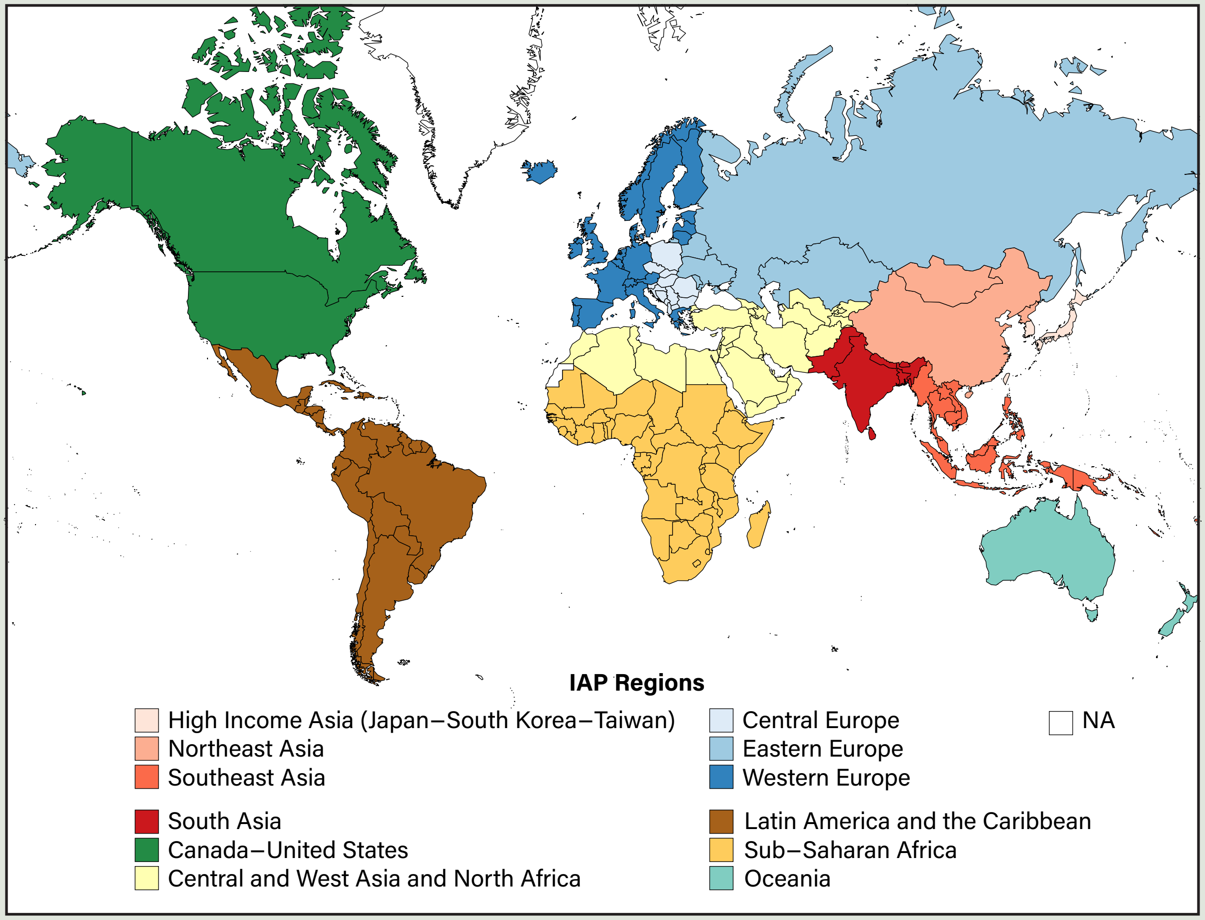
- LAC: Latin America and the Caribbean;
- SSA: Sub-Saharan Africa;
- CWANA: Central and West Asia and North Africa;
- Northeast (NE) Asia: China, Mongolia, and North Korea;
- Southeast (SE) Asia: Southeast Asia and Pacific Island states and territories; and
- South Asia: India, Pakistan, Bangladesh, Sri Lanka, Nepal, and Bhutan.

The Global North:

- High-Income (HI) Asia: Japan, South Korea, and Taiwan;
- Oceania: Australia and New Zealand;
- Europe (including Kazakhstan and all of Russia), which is further broken down into:
  - Eastern Europe: Russia, Ukraine, Belarus, Moldova, and Kazakhstan;
  - Central Europe: Poland, Hungary, Czechia, Slovakia, Romania, Bulgaria, Albania, and the states that make up former Yugoslavia (i.e., Croatia, Slovenia, Serbia, Bosnia and Herzegovina, Montenegro, and Macedonia);
  - Western Europe: the rest of Europe; and
- Canada-United States.

Figure B2

Global regions in the International Agricultural Productivity data product



IAP = International Agricultural Productivity. NA = Not available.

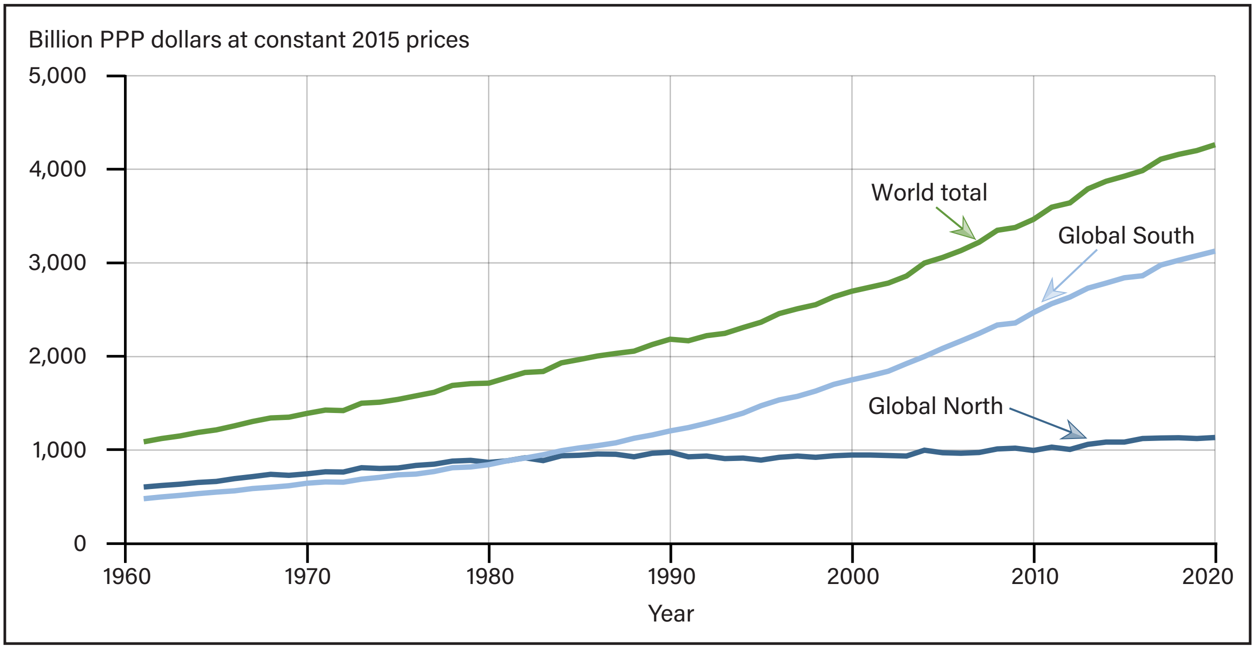
Source: USDA, Economic Research Service (ERS) using the USDA, ERS October 2022 International Agricultural Productivity data product.

Agricultural Outputs: Changing Location and Composition

Production Shifted to the Global South

Over the six decades from 1961 to 2020, the volume of global agricultural output increased nearly fourfold, from just over $1.1 trillion to over $4.3 trillion at constant 2015 prices (figure 3). In the 1960s and 1970s, agricultural output was evenly divided between the Global North and Global South, but subsequently agriculture expanded more rapidly in the Global South. By 2020, the Global South accounted for 73 percent of global agricultural production, up from 44 percent in 1961. These patterns of growth were stimulated by the rising world population, shifts in demand, technological change, and policy reforms.

Figure 3
World agricultural output in the Global North and Global South, 1961–2020

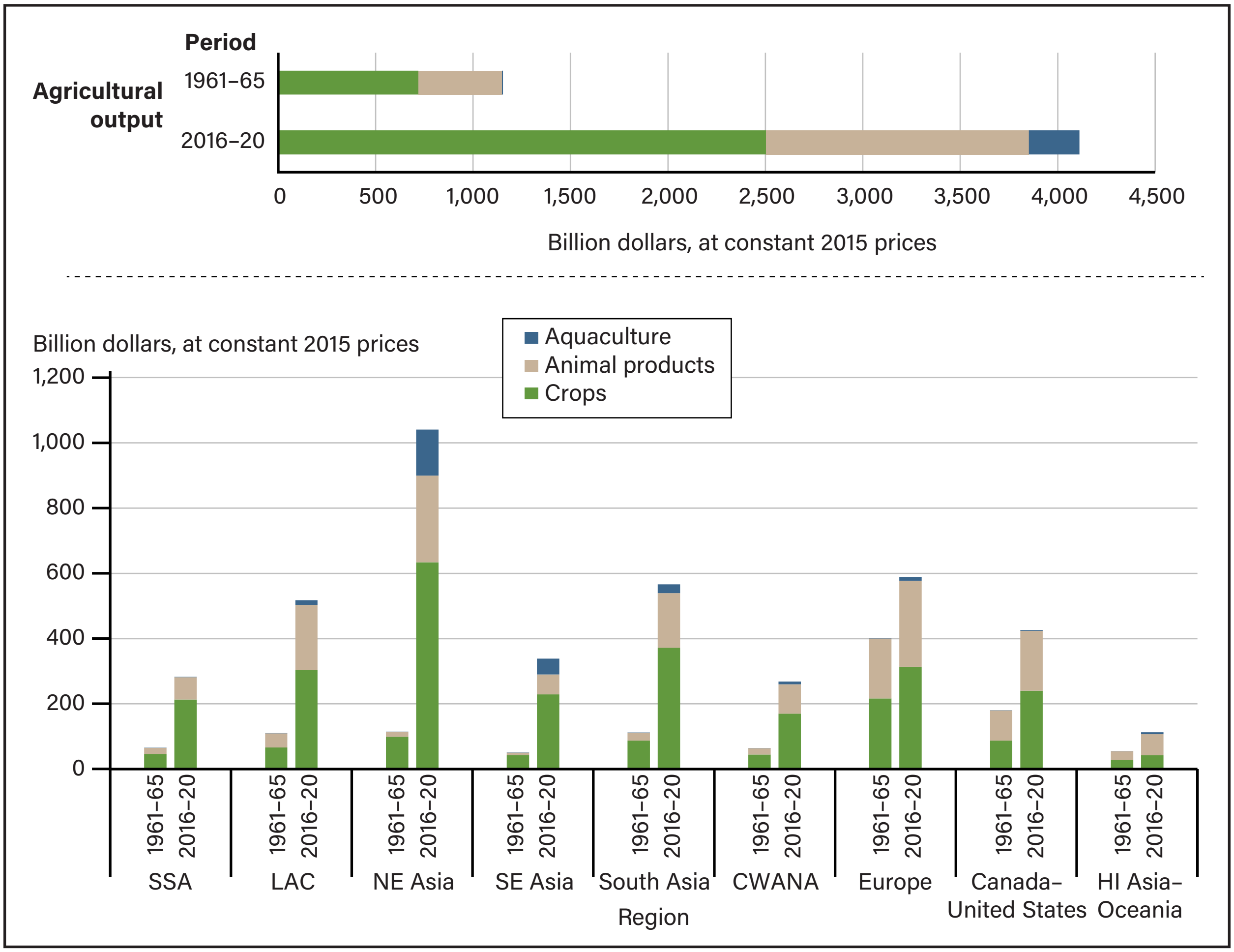


Note: Agricultural output is the sum of 200 crop, livestock, and aquaculture commodities aggregated using constant global average farm prices in purchasing-power-parity dollars (PPP) from 2014–16. Using PPP dollars means that a given quantity of agricultural product will have the same local purchasing power. For the purposes of this study, the Global South is defined to include all of Africa, Asia, and Latin America and the Caribbean except for Japan, South Korea, Taiwan, and Kazakhstan. The Global North includes Europe, all of Russia, Kazakhstan, the United States, Canada, Japan, South Korea, Taiwan, Australia, and New Zealand.

Source: USDA, Economic Research Service (ERS) using the USDA, ERS October 2022 International Agricultural Productivity data product.

Agricultural (farm) production consists of three main types of commodities: crops, animal products, and aquaculture products. Figure 4 shows changes in the quantity and composition of agricultural output at the global level and by region, comparing annual average production in 1961–65 with the average annual production in 2016–20. In 1961–65, aquaculture production was practically nonexistent, but grew to account for 6 percent of global agricultural output by 2016–20. Crop production made up about 61 percent of agricultural production in 2016–20 and animal products the remaining 33 percent.

Figure 4
World agricultural output by region, 1961–65 and 2016–20



SSA = Sub-Saharan Africa. LAC = Latin America and the Caribbean. NE Asia = Northeast Asia. SE Asia = Southeast Asia. CWANA = Central and West Asia and North Africa. HI Asia-Oceania = High-Income Asia and Oceania (i.e., Japan, South Korea, Taiwan, Australia, and New Zealand).

Note: Agricultural output is averaged over 1961–65 and 2016–20 and valued at constant global average prices from 2014–16 for comparison purposes.

Source: USDA, Economic Research Service (ERS) using the USDA, ERS October 2022 International Agricultural Productivity data.

By region, Northeast Asia is by far the most significant agricultural producer, accounting for about one-fourth of world agricultural production in 2016–20. Northeast Asia alone is responsible for more than half of global aquaculture production. To contrast, in 1961–65, Europe was the most significant agricultural region, followed by Canada-United States. In 2016–20, Europe was the second-leading agricultural producer, closely followed by South Asia and LAC. Canada-United States had fallen to fourth place. These changing patterns reflect the faster pace of agricultural growth in Global South regions compared with Global North regions, especially since the 1990s.

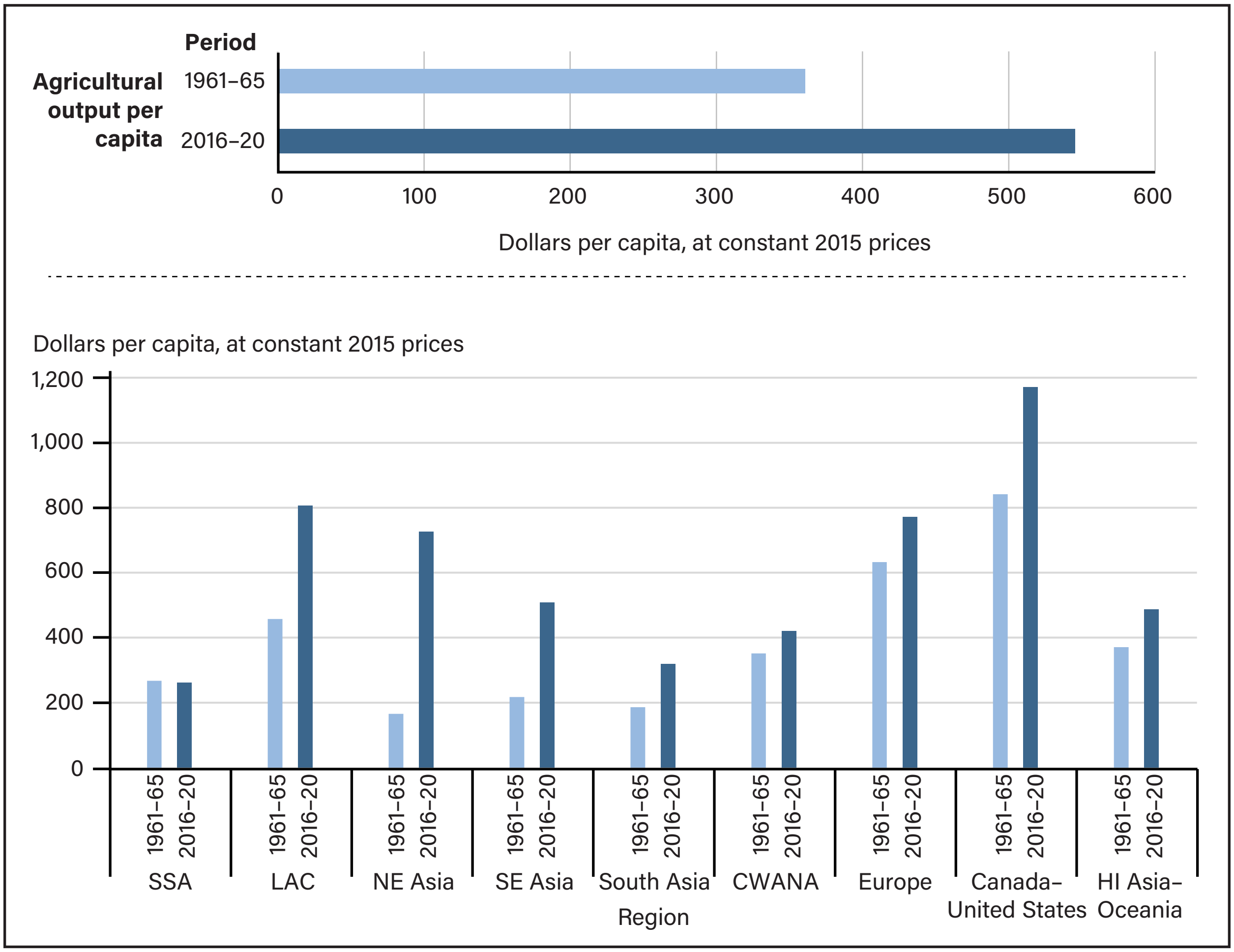
Global per capita agricultural output grew by just over 50 percent between 1961–65 and 2016–20 (figure 5). On a regional basis, Canada-United States generated the greatest per capita output starting in the early 1960s (at $841 of agricultural output per capita in 1961–65) and most recently in the late 2010s ($1,171 in 2016–20). LAC ($807) had the second-largest agricultural output per capita in 2016–20, followed by Europe ($771). All of these regions are net exporters of agricultural products. At the other extreme, SSA ($262) and

South Asia ($319) had the lowest level of agricultural output per capita in 2016–20. The populations of these regions also experienced the highest levels of extreme poverty, undernourishment, and child stunting (World Bank, 2023).[1]

Although self-sufficiency in food production is not necessary for food security (food can be imported, so long as a country produces other goods for trade), low levels of agricultural productivity are often associated with high levels of poverty, especially in countries with a large share of the population engaged in food production. Low agricultural productivity can also constrain the growth of nonfarm sectors and stymie countries' transformation into modern economies (Gollin, 2010; Johnston & Mellor, 1961; Timmer, 1988). On the other hand, when low-income countries can improve agricultural productivity, especially in food staples, it can boost not only farm income but also reduce food prices, lowering food expenditures for nonfarm households. Thus, improvements in agricultural productivity (more so for small-holder food commodities than plantation crops) can generate inclusive economic growth where benefits are widely shared across the farm, rural, and urban populations. Recent studies have found that agricultural growth in low-income countries generates two to four times more poverty reduction than comparable growth in nonfarm sectors (Ivanic & Martin, 2018; Ligon & Sadoulet, 2018). In turn, less poverty reduces the prevalence of undernourishment and child stunting as households are able to afford more nutritious food, sanitation, and healthcare services.

[1] Extreme poverty is defined as per capita consumption expenditures of less than $2.15 per day, in purchasing-power-parity dollars (World Bank, 2023). Undernourishment is defined as insufficient caloric consumption to sustain normal activities (FAO et al., 2022). Child stunting (low-height for age) is a largely irreversible condition resulting from poor nutrition and repeated infection during the first 1,000 days of a child's life. Stunting has long-term effects on diminished cognitive and physical development, reduced productive capacity, and poor health (World Health Organization (WHO), 2014).

Figure 5
Agricultural output per capita worldwide and by region, 1961–65 and 2016–20



SSA = Sub-Saharan Africa. LAC = Latin America and the Caribbean. NE Asia = Northeast Asia. SE Asia = Southeast Asia. CWANA = Central and West Asia and North Africa. HI Asia-Oceania = High-Income Asia and Oceania (i.e, Japan, South Korea, Taiwan, Australia, and New Zealand).

Note: Per capita agricultural output is measured as the aggregate value of agricultural output at constant 2015 prices divided by the regional population, with both measures averaged over the 5-year periods (1961–65 and 2016–20).

Source: USDA, Economic Research Service (ERS) using the USDA, ERS October 2022 International Agricultural Productivity data; and United Nations. (2022). *World population prospects 2022.* United Nations, Department of Economic and Social Affairs, Population Division.

Commodity Composition of World Agriculture Gradually Changed

The composition of global output by agricultural product category reveals several notable trends (table 1). By share, aquaculture experienced the greatest relative expansion over the last six decades from only 0.4 percent in 1961–65 to 6.3 percent in 2016–20. Vegetables, fruits and tree nuts, and oil crops also increased their shares of total value of global output between 1961–65 and 2016–2020, while output shares of cereal grains, roots and tubers, and livestock all declined. The relatively rapid growth in oil crop production reflects rising demand for vegetable oils (for food and biodiesel) and oil crop meals (for animal feed) (Byerlee et al., 2017). The rapid growth in aquaculture was spurred by technological innovations that significantly reduced costs of production, as well as strong growth in market demand (Naylor et al., 2021). Per capita consumption of vegetables, fruits, and tree nuts increased in both emerging economies and wealthier nations, where innovations in transportation, handling, storage, packaging, processing, and retailing have increased the year-round supply of a wider variety of these products (Reardon et al., 2003).

Table 1
Composition of world agricultural output, 1961–65 and 2016–20

Commodity group	1961–65 annual average		2016–20 annual average	
	Value	Output share	Value	Output share
	(billion 2015 PPP$)	(percent)	(billion 2015 PPP$)	(percent)
Cereal grains	250	21.7	766	18.5
Oil crops	74	6.4	380	9.2
Roots and tubers	105	9.1	178	4.3
Vegetables, fruits, and tree nuts	204	17.7	942	22.7
Other crops	87	7.6	252	6.1
Total crops	**720**	**62.5**	**2,519**	**60.8**
Ruminant meat	166	14.4	372	9.0
Nonruminant meat	76	6.6	475	11.5
Milk	149	12.9	376	9.1
Other livestock products	37	3.2	141	3.4
Total livestock	**428**	**37.2**	**1,364**	**32.9**
Aquaculture	**4**	**0.4**	**261**	**6.3**
All agriculture	**1,153**	**100.0**	**4,143**	**100.0**

PPP$ = Purchasing-power-parity dollars.

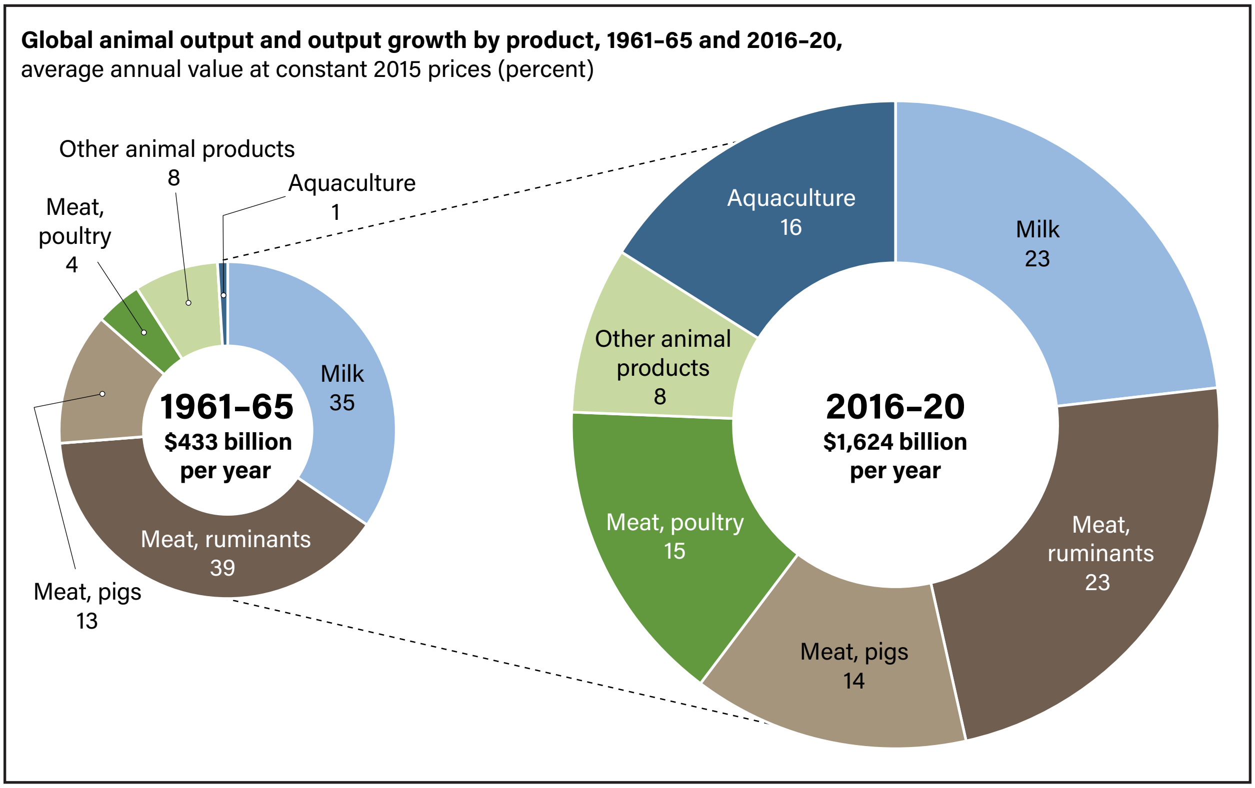
Note: Agricultural output is composed of 200 crop, animal, and aquaculture commodities and aggregated using constant global average prices from 2014–16.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Animal Output Composition Shows Declining Value Share for Ruminants

Taken together, products from livestock and aquaculture grew by more than fourfold from $433 billion per year to $1.62 trillion per year and increased their overall share in global agricultural output from 37.5 percent to 39.2 percent between 1961–65 and 2016–20 (figure 6). Within the livestock and aquaculture sectors, the composition of output changed to include more aquaculture and poultry products and relatively less meat and milk from ruminant livestock (mainly cattle, buffalo, goats, and sheep, but also equines and camelids). In many low- and middle-income countries, poultry and fish are cheaper sources of dietary protein than beef. Technological progress in reducing costs of production and improving quality in poultry and aquaculture has also advanced rapidly (Delgado et al., 1999; Naylor et al., 2020). This has helped make these products more widely available and affordable to consumers.

Figure 6
Diversification in global animal and aquaculture production, 1961–65 and 2016–20



Note: The figure shows the size and composition of the animal-aquaculture output using annual global averages from 1961–65 and 2016–20. Quantities harvested each year are valued at constant 2015 prices.

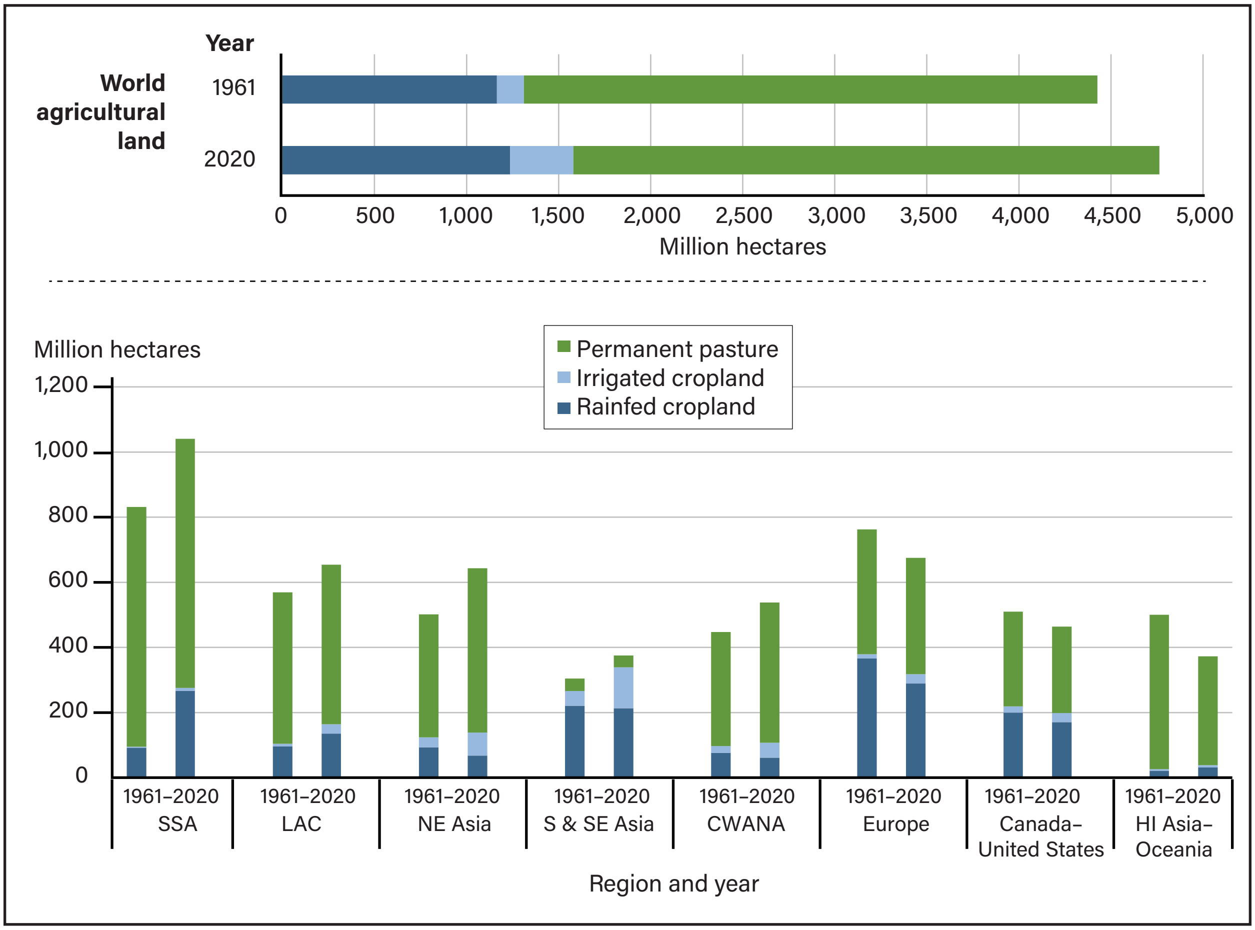
Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Agricultural Input Use

Agricultural Land Expanded in the Global South and Contracted in the Global North

Global agricultural land area is reported by FAO and includes rainfed cropland, irrigated cropland, and permanent pasture area. Overall, total world agricultural land use has slowly increased from 4.427 billion hectares in 1961 to 4.763 billion hectares in 2020 (figure 7). This translates to an average growth rate of 0.13 percent per year. Over this period the most rapid growth has been in irrigated cropland, which increased by 134 percent from 1961 to 2020, with rainfed cropland increasing by 20 percent and permanent pasture by 2 percent.

Figure 7
World and regional agricultural land area in 1961 and 2020



SSA = Sub-Saharan Africa. LAC = Latin America and the Caribbean. NE Asia = Northeast Asia. S & SE Asia = South and Southeast Asia. CWANA = Central and West Asia and North Africa. HI Asia-Oceania = High-Income Asia and Oceania (i.e., Japan, South Korea, Taiwan, Australia, and New Zealand).

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

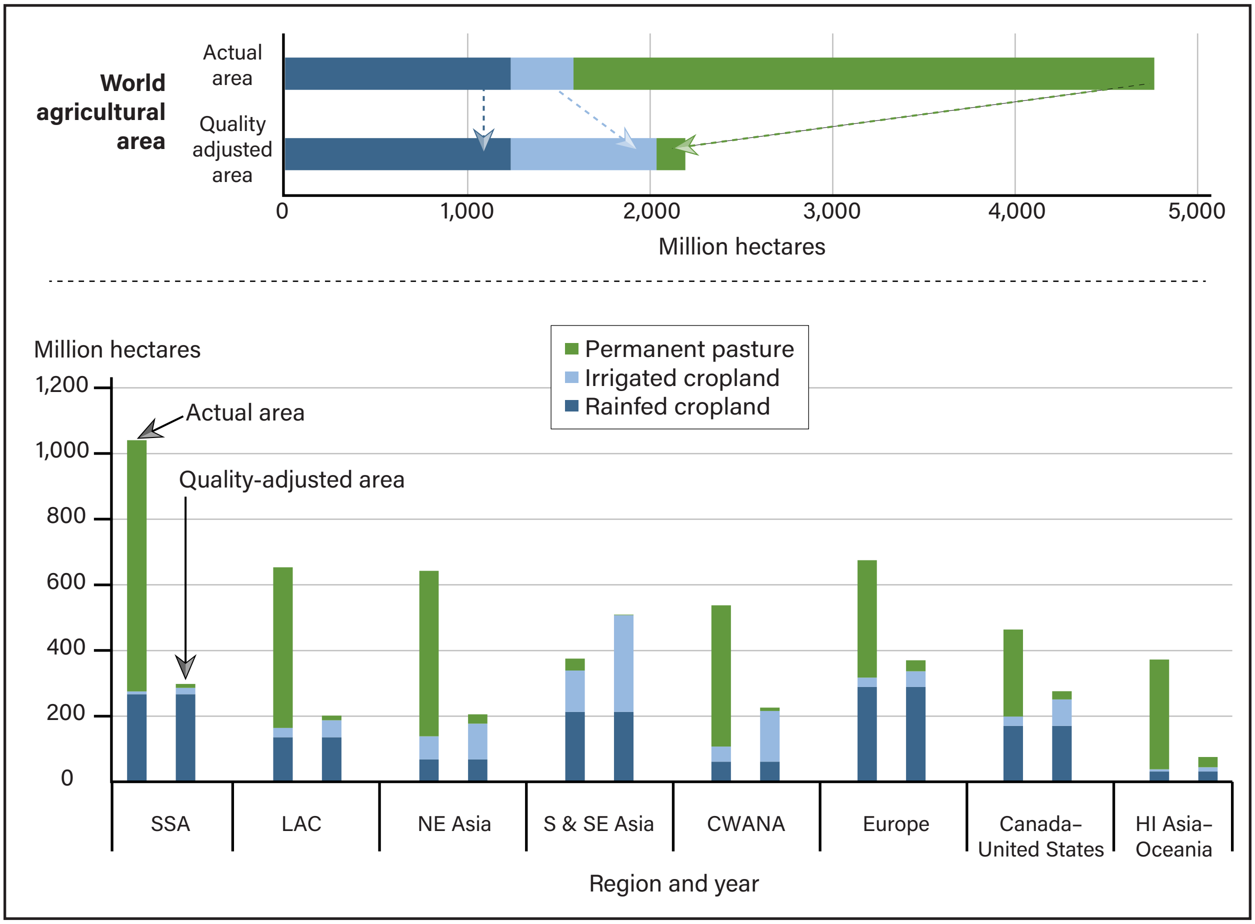
Figure 7 also highlights significant regional heterogeneity in agricultural land use patterns. One important trend is an overall reduction of agricultural land area in Global North regions (i.e., Europe, Canada-United States, and HI Asia-Oceania) and an increase in agricultural land area in Global South regions (i.e., SSA, LAC, Asian regions, and CWANA). From 1961 to 2020, total agricultural land area declined by 15 percent in the Global North and increased by 22 percent in the Global South. Agricultural land area has expanded most rapidly in South and Southeast Asia (27 percent) and Sub-Saharan Africa (25 percent) since 1961. However, there were differences in the types of agricultural land expansion as well. For example, land expansion in South and Southeast Asia was primarily in permanent pasture and irrigated cropland, whereas land expansion in Sub-Saharan Africa was in rainfed cropland. A second important trend is in the increasing share of cropland being harvested. In 1961, 74 percent of world cropland was harvested while 26 percent was left fallow, put into temporary pasture, or experienced a crop failure and couldn't be harvested. By 2020, the ratio of crop area harvested to total crop land had increased to 92 percent. A major reason for the increased intensity of cropland use is that a larger share of cropland is being irrigated, which can enable more crops to be harvested in a year. In addition, temporary fallowing of cropland, a practice used to help restore soil fertility, is declining. The increased use of synthetic fertilizers to maintain soil fertility has lessened the need to fallow land for this purpose. At the same time, continuous cereal cultivation and application of synthetic fertilizer can negatively affect soil health in other ways, including increased soil acidity (Bouman et al., 1995). Furthermore, there is some evidence that land-use change has been recently decelerating. Land-use change refers to human decisions about how land will be used and often classifies land into different categories, including cropland, permanent pasture, urban, and forest use, among others. Winkler et al. (2021) estimated that land-use change has affected one-third of global land area since 1960 and identified phases of accelerating (1960–2005) and decelerating (2006–2019) land-use change.

Agricultural land varies markedly in its quality and productive potential. Cropland, for example, on average produces much more output that permanent pasture. Even though permanent pastures and rangeland account for about two-thirds of total agricultural land, much of it is in arid and semi-arid areas and produces very little meat and milk from the livestock grazed there. A major determinant of cropland quality is the length of the growing season, which is determined by temperatures, rainfall patterns, and access to irrigation. Irrigated cropland can sometimes produce two to three times as much as rainfed cropland, especially if it enables multiple crops to be grown year-round. Land quality is also influenced by soil characteristics and topography.

One way to account for at least some of the differences in agricultural land quality is illustrated in figure 8. Irrigated area and permanent pasture are assigned quality weights to reflect their productivity relative to rainfed cropland. For each country included in the USDA, ERS International Agricultural Productivity data product, irrigated area is given a weight that reflects its productivity relative to rainfed cropland from Seibert et al. (2010). Similarly, weights for permanent pasture are applied to get rainfed cropland equivalents and are derived from regression analysis in Fuglie (2015). With this quality adjustment, the effective agricultural land area in a country or region is measured in hectares of rainfed cropland equivalents. For example, one hectare of irrigated cropland may have the same productivity potential as 2 or 3 hectares of rainfed cropland. It may take 20 or more hectares of permanent pasture to produce the same agricultural output as 1 hectare of rainfed cropland. At the global level, this scales down the effective agricultural area in 2020 from 4.763 billion hectares of actual land area to a rainfed cropland equivalent of 2.193 billion hectares. At the regional level with this quality adjustment, Sub-Saharan Africa no longer has the largest effective agricultural area. Instead, the region South and Southeast Asia has more effective agricultural land because a high proportion of its cropland is irrigated (i.e., high quality land) and it has relatively little pasture area (i.e., low quality land).

Applying the quality adjustment to the whole 1961–2020 period shows that effective agricultural area grew much faster than actual area because of quality improvements to land. First, cropland grew faster than pasture area (or some pasture and grasslands were converted to cropland), and second, irrigation was extended to a greater proportion of cropland. When measured in actual area, between 1961 and 2020 agricultural land increased worldwide from 4.427 billion hectares to 4.763 billion hectares, an increase of 7.5 percent. When measured in terms of rainfed cropland equivalent hectares, however, the effective rainfed cropland equivalent agricultural area expanded from 1.674 billion hectares in 1961 to 2.193 billion hectares in 2020, an increase of 31 percent. In other words, these quality improvements alone would have increased output by 31 percent even if no other changes in input use or productivity occurred.

Figure 8
Actual and quality-adjusted agricultural land area in 2020



SSA = Sub-Saharan Africa. LAC = Latin America and the Caribbean. NE Asia = Northeast Asia. S & SE Asia = South and Southeast Asia. CWANA = Central and West Asia and North Africa. HI Asia-Oceania = High-Income Asia and Oceania (i.e., Japan, South Korea, Taiwan, Australia, and New Zealand).

Note: The quality adjustments measure agricultural land in hectares of rainfed cropland equivalents. Irrigated cropland area is adjusted upward whereas permanent pasture area is adjusted downward according to its productivity potential relative to rainfed cropland in a country. The productivity weights given to irrigated cropland and permanent pasture vary by region.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Related to the levels of agricultural land used in production is the distribution in the number of farm holdings globally. Table 2 summarizes the number of farms by region using the most recent census data by country, which for most countries last occurred in the decade centered on 2010. For a more detailed exploration of these trends, see Lowder et al. (2021). Globally, there are over 606 million farms. Over 72 percent of total farm holdings are located in China and Southeast and South Asia, totaling nearly 435 million farms. Sub-Saharan Africa is the region with the next highest number of holdings, totaling over 80 million farms. Although cropland per farm shows large variation in regional averages (from only 0.6 hectares per farm in Northeast Asia to 148.3 hectares per farm in Oceania), the number of workers per farm shows much greater consistency across the globe, averaging 1.4 workers per farm. This reflects the large number of family-operated farms around the world, where family members provide most agricultural labor (Lowder et al., 2021).

Table 2
Number and average size of farm holdings by region, circa 2010

Region		Number of farms (thousand)	Cropland per farm (hectares per farm)	Labor per farm (workers per farm)
Global South	Sub-Saharan Africa	80,101	2.5	2.0
	Latin America and Caribbean	21,598	7.8	1.7
	NE Asia	209,706	0.6	1.0
	SE Asia	48,027	2.5	2.3
	South Asia	177,689	1.2	1.5
	CWANA	25,134	4.1	1.5
Global North	Eastern Europe	24,126	5.2	0.3
	Central Europe	8,277	4.9	0.9
	Western Europe	5,652	15.3	1.1
	Canada-United States	2,315	84.3	1.1
	Oceania	179	148.3	2.8
	High-Income Asia	3,574	2.0	1.3
Global South		562,256	1.7	1.4
Global North		44,123	10.9	0.6
World		606,379	2.3	1.4
Global South share of total		0.93		

NE Asia = Northeast Asia. SE Asia = Southeast Asia. CWANA = Central and West Asia and North Africa.

Source: USDA, Economic Research Service, using Food and Agriculture Organization (FAO) of the United Nations. (2014). *The State of Food and Agriculture 2014 (SOFA): Innovation in Family Farming*. FAO; and Lowder, S. K., Sánchez, M. V., & Bertini, R. (2021). Which farms feed the world and has farmland become more concentrated? *World Development*, *142*, 105455.

The preference for family labor in farm work reflects the difficulties of supervising complex agricultural tasks of a large workforce and is a key reason why efforts to run large-scale collective or cooperative farms have often failed (Pryor, 1992). Corporate plantations have been successfully sustained on a very limited scale, mostly with crops that require close coordination between harvesting and processing (i.e., cases where harvested crops rapidly deteriorate in quality if not processed immediately), such as sugar, bananas, oil palm, and tea. Even in these cases, family-run operations can compete successfully so long as coordination issues can be solved, such as through contracting between producers and processors (Binswanger & Rosenzweig, 1986).

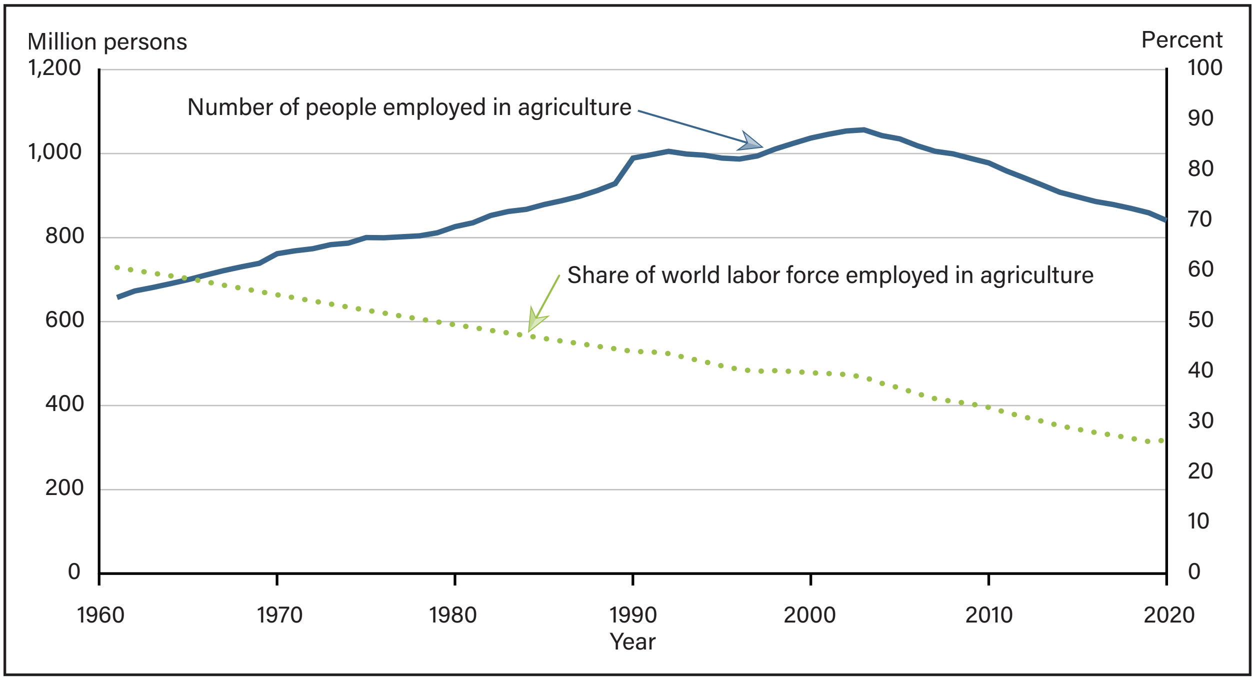
The dominance of family farms, however, has not prevented farms from becoming large. Instead, families manage large farms principally by employing more capital per worker (i.e., through mechanization). In this way, they continue to rely mainly on their own labor rather than hiring a large pool of workers, although hired labor may be used for certain operations where work performance can be easily monitored, such as paying fruit pickers by the amount of fruit picked rather than by hours worked. The movement toward larger farms evolves organically in an economy as wages rise, as long as land markets are allowed to operate freely. Land may not necessarily be owned by the family but instead rented, leased, or sharecropped. The relative price of labor to capital appears to be driving the growth of farm size and choice between capital-intensive versus labor-intensive farming techniques (Kislev & Peterson, 1982), rather than economies of scale or size (Rada & Fuglie, 2019). And because scale economies are generally not large in agriculture, small and large farms often coexist even in a high-wage economy, so long as families operating small farms can find off-farm work to supplement their income from farming.

Despite the continued dominance of family farms in world agriculture, Deininger and Byerlee (2012) documented recent expansion of large corporate farms in some land-abundant countries with low population density. These farms produced not only plantation crops but also grains and oilseeds. New technologies have made it easier to standardize supervision of the production processes for bulk commodities in these highly mechanized operations. Large corporate farms were also able to benefit from access to cheaper capital, negotiate for more favorable output and input prices, and achieve better coordination between production and marketing. However, Deininger and Byerlee (2012) also noted that many announced investments in corporate farming schemes have failed to materialize and that the advantages enjoyed by corporate farms may dissipate once market infrastructure, technical and innovation services, and property rights to land are more fully developed and accessible to family farms in these areas.

Labor Employed in Agriculture Peaked While Agricultural Capital Stock Grew

The amount of labor used in world agricultural production steadily increased from 658 million workers in 1961 to a high of 1.06 billion workers in 2003. Following this 2003 peak, the total number of agricultural workers declined, reaching 841 million by 2020 (figure 9). However, despite the increase in the total number of workers in agricultural production, agriculture's share of total global employment steadily declined throughout this period from nearly 61 percent in 1961 to 26 percent in 2020.

Figure 9
World agricultural employment and agriculture's share of total employment, 1961–2020

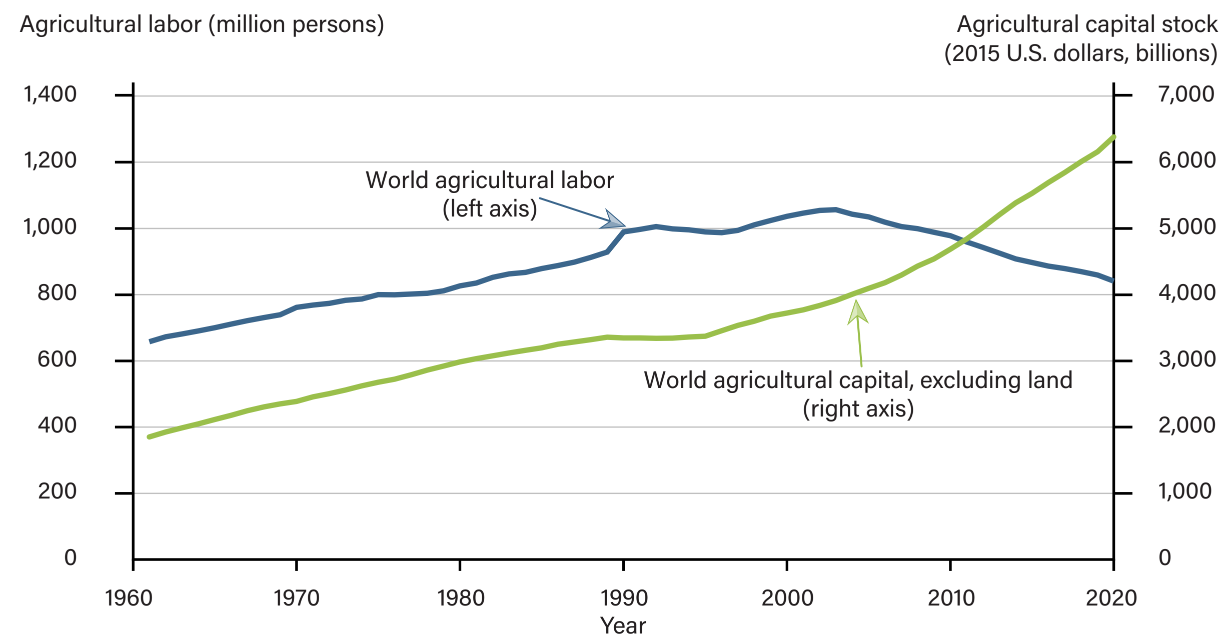


Note: Agricultural labor is measured as the number of adults (male and female over 15 years old) whose primary economic activity is agriculture.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Part of the decline in the number of agricultural workers since the 2000s is due to the substitution of capital for labor in agricultural production. Figure 10 depicts the number of agricultural laborers and the amount of agricultural capital stock in global agriculture. From 1961 to 2020, the value of agricultural capital stock increased from $1.9 trillion to $6.4 trillion (in constant 2015 U.S. dollars), which is an average increase of $76 billion annually. Additionally, since the 1990s, most of the growth of agricultural capital took place in the Global South. For example, from 1995 to 2020, agricultural capital stock in the Global South increased by 172 percent, compared with a 25-percent increase in capital stock in the Global North.

Figure 10
World agricultural labor and capital stock, 1961–2020



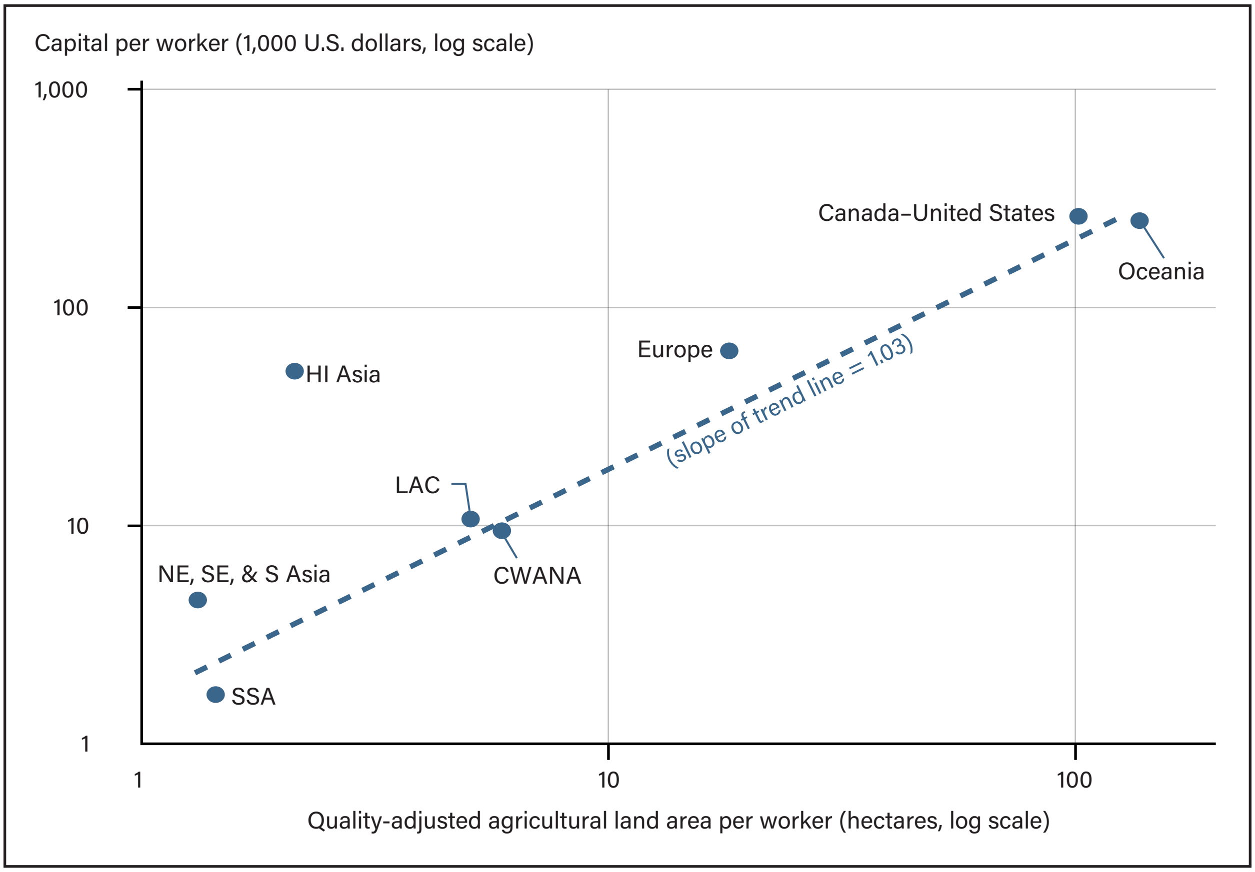
Note: Agricultural capital includes structures, machinery, breeding stock, and tree stock, but excludes land.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

The decline in world agricultural labor and the accelerated growth in farm capital stock shown in figure 10 suggests that in recent decades capital has substituted for labor as the labor force declines. This phenomenon also appears in cross-regional comparisons. Figure 11 plots the average capital per worker by land area per worker (using the quality-adjusted rainfed cropland equivalent measure for land) for major global regions in 2016–20. For example, in the Global South regions of Asia and SSA the average agricultural area per worker was less than 2 hectares in 2016–20; capital per worker in these regions was also very low, under $5,000 per worker. But in the Canada-United States and Oceania regions where land area per worker was over 100 hectares, capital stock was over $100,000 per worker. Other regions fell between these extremes. As table 2 showed, the number of workers per farm across global regions is fairly consistent, about one to two workers per farm on average both in regions with large farms of several hundred hectares and regions where farms may average only 1 or 2 hectares. Thus, in each of the regions depicted in figure 11, there are about the same number of workers on a single farm. However, farmers are using either labor-intensive methods on small farms or more capital-intensive methods on larger farms. The choice of technique is likely to be heavily influenced by the relative prices of labor and capital. Farmers in high-wage regions like Canada-United States adopt capital-intensive methods on large farms, whereas farmers in low-wage regions like Asia and Africa adopt labor-intensive methods on small farms. High-Income Asia (HI Asia) appears to be an outlier from this general trend where farmers use relatively capital-intensive methods on small farms. Otsuka et al. (2016) showed that in some Asian countries where wages have been rising, agricultural and land policies have slowed the growth of farm size, leading to inefficient farm sizes and excessive amounts of capital on small farms.

Among the regions presented in figure 11, there is a consistent and positive relationship between capital per worker and land area per worker, although HI Asia is an outlier. Excluding HI Asia, each 1-percent increase in land area per worker is associated with approximately a 1-percent increase in capital per worker.

Figure 11
Capital-labor substitution in agriculture



SSA = Sub-Saharan Africa. NE, SE, & S Asia = Northeast Asia, Southeast Asia, and South Asia. HI Asia = High-Income Asia. LAC = Latin America and the Caribbean. CWANA = Central and West Asia and North Africa.

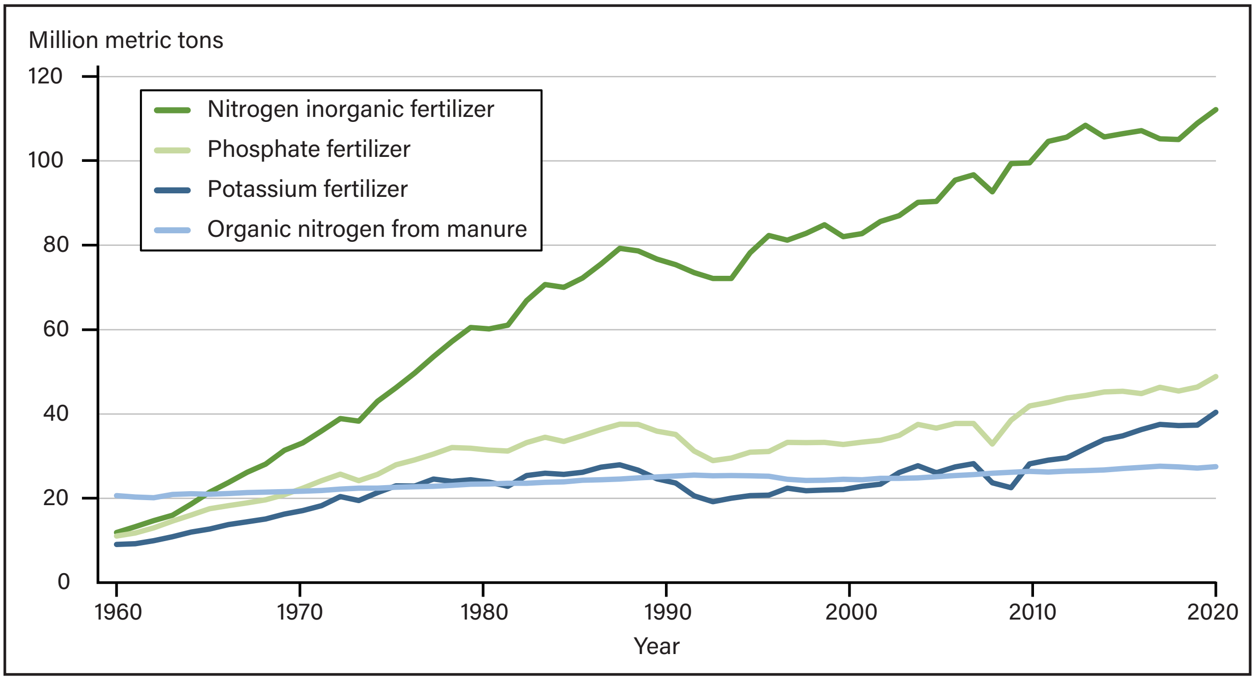
Note: Units are shown in logarithmic scale so each equidistant interval represents the same percent change in either capital per worker (up-to-down change) or land area per worker (left-to-right change).

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Intermediate Inputs Often Embody New Technologies

Material or intermediate inputs in agriculture consist of inputs that are used in a single growing season, unlike capital inputs that contribute to production over several years. These intermediate inputs include seeds, fertilizers, chemicals, animal feeds, animal pharmaceuticals, fuels, and electricity. In more traditional agricultural systems, many intermediate inputs are produced by farms themselves (e.g., saving a portion of the crop as seed for replanting the next season, feeding crops to farm raised livestock, and using animal manures for fertilizer). In more modern systems many of these inputs are purchased from specialized manufacturers. These agricultural input manufacturers may conduct R&D to embody new technologies in these inputs. Public research institutes and agricultural universities are also major sources of agricultural innovations, especially in crop and livestock genetics and crop and animal husbandry.

Figure 12
Quantity and composition of agricultural fertilizers applied worldwide, 1961–2020

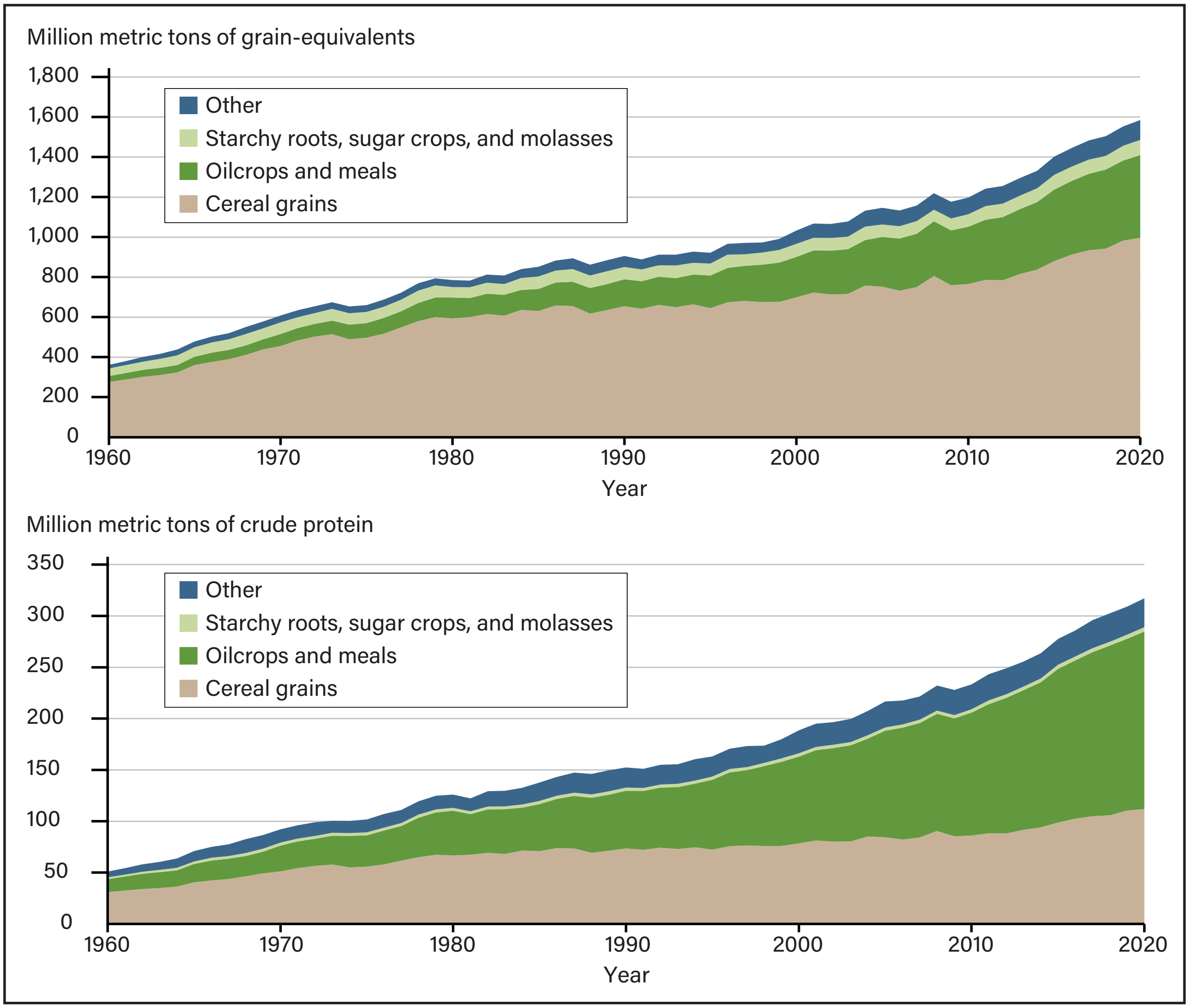


Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data; and Food and Agriculture Organization of the United Nations. (2023a). *FAOSTAT* [database]. Food and Agriculture Organization of the United Nations.

The key limiting nutrient in global crop production has been nitrogen (N). Manufactured or synthetic fertilizers, especially for the macro nutrients nitrogen, phosphate (P_2O_5), and potassium (K), became widely available for agricultural use in the second half of the 20th century. Figure 12 shows global trends in the amount of synthetic nitrogen, phosphate, and potassium and an estimate of the amount of organic nitrogen fertilizer obtained from animal manures used in global crop production over 1961–2020. Synthetic or inorganic nitrogen showed the fastest growth, with global use increasing from 12 million metric tons in 1961 to 112 million metric tons in 2020. Meanwhile, organic nitrogen supplied from animal manures increased from 17 million metric tons to 25 million metric tons. Other important sources of nitrogen for crop production (not shown in figure 12) are biological nitrogen fixation and atmospheric deposits from rainfall, which are estimated to have provided another 39 million metric tons and 15 million metric tons, respectively, for crop production in 2020 (FAO, 2023a). Use of synthetic phosphate and potassium fertilizers also increased in world agriculture over 1961–2020, but at a slower rate than nitrogen.

In livestock and aquaculture production, feed is the most important intermediate input. Not including feed from forages and fodder crops, total feed use in agriculture increased from 381 million metric tons (in dry matter or grain-equivalent tons) in 1961 to 1.585 billion metric tons in 2020 (figure 13). Cereal grains are the single most important type of animal feed, with oil crops and meals second. Oil crops and meals provide most of the protein in animal feed and were the fastest growing component of animal feeds globally over 1961–2020. By 2020, oil crops and meals provided 56 percent of total crude protein in animal feeds (compared with 35 percent for cereal grains), whereas cereal grains supplied 63 percent of caloric energy (versus 23 percent from oil crops and meals), not including contributions from forages and fodders.

Figure 13
Global quantity and composition of animal feed concentrates, 1961–2020

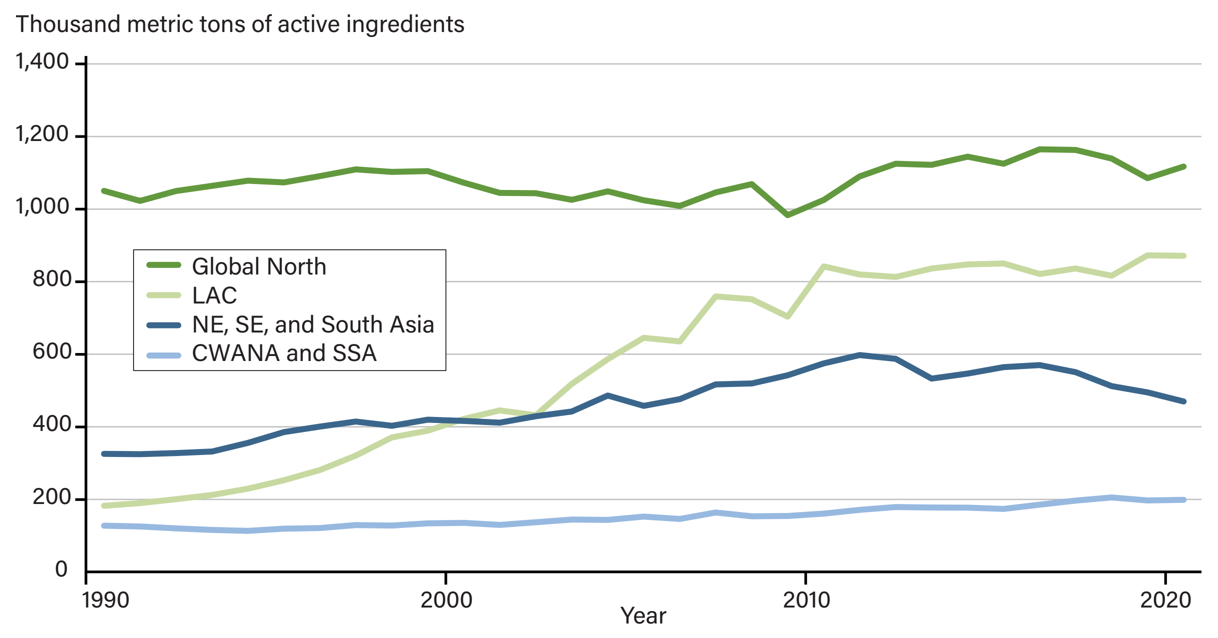


Note: Grain-equivalents are based on dry-matter content of crops. This is closely correlated with the metabolizable energy content of feeds.

Source: USDA, Economic Research Service (ERS) using USDA, ERS October 2022 International Agricultural Productivity data; and National Research Council. (1982). *United States-Canadian tables of feed composition: Nutritional data for United States and Canadian feeds* (Third revision). The National Academies Press.

Agricultural pesticides protect crops from pests and diseases. Detailed information is available on global pesticide use since 1990. Over 1990–2020, global agricultural pesticide use increased from 1.7 million metric tons of active ingredients to 2.7 million metric tons of active ingredients (figure 14), with most of this increase occurring in Global South regions—especially in LAC. Herbicides are the largest component of global pesticide use, accounting for 52 percent of total pesticide active ingredients in 2020, followed by fungicides (23 percent), insecticides (18 percent), and other products (7 percent).

Figure 14
Quantity of agricultural pesticide use by region, 1990–2020



LAC = Latin America and Caribbean. NE, SE, and South Asia = Northeast, Southeast, and South Asia. SSA = Sub-Saharan Africa. CWANA = Central and West Asia and North Africa. Global North includes Europe, Canada-United States, Japan, South Korea, Taiwan, and Oceania.

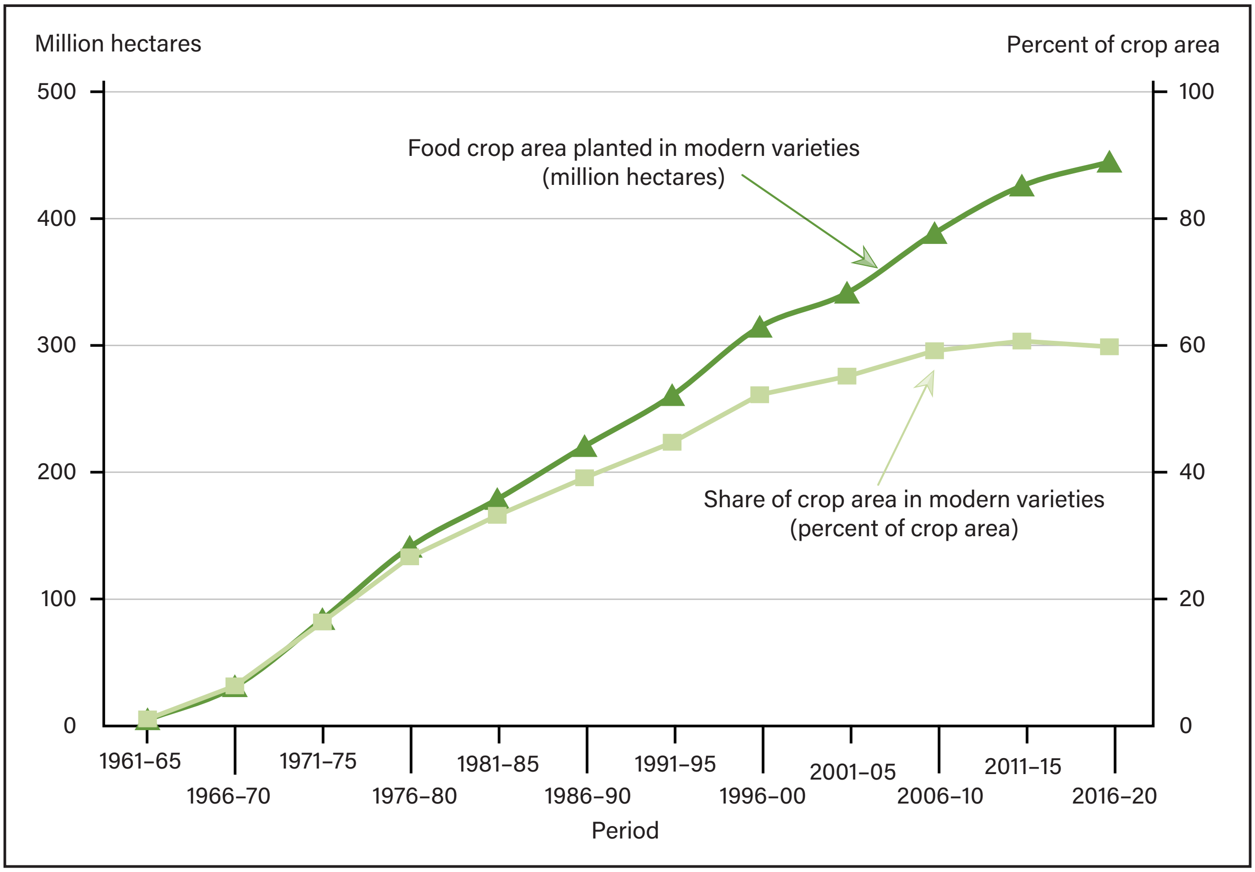
Note: Food and Agriculture Organization (FAO) of the United Nations defines total pesticides to include the following: insecticides, fungicides and bactericides (including seed treatments), herbicides, plant growth regulators, rodenticides, mineral oils, disinfectants, and others.

Source: USDA, Economic Research Service using Food and Agriculture Organization of the United Nations. (2023a). *FAOSTAT* [database]. Food and Agriculture Organization of the United Nations.

Another important material input in agriculture is seed. Crop seed is a major conduit for introducing improved technology in agriculture. Although plant breeding and selection have been conducted by farmers for thousands of years, the application of Mendelian genetics to agriculture in the early 20th century by scientists enabled the rate of genetic improvement to greatly accelerate. These improvements have raised yield potential, improved resistance to biotic and abiotic stresses, made harvesting easier, and improved the quality of agricultural commodities. In the late 20th century, advances in biotechnology provided a new set of tools for scientists to improve crop seed. Similarly, animal breeding has been a major vehicle for technological improvements in livestock, which has driven increases in animal output.

By the 1950s and 1960s, the crop varieties and animal breeds improved through scientific breeding programs had been widely adopted by farmers in the Global North but not in the Global South. Unless produced under controlled conditions, crop varieties and animal breeds need to be adapted to local environmental conditions, and, thus, are not easily transferrable across different agricultural ecologies. The development and adoption of improved crop varieties in the Global South was bolstered by the Green Revolution beginning in the 1960s (figure 15). A major driving force behind the Green Revolution was the establishment of a system of international agricultural research centers in developing nations, today known as CGIAR (formerly the Consultative Group for International Agricultural Research). Many Global South countries also boosted their investments in national agricultural R&D systems, often working collaboratively with CGIAR. By 2020, improved varieties had been adopted on about 60 percent of the total area planted to food crops in the Global South, or on about 447 million hectares. Improved crop germplasm from CGIAR breeding programs could be found in more than 40 percent of this area (Fuglie & Echeverria, 2024).

Figure 15
Diffusion of modern varieties of food crops in the Global South, 1961–2020



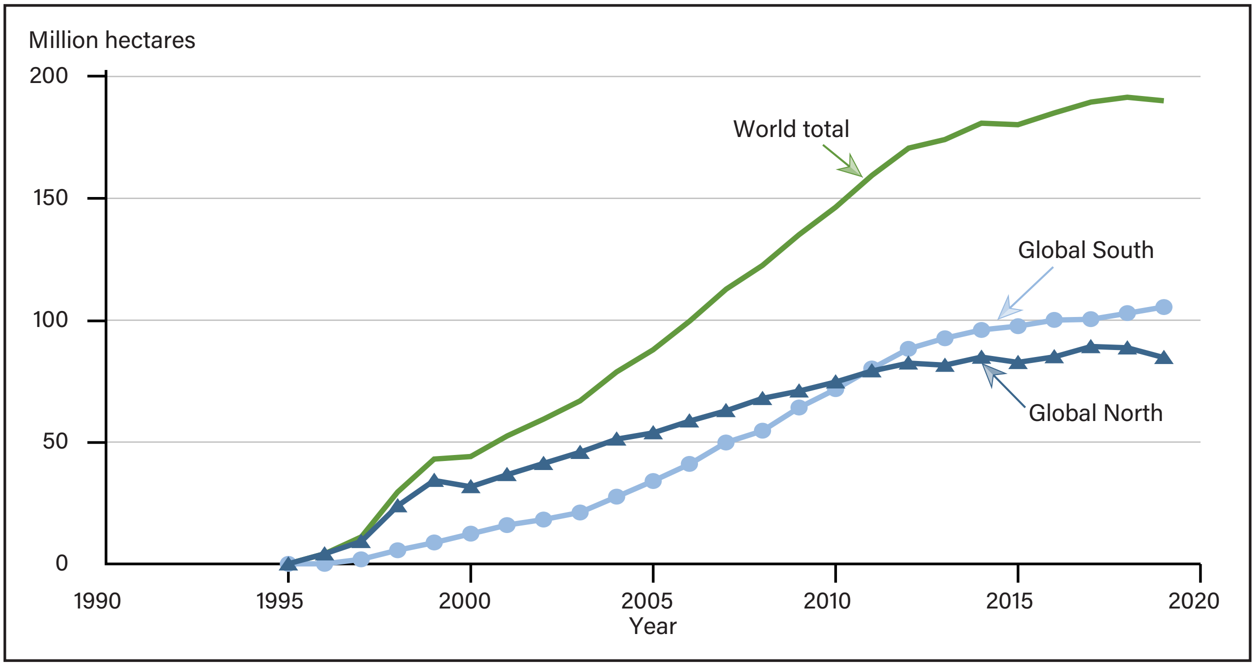
Note: Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean.

Source: USDA, Economic Research Service using Fuglie, K., & Echeverria, R. (2024). The economic impact of CGIAR-related crop technologies on agricultural productivity in developing countries, 1961–2020. *World Development, 176*, 106523.

In the 1990s, another major innovation in crop genetics occurred with the adoption of genetically modified (GM) crops. Developed primarily by private seed companies, GM crops were developed to offer improved resistance to insect pests, reduce reliance on insecticides, and build tolerance for certain herbicides, allowing for better weed control and less mechanical tillage. The first GM crops were commercially available in the mid-1990s, and by 2019 nearly 187 million hectares of GM crops were planted worldwide, or about 12 percent of total global crop area harvested (figure 16). The crops with the largest area in GM varieties are corn, soybean, cotton, and canola, and the most common GM traits that have been integrated into these crops are insect resistance and herbicide tolerance. First adopted by farmers in the Global North, GM crop varieties were soon also developed for regions in the Global South. By 2010, GM adoption area in the Global South exceeded the adoption area of the Global North.

The adoption of GM crops has resulted in net economic and environmental benefits, including increasing crop yield, reducing pesticide use, increasing farm profits, and reducing food prices for consumers (Klümper & Qaim, 2014; Brookes & Barfoot, 2020; Brookes, 2020). However, public reservations regarding the use of GM traits in agriculture have led to complex systems of regulations, which have slowed or restricted their use in many countries (Qaim, 2009).

Figure 16
Diffusion of genetically modified (GM) crop varieties worldwide, 1995–2019



Note: Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. Global North includes Europe, Canada-United States, Japan, South Korea, Taiwan, and Oceania.

Source: USDA, Economic Research Service using International Service for the Acquisition of Agri-biotech Applications (ISAAA) data.

Agricultural Productivity

The relationship between agricultural outputs and inputs is the crux of productivity measurement. Productivity can be examined for a single input, such as output per worker or per hectare of land, as well as for all inputs to calculate total factor productivity (TFP). TFP measures the total amount of economic outputs (i.e., agricultural harvests) relative to the total amount of land, labor, capital, and material resources used to produce them. An increase in TFP implies that more output is produced from a given set of inputs, or equivalently, that total output is growing faster than the use of total inputs. The USDA's International Agricultural Productivity data product aggregates agricultural outputs and inputs at the country level. It then uses the ratio of total output to total input to derive an index of TFP (for further information on methods and data sources for TFP measurement, see the USDA, ERS web page for Supplementary Materials to this report).

An increase in TFP reflects an increase in the efficiency with which inputs are used in production. Adopting new technology, using inputs to produce more high-valued or high-quality products, reducing waste, achieving economies of scale, and managing available resources more effectively can increase TFP. At the same time, if natural and climate resources become degraded, such as through soil erosion, groundwater contamination, or climate change, then TFP could decline.

Changes in TFP at the national or sectoral level have reflected the sum of TFP changes occurring at the farm level. Aggregate TFP will improve if TFP on individual farms improves and/or through the entry and exit of farms from the sector (Cusolito & Maloney, 2018; Fuglie et al., 2020). For example, if the least productive farms (or least productive farmland) leave the sector or more productive farms increase their market share, then aggregate TFP will improve.

Land and Labor Productivity Increased Across a Broad Range of Factor Endowments

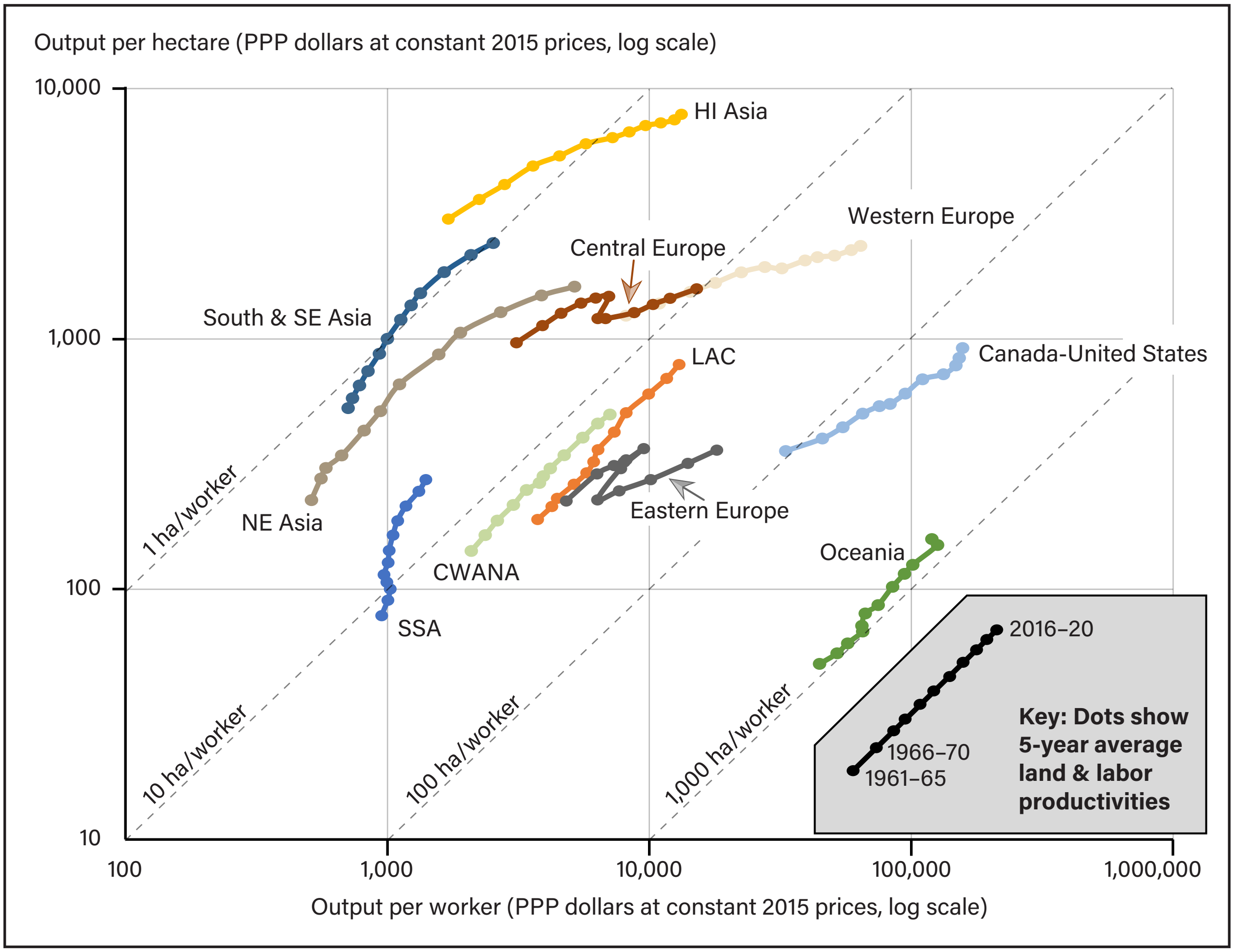
Trends in agricultural land and labor productivity across global regions over 1961–2020 (in increments of 5-year averages) are shown in figure 17. Labor productivity (output per worker) is measured along the horizontal axis and land productivity (output per hectare) on the vertical axis. Both are measured in constant 2015 purchasing-power-parity dollars (PPP$) in a logarithmic scale. Since both axes are expressed as a logarithmic scale, each of the dashed 45° lines on the graph represents a particular land-to-labor ratio, corresponding to a certain land area per worker. If a region's productivity line crosses a 45° line, the region has that land-to-labor ratio at that point in time. If the productivity line bends to the right (has a slope less than 45°), then the land-to-labor ratio in that region is increasing. Similarly, if the productivity line has a slope greater than 45°, then the land-to-labor ratio is declining. Note that higher labor productivity arises from (1) more land per worker and (2) more output per hectare. Even if land productivity is increasing, labor productivity might not increase if land per worker is falling. Also, the land-to-labor ratio gives a rough indication of average farm size and there are on average about 1.4 workers per farm worldwide, a number that is fairly homogeneous across regions (table 2).

All regions in figure 17 saw gains in both land and labor productivity over 1961–2020. This occurred in regions where small farms of only about 1 hectare per worker dominate, as in Asia, and in regions where average farm size may exceed 100 hectares per worker, such as Canada-United States and Oceania. Farm size (or land per worker) does not appear to be a constraint to agricultural productivity growth, nor do larger farms achieve higher yields, although they do tend to have higher output per worker. Larger farms tend to use more capital per worker and tend to produce more output per worker (figure 11). However, in many situations smaller farms in developing countries have been observed to obtain higher value of output per hectare (Berry & Cline, 1979; Eastwood et al., 2010; Rada & Fuglie, 2019).

In most of the Global North regions, land per worker grew over time as labor exited the farm sector. Output per worker increased due to both increases in land productivity and land per worker. Exceptions to steady productivity growth in the Global North are Central and Eastern Europe. These regions experienced a temporary productivity reversal in the 1990s as they transitioned from centrally planned to market economies.

Figure 17

Trends in labor productivity, land productivity, and land-labor ratios by region, 1961–2020



SSA = Sub-Saharan Africa; LAC = Latin America and the Caribbean; NE Asia = Northeast Asia; S & SE Asia = South and Southeast Asia; CWANA = Central and West Asia and North Africa; HI Asia = High-Income Asia. 1 ha/worker = 1 hectare per worker. 10 ha/worker = 10 hectares per worker. 100 ha/worker = 100 hectares per worker. 1,000 ha/worker = 1,000 hectares per worker.

Note: Each point on the figure represents a 5-year average of agricultural output per worker and per hectare of agricultural land (on a logarithmic scale), starting from 1961–65 and continuing to 2016–20, measured in purchasing-power-parity dollars (PPP$) at constant 2015 prices. Labor productivity (output per worker) is measured along the horizontal axis and land productivity (output per hectare) on the vertical axis. Since both axes are expressed as a logarithmic scale, each of the dashed 45° lines on the graph represents a particular land-to-labor ratio, corresponding to a certain land area per worker. If a region's productivity line crosses a 45° line, the region has that land-to-labor ratio at that point in time. If the productivity line bends to the right (has a slope less than 45°), then the land-to-labor ratio in that region is increasing. Similarly, if the productivity line has a slope greater than 45°, then the land-to-labor ratio is declining. Note that higher labor productivity arises from (1) more land per worker and (2) more output per hectare. Even if land productivity is increasing, labor productivity might not increase if land per worker is falling. Also, the land-to-labor ratio gives a rough indication of average farm size and there are on average about 1.4 workers per farm worldwide, a number that is fairly homogeneous across regions.

Source: USDA, Economic Research Service (ERS) using USDA, ERS October 2022 International Agricultural Productivity data.

In LAC and CWANA, land area per worker remained constant over 1961–2020 as their productivity lines moved in parallel with the constant land-to-labor ratio 45° dashed lines. Labor productivity increases came from increases in output per hectare. By contrast, land area per worker declined over 1961–2020 in SSA. Rapid population growth and limited nonfarm employment opportunities caused the agricultural labor force to grow faster than agricultural land area. However, land productivity grew fast enough to keep output per worker from declining and to even achieve some modest gains in labor productivity from 2000–20.

Regions in Asia achieved some of the most rapid gains in agricultural land and labor productivity over the 1961–2020 period. In South and Southeast Asia, land area per worker declined over 1961–2000 to under 1 hectare per worker but somewhat recovered during 2001–20. Nonetheless, both land and labor productivity steadily increased. Northeast Asia achieved the most rapid rates of land and labor productivity gain of any global region, with most of these gains occurring after 1980 when China implemented agricultural reforms, abandoning farm collectives in favor of family-operated farms.

Total Factor Productivity (TFP) Accounted for an Increasing Share of Agricultural Growth

Although increases in single-factor productivity (such as land and labor productivity discussed above) can be due to efficiency changes or increases in other inputs like capital or materials, TFP focuses just on technological or efficiency changes since the contributions to growth of all measured factor inputs are taken into account. In fact, it is possible to decompose the sources of agricultural growth into components due to changes in the amounts of inputs employed and the efficiency with which those inputs are used (i.e., changes in TFP). It is also possible to isolate the contribution to growth of changes in specific factor inputs. In figure 18, the growth in world agricultural output in each of the six decades over 1961–2020 is decomposed into four different components:

(1) Increases in agricultural land area (holding other inputs per hectare constant);

(2) The extension of irrigation to cropland, which augments land quality (again, holding inputs per hectare constant);

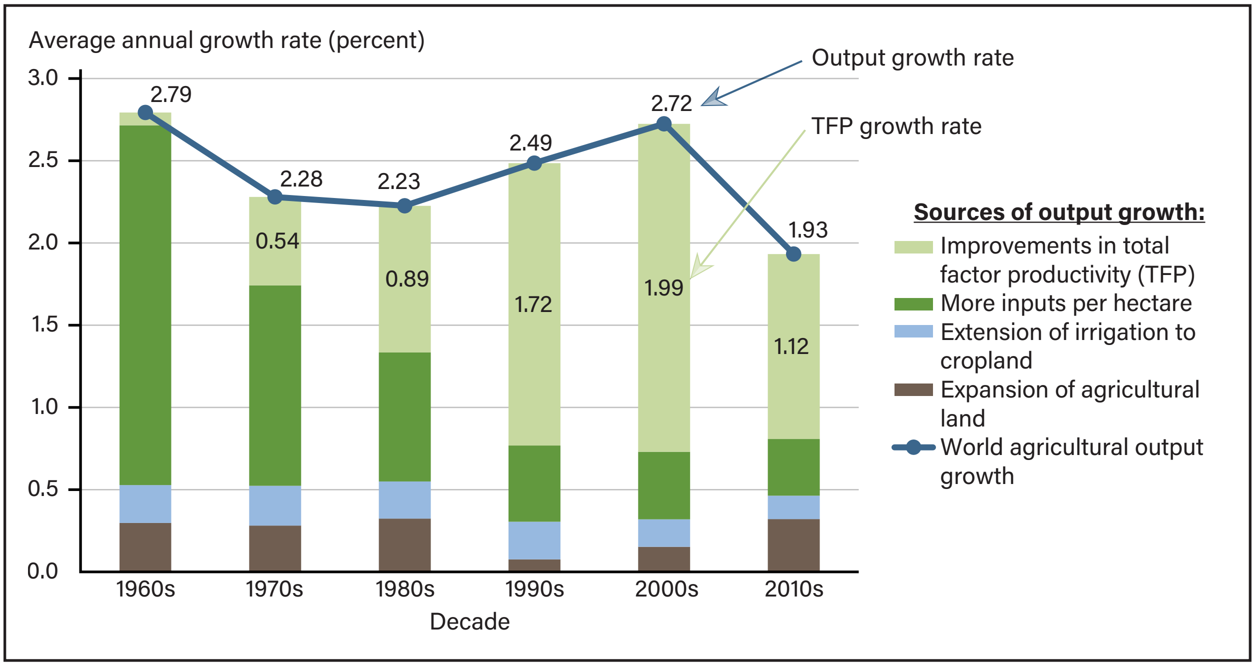
(3) Increased intensity of the use of other inputs (labor, capital, and materials) per hectare; and

(4) Improvements in TFP.

The first component, area expansion, is often referred to as extensive growth. The last three sources of growth all contribute to raising land productivity and may be referred to as intensive growth, which has for a century or more been far more important for increasing the world's food supply than extensive growth (figure 1). Among the three sources of yield growth, TFP growth has replaced input intensification as the primary driver of global agricultural growth (figure 18). In the 1960s and 1970s, input intensification was the main source of yield and output growth, when the share of growth attributable to TFP was small but gradually rising over time. Since the 1990s, TFP has been the primary driver of global agricultural growth.

However, the rate of world agricultural output and TFP growth significantly slowed in the most recent decade (2011–2020) compared with previous decades (figure 18). Output growth fell below 2 percent per year during 2011–20, the lowest rate of growth since 1961. Most of the decline in output growth can be traced to declining TFP growth; between the 2001–2010 decade and the 2011–2020 decade, annual TFP growth fell by nearly half from 1.99 percent to 1.12 percent. The rate of land expansion, although still a relatively small part of agricultural growth, increased significantly in 2011–20 compared with the previous two decades.

Figure 18
Sources of growth in world agricultural output by decade, 1961–2020



Note: The blue line shows the average annual growth rate in agricultural output in each decade. The brown-shaded area is the share of output growth due to land expansion, holding output per land area fixed. The other shaded areas show the sources of growth in output per land area due to (1) extension of irrigation to cropland; (2) intensification of labor, capital, and material inputs per unit of land; and (3) improvements in total factor productivity, which is an indicator of the rate of technical change.

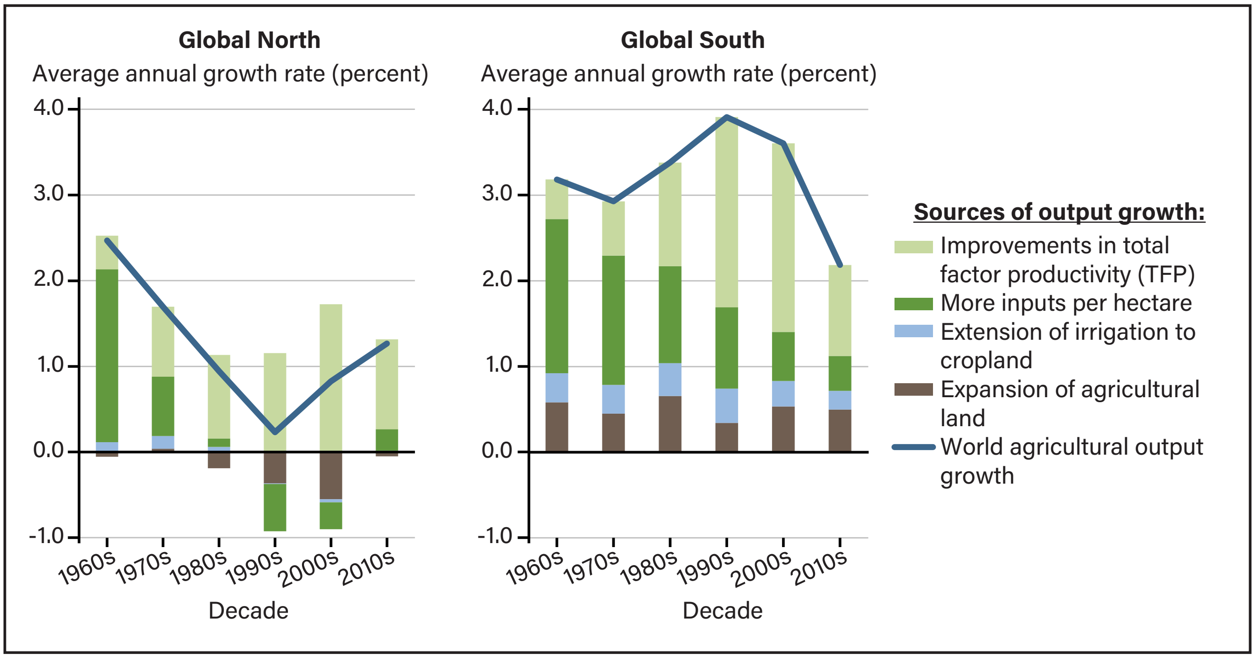
Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Where Has Agricultural Growth Been Slowing?

The slowdown in world agricultural output growth during 2011–20 occurred primarily in the Global South (figure 19). In the Global North, agricultural output growth actually accelerated over the past decade, although the average rate of output growth in the Global South was still higher than that of the Global North. In the Global North, agricultural input use declined during the 1980s, 1990s, and 2000s; it was only the TFP increase that allowed output growth to expand in this region during these decades. In the 2010s, the application of inputs per acre increased once again, which was likely incentivized by higher commodity prices since the 2007–08 global food price crisis.

Agricultural TFP growth slowed during 2011–20 in both the Global North and Global South. The slowdown in TFP growth in the Global South was especially pronounced, falling from an average annual rate of 2.2 percent in 2001–2010 to 1.1 percent in 2011–2020. Moreover, the slowdown in agricultural TFP growth in the Global South virtually affected all regions (Morgan et al., 2022).

Figure 19
Sources of growth in agricultural output in the Global North and Global South by decade, 1961–2020



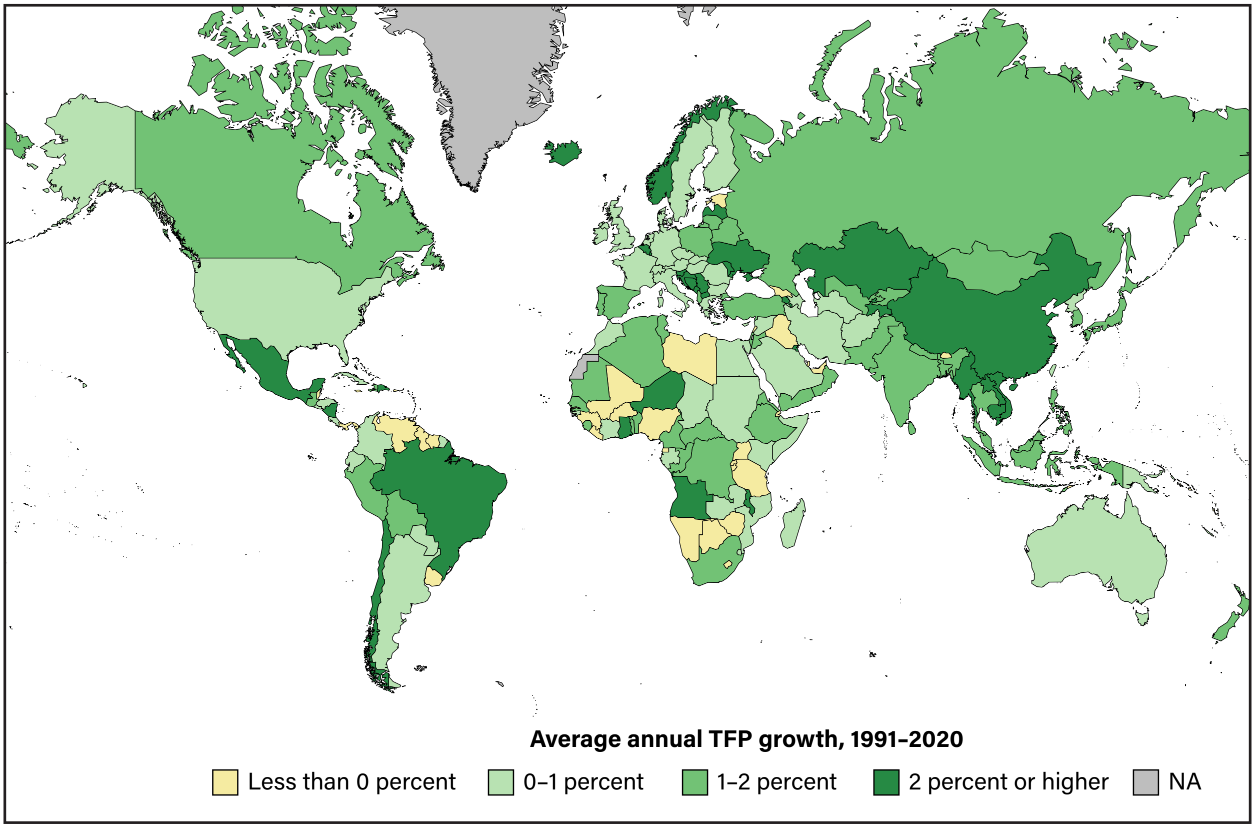
Note: The Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. The Global North includes Europe, Canada-United States, Japan, South Korea, Taiwan, and Oceania. The blue line shows the average annual growth rate in agricultural output in each decade. The brown-shaded area is the share of output growth due to land expansion, holding output per land area fixed. The other shaded areas show the sources of growth in output per land area due to (1) extension of irrigation to cropland; (2) intensification of labor, capital, and material inputs per unit of land; and (3) improvements in total factor productivity, which is an indicator of the rate of technical change.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Over the longer term, agricultural TFP growth has varied significantly across countries, even for countries within the same region. For example, from 1991 to 2020, TFP grew at an annual rate of more than 2 percent in large agricultural producing countries including Brazil, China, Mexico, and Ukraine (figure 20). In the same period, annual TFP growth was between 1 and 2 percent per year in Canada, India, and Russia, and between 0 and 1 percent per year in the United States and Australia. Several countries in Africa have experienced negative TFP growth in the past 30 years. While TFP fluctuates from year-to-year because of weather and other factors, over the long term, growth in TFP can be negative if farmers are expanding into less productive agricultural land or natural resources are degrading, or from climate change. Sustaining positive TFP growth in agriculture requires both the protection of natural resource quality and a steady stream of technological improvements that are readily adopted by farmers.

Although the causes of the recent slowdown in global agricultural TFP growth are not precisely known, several factors are likely contributing to the reduced rate of growth. Pardey et al. (2013) suggested that the pace of innovation in agriculture may be slowing as a consequence of the long-term slowing of global investment in public agricultural R&D, particularly in high-income countries. In many countries, consumer attitudes and regulatory burdens have also restricted or slowed the application of some agricultural technologies like GM crops (Qaim, 2009). Climate change and the increased frequency of adverse weather shocks is also likely contributing to slowed productivity. Ortiz-Bobea et al. (2021) estimated that between 1961 and 2015, anthropogenic climate change reduced global agricultural TFP growth by about one-fifth (21 percent), which is equal to losing the last 7 years of productivity growth.

Figure 20
Average annual growth in agricultural total factor productivity by country, 1991–2020



NA = No data available.

Note: The darker colors identify countries that have achieved more rapid growth in agricultural total factor productivity (TFP) over the three decades from 1991 to 2020. Lighter colored countries have achieved slower, or in some cases negative, agricultural TFP growth. Degradation of climate and natural resources could be contributing factors to low or negative TFP growth.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Policy Drivers of Productivity Growth in Agriculture: Investment in Research and Extension

The slowdown in global agricultural TFP growth during the last decade may have serious implications for food security and exploitation of natural resources if it continues. Less TFP growth may lead to more reliance on extensive growth (expansion of agricultural land area) to meet the growing global demand for agricultural products. However, policies have a powerful influence on long-term TFP growth in agriculture; for instance, policy reforms that improved incentives for farmers, such as the reforms China enacted after 1979, helped correct inefficiencies in resource use and allocation in agriculture. More generally, governments have had a major influence on long-term TFP growth in agriculture by supporting agricultural R&D. In almost every country of the world, a large share of agricultural R&D is either funded or directly provided by the public sector due to pervasive market failures in incentivizing private investment. Governments often complement R&D spending with extension programs to provide informal education and training for farmers in the use of new technologies and farm husbandry practices. A review of more than 40 studies of long-term TFP growth in global agriculture found that public R&D spending was a major factor in explaining agricultural TFP growth (Fuglie, 2018).

Global spending on public agricultural R&D trended upward from 1991 to 2016, increasing from $27.2 billion to $48.9 billion in constant 2015 purchasing-power-parity dollars (PPP$) (table 3). Over this period, agricultural R&D spending grew much faster in the Global South than in the Global North. In 1991, the Global South accounted for 38 percent of global public R&D spending, but this share had increased to 58 percent by 2016. Regionally, Northeast Asia was the leading investor in agricultural R&D by 2016, surpassing Western Europe. At the country level, the United States was the leading investor in public agricultural R&D until 2009, when it was surpassed by China (Nelson & Fuglie, 2022).

Table 3

Public agricultural research and development (R&D) spending by world region, 1991–2016

		Public agricultural R&D expenditures				R&D intensity in 2016		
	Region	1991	2001	2011	2016	R&D investment per farm	R&D investment per hectare of cropland	R&D investment per agricultural GDP
		(Million PPP$)				(PPP$)	(PPP$)	(Percent)
Global South	SSA	1,591	1,628	2,047	2,121	26	8	0.29
	LAC	3,554	3,466	4,793	5,124	237	31	1.21
	NE Asia	1,538	2,697	7,471	10,428	50	75	0.64
	SE Asia	1,196	2,363	2,627	2,793	58	23	0.35
	South Asia	1,465	2,371	3,610	4,783	27	22	0.28
	CWANA	1,109	1,727	2,307	2,754	110	26	1.71
Global North	Eastern Europe	460	398	674	744	31	4	0.36
	Central Europe	586	615	714	896	108	23	0.97
	Western Europe	6,000	6,734	7,728	7,210	1,276	85	3.03
	Canada-U.S.	5,104	6,067	6,274	5,528	2,388	28	2.27
	Oceania	1,148	1,480	1,268	993	5,546	31	2.37
	HI Asia	3,502	4,341	4,906	4,606	1,289	676	4.61
Global South		10,453	14,251	22,854	28,003	50	28	0.66
Global North		16,799	19,636	21,563	19,978	453	36	2.47
World		27,245	33,835	44,323	47,876	79	30	0.93
Global South percent of total		**38**	**42**	**52**	**58**			

GDP = Gross Domestic Product. PPP$ = Purchasing-power-parity dollars. SSA = Sub-Saharan Africa. LAC = Latin America and Caribbean. NE Asia = Northeast Asia. SE Asia = Southeast Asia. CWANA = Central and West Asia and North Africa. Eastern Europe = Russia, Belarus, Ukraine, Moldova, and Kazakhstan. Central Europe = Poland, Hungary, Czechia, Slovakia, Romania, Bulgaria, Albania, and former Yugoslav States (i.e., Croatia, Slovenia, Bosnia and Herzegovina, North Macedonia, Montenegro, and Serbia). Western Europe = All other European countries. HI Asia = High-Income Asia (i.e., Japan, South Korea, and Taiwan).

Note: Dollars are constant 2015 purchasing-power-parity dollars (PPP$). The Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. The Global North includes Europe, Canada, the United States, Japan, South Korea, Taiwan, and Oceania.

Source: USDA, Economic Research Service using Fuglie, K. (2018). R&D capital, R&D spillovers, and productivity growth in world agriculture. *Applied Economic Perspectives and Policy, 40*(3), 421–444; Agricultural Science and Technology Indicators. (2022). *Online database* [database]. International Food Policy Research Institute; and Organisation for Economic Co-operation and Development. (2020). *Online database, research and development statistics*.

Countries with larger agricultural sectors generally need to spend more on R&D to address the more diverse needs of its agricultural sector. Table 3 presents three measures of research intensity, or R&D spending relative to the size of a country's agricultural sector: R&D investment per farm, per hectare of cropland, and as a percentage of agricultural Gross Domestic Product (GDP). As a percentage of agricultural GDP, the Global North spends nearly four times as much on public agricultural R&D as the Global South (2.47 percent versus 0.66 percent in 2016). The Global North also spends more per farm and per hectare of cropland. Within the Global North, Central and Eastern Europe lag far behind other regions in R&D investment. In the Global South, Sub-Saharan Africa has the lowest levels of agricultural R&D intensity, with an R&D-to-GDP ratio of less than 0.3 percent in 2016. Sub-Saharan Africa also achieved the least improvement in agricultural TFP between 1961 and 2020 of any major global region. In addition to persistently low levels of R&D investment, agricultural productivity growth in Sub-Saharan Africa has been stymied by inadequate market infrastructure and trade barriers, poorly developed agricultural extension services, armed conflict, and macro-economic instability (Jayne et al., 2022).

Almost every agricultural research institution also devotes resources to outreach and training. Most countries, though, have created separate agencies that specialize in agricultural extension. The extension staff employed by these agencies are typically posted in rural areas and work directly with farms and other farm service providers in training and outreach. Extension agencies may take on other tasks as well, including implementing agricultural and rural development programs, training for household nutrition and sanitation, and community development.

Table 4 compiles estimates of the number of full-time equivalent (FTE) agricultural extension staff employed by government agencies over 1981–2012, summed by region. However, information on national capacities in agricultural extension services are incomplete and do not always use consistent definitions for extension. With these limitations in mind, the estimates in table 4 indicate that there were at least 1 million extension staff members working worldwide in 2012, or about 2 staff for every 1,000 farms. The vast majority of these were employed in the Global South. In general, countries in the Global South appear to have increased their extension capacities over 1981–2012, whereas countries in the Global North reduced their extension staffing.

Across countries, extension capacities appear to be highly variable. For example, China, India, Brazil, Ethiopia, and Turkey each account for more than 40 percent of the total extension FTEs in their respective regions. Several countries have instituted reforms to extension services, such as decentralizing responsibilities for extension from central to local governments, charging fees for extension services, or privatizing extension services (Birner et al., 2009; Davis et al., 2020; Norton & Alwang, 2020). Many extension services are also changing the ways they communicate with farmers, relying increasingly on digital technologies (i.e., information and communications technology, or ICT) for communicating training and information materials to the general farm population (Deichmann et al., 2016).

Public investment in agricultural research and extension services are some of the primary policy drivers of long-term TFP growth in agriculture. Research and extension are complementary. In addition to directly generating new agricultural technologies, spending on agricultural R&D, extension, and other agricultural services can help farmers adapt new technologies invented elsewhere to local agro-ecological conditions. These opportunities are referred to as technology spillovers, or technology transfer when an innovation is applied in new or different locations and contexts. Countries that have relied on extension to transfer technologies to farmers without first investing in research to adapt technologies to local conditions have often had poor results in raising agricultural TFP (Judd et al., 1986). Similarly, countries that invest in research, but without well-coordinated extension and outreach, may see slow uptake of new technologies and farming practices (Fuglie, 2012).

Table 4
Public agricultural extension staff employed in selected countries and by region

Region		Full-time equivalent (FTE) extension staff 1981	1991	2012	2012 FTE per 1,000 farms	2012 FTE per 1,000 hectares of cropland
Global South	SSA	44,885	60,738	97,718	1.47	0.45
	Ethiopia	826	6,584	45,812	4.68	2.94
	LAC	24,360	29,672	46,533	2.20	0.28
	Brazil	11,567	4,740	24,000	4.64	0.38
	NE Asia	399,052	509,752	669,454	3.33	4.84
	China	391,404	501,773	663,770	3.31	4.94
	SE Asia	56,467	86,461	77,837	1.58	0.67
	Indonesia	17,000	38,720	13,875	0.85	0.30
	South Asia	118,235	93,301	117,458	0.71	0.55
	India	99,395	65,957	90,000	0.65	0.53
	CWANA	21,949	35,590	47,491	2.03	0.52
	Turkey	5,523	16,067	14,644	4.76	0.61
Global North	Eastern Europe	33,454	89	981	1.09	0.03
	Central Europe	108	516	5,578	0.53	0.16
	Western Europe	30,922	27,716	24,839	2.87	0.29
	Canada-United States	17,226	15,177	11,863	4.84	0.06
	Oceania	1,702	1,672	1,672	7.92	0.05
	HI Asia	34,441	22,939	12,828	1.80	1.82
Global South		664,948	815,514	1,056,490	2.00	1.12
Global North		117,852	68,108	57,761	1.94	0.15
World total		782,801	883,622	1,114,251	2.00	0.83
Global South percent of world total		**85**	**92**	**95**		

SSA = Sub-Saharan Africa. LAC = Latin America and Caribbean. NE Asia = Northeast Asia. SE Asia = Southeast Asia. CWANA = Central and West Asia and North Africa. Eastern Europe = Russia, Belarus, Ukraine, Moldova, and Kazakhstan. Central Europe = Poland, Hungary, Czechia, Slovakia, Romania, Bulgaria, Albania, and former Yugoslav States (i.e., Croatia, Slovenia, Bosnia and Herzegovina, North Macedonia, Montenegro, and Serbia). Western Europe = All other European countries. HI Asia = High-Income Asia (i.e., Japan, South Korea, and Taiwan).

Note: The Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. The Global North includes Europe, Canada, the United States, Japan, South Korea, Taiwan, and Oceania.

Source: Compiled by USDA, Economic Research Service using Judd, M. A., Boyce J. K., & Evenson, R. E. (1986). Investing in agricultural supply: the determinants of agricultural research and extension investment. *Economic Development and Cultural Change*, *35*, 77–113; Davis, K. E., Babu, S. C., & Ragasa, C. (2020). *Agricultural extension: Global status and performance in selected countries*. International Food Policy Research Institute; Deng, H., Jin Y., Pray C., Hu R., Xia E., & Meng H. (2021). Impact of public research and development and extension on agricultural productivity in China from 1990 to 2013. *China Economic Review*, *70*, 101699; U.S. Department of Agriculture, National Institute of Food and Agriculture. (2023). *Agricultural Research, Extension, and Education Reform Act (AREERA) annual report*. U.S. Department of Agriculture, National Institute of Food and Agriculture; van der Eng, P. (1996). *Agricultural growth in Indonesia: Productivity change and policy impact since 1880*. St Martin's Press; and Indonesian Ministry of Agriculture (2013). *Agricultural statistics*. Jakarta: Indonesian Ministry of Agriculture.

Agriculture and the Environment

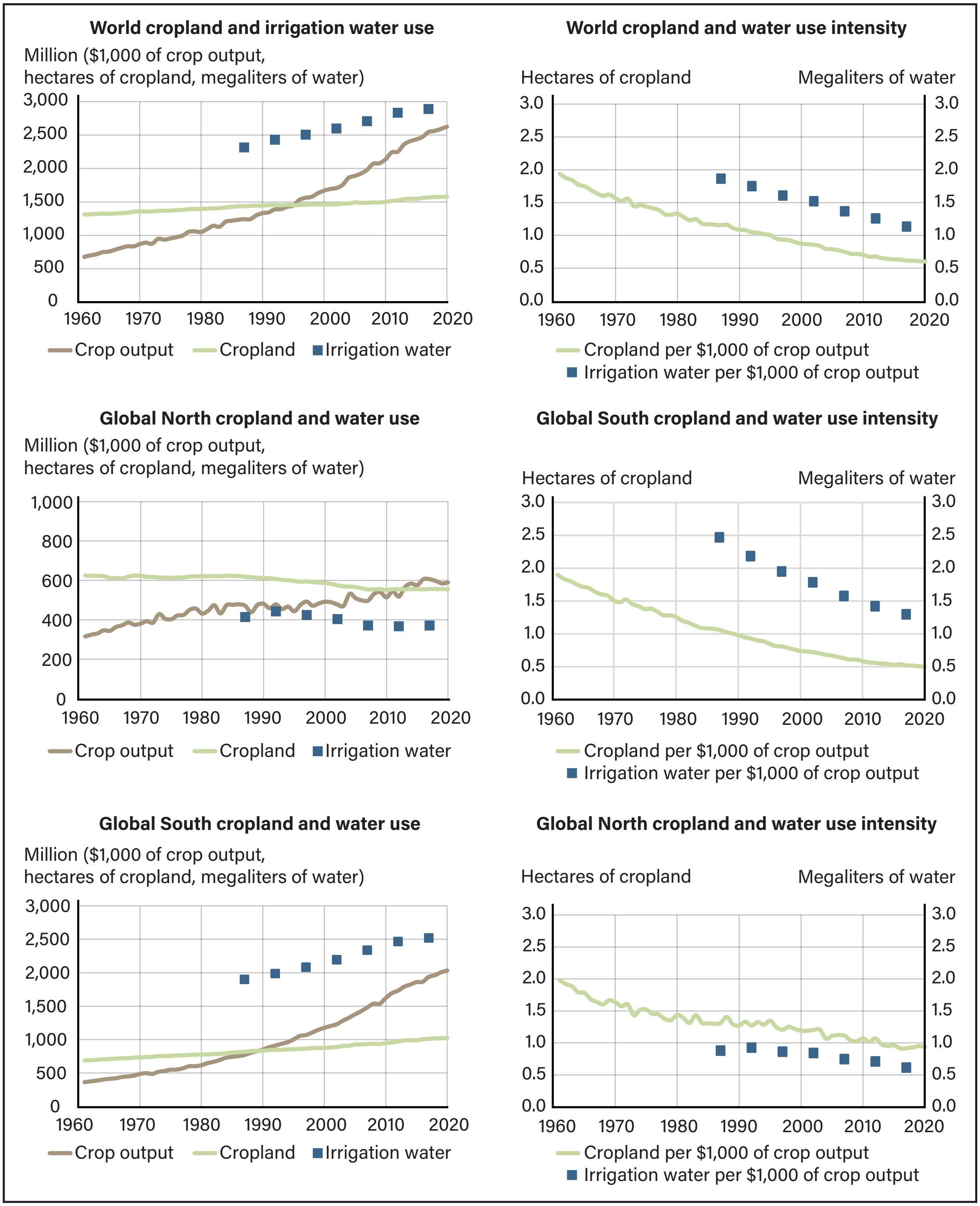
In addition to using land, labor, capital, and material resources, agriculture also has a major imprint on the environment. Agriculture occupies 37 percent of the Earth's land area and accounts for about 70 percent of the world's freshwater resources withdrawals. Agriculture is responsible for about one-quarter of world greenhouse gas (GHG) emissions, and farm applications of fertilizer have led to loadings of excess nutrients in surface and groundwater bodies. Although improvements in agricultural land productivity have been critical to saving natural lands from further agricultural expansion, the intensification of agricultural production on existing croplands, pastures, and fishponds may come at the expense of environmental quality. If resources are degraded (e.g., due to soil erosion, declining water quality, or worsening climatic conditions), agricultural TFP may be reduced. On the other hand, if intensification is based on efficiency improvement in the use of existing inputs (i.e., growth in TFP), and not the use of more inputs per hectare of land, it is possible that productivity growth could also be conserving these environmental resources, or at least allowing agricultural output to grow without imposing additional stress on the environment.

This section presents some evidence on long-term trends for the use of environmental resources by agriculture, based on how much land, water, nutrient loadings, and GHG emissions are associated with agricultural production and on resource-use intensity, or the amount of resource used or emitted per unit of agricultural output. These resource-use-intensity measures are simply the inverse of partial productivity. Although partial production is the quantity of output per unit of an input or resource, resource-use-intensity is the quantity of a resource used per unit of output. Declining resource-use-intensity implies that agricultural growth is becoming less dependent on, or decoupled from, the use of environmental resources.

Figure 21 focuses on cropland and water use in agriculture since 1961 (comprehensive statistics on water used for irrigation are only available every 5 years, starting in 1987). At the global level, crop output (measured in billions of purchasing-power-parity dollars at constant 2015 prices) increased by nearly fourfold over six decades while total net cropland expanded by only 20 percent (268 million hectares). Similarly, water withdrawals for irrigation grew more slowly than crop output and irrigated area, implying efficiency gains over time. Part of these efficiency gains came from application of improved irrigation methods and switching to crops requiring less water per dollar of output. Part may also be due to shifting a greater share of irrigated cropland to areas with more natural rainfall, so that irrigation water requirements are less.

Since the 1990s, both total cropland and total water withdrawals for irrigation have been declining in the Global North, while they are still increasing in the Global South and worldwide (figure 21). Despite the increased use of cropland and irrigation water in the Global South, significant improvements occurred in resource-use efficiencies, including between 1961 and 2020, the amount of cropland required to produce $1,000 of output declined from nearly 2 hectares to 0.5 hectares in the Global South (and from 2 hectares to just under 1 hectare in the Global North). Between 1987 and 2017, irrigation water use per $1,000 of crop output declined by about 47 percent in the Global South and 30 percent in the Global North.

Figure 21
Crop output, cropland and irrigation water use, and resource-use intensity, 1961–2020



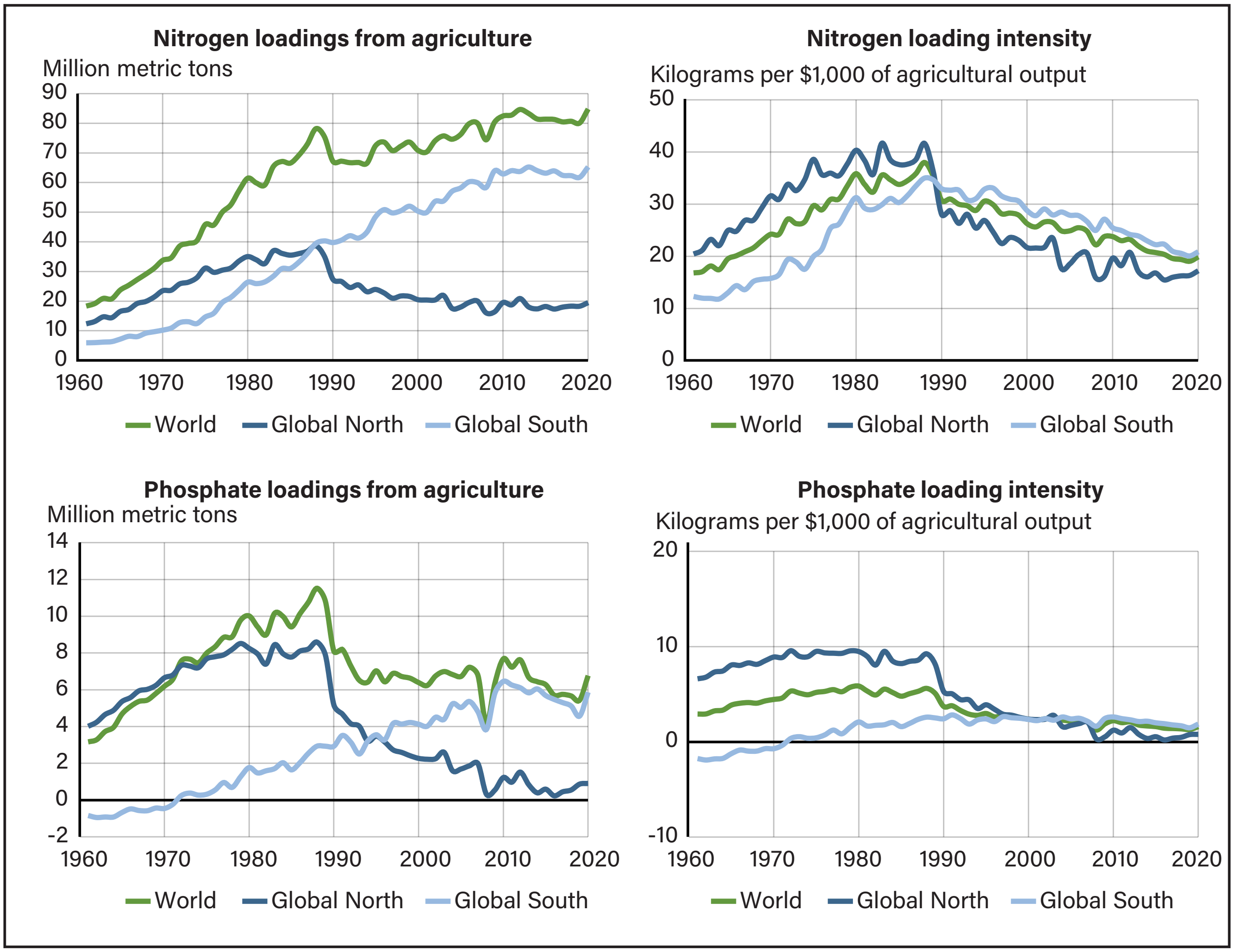
Note: The Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. The Global North includes Europe, Canada, the United States, Japan, South Korea, Taiwan, and Oceania.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data.

Nutrient loadings of nitrogen (N) and phosphorous (P) from agriculture are a major contributor to water quality degradation, and nitrogen loadings are also a potential greenhouse gas (in the form of nitrous oxide (N_2O)). Nutrient loading is the difference between the total amount of a nutrient deposited on agricultural fields (from synthetic fertilizers, animal manure, rainfall, and in the case of nitrogen from biological nitrogen fixation from leguminous crops) and the nutrient content of the harvested crops.

Figure 22 shows total nitrogen and phosphorous loadings for the world, Global South, and Global North, and trends in nutrient loading intensity (loadings per $1,000 of agricultural output). Before 1990, quantities of nitrogen and phosphorous loadings were rising very rapidly, faster than agricultural output and loadings per volume of output were increasing as well. In these decades (the 1960s, 1970s, and 1980s), fertilizer use expanded very rapidly, which was sometimes encouraged by government subsidies, especially in developing countries and in countries that made up the former Soviet Union. However, since the early 1990s, when TFP became the major source of growth in world agriculture, nutrient loading-intensity has declined dramatically. Since peaking in 1988, global average nitrogen loading intensity declined by nearly one-half by 2020 (from 38 to 20 kilograms of nitrogen per $1,000 of output), while phosphorous loading intensity fell by over 70 percent (from 5 to 1.7 kilograms of phosphorous per $1,000 of output). The improvement in phosphorous loading intensity was enough to reduce total global phosphorous loadings after 1990, although total nitrogen loadings continued to grow but at a slower pace. By 2020, total nitrogen loadings in the Global North were about half their 1990 level and total phosphorous loadings were approaching zero. One reason for the greater improvement in phosphorous loading efficiency is that phosphate (P_2O_5) fertilizer is less mobile in agricultural soils; high levels of phosphate fertilizer application in prior years has built up nutrient soil stocks, reducing current requirements. Nitrogen, on the other hand, is more affected by groundwater leaching, surface runoff, and atmospheric volatilization.

Figure 22
Agricultural nutrient loadings and nutrient-loading intensities, 1961–2020



Note: The Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. The Global North includes Europe, Canada, the United States, Japan, South Korea, Taiwan, and Oceania.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data; and Food and Agriculture Organization of the United Nations. (2023a). *FAOSTAT* [database]. Food and Agriculture Organization of the United Nations.

Another important environmental impact of agriculture is greenhouse gas (GHG) emissions. Agricultural production of crops and livestock and conversion of forests and grasslands to agricultural land (i.e., a land-use change) produces carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) that build up in the atmosphere and contribute to climate change. These different GHG gasses can be combined into a measure of metric tons of carbon dioxide equivalents in terms of their relative contribution to global warming.

The Food and Agricultural Organization (FAO) of the United Nations publishes annual GHG emissions estimates from various agricultural activities, associated land-use change,[2] and preharvest and postharvest activities such as fertilizer manufacturing and food transportation, processing, and retailing, for each country since 1990 (FAO, 2023a). According to these estimates, agricultural and food systems emitted nearly 36 gigatons of carbon dioxide equivalents in 2020, about 31 percent of total global anthropogenic GHG emissions from all sectors of the global economy. Agriculture alone produced approximately 10.4 gigatons of carbon dioxide

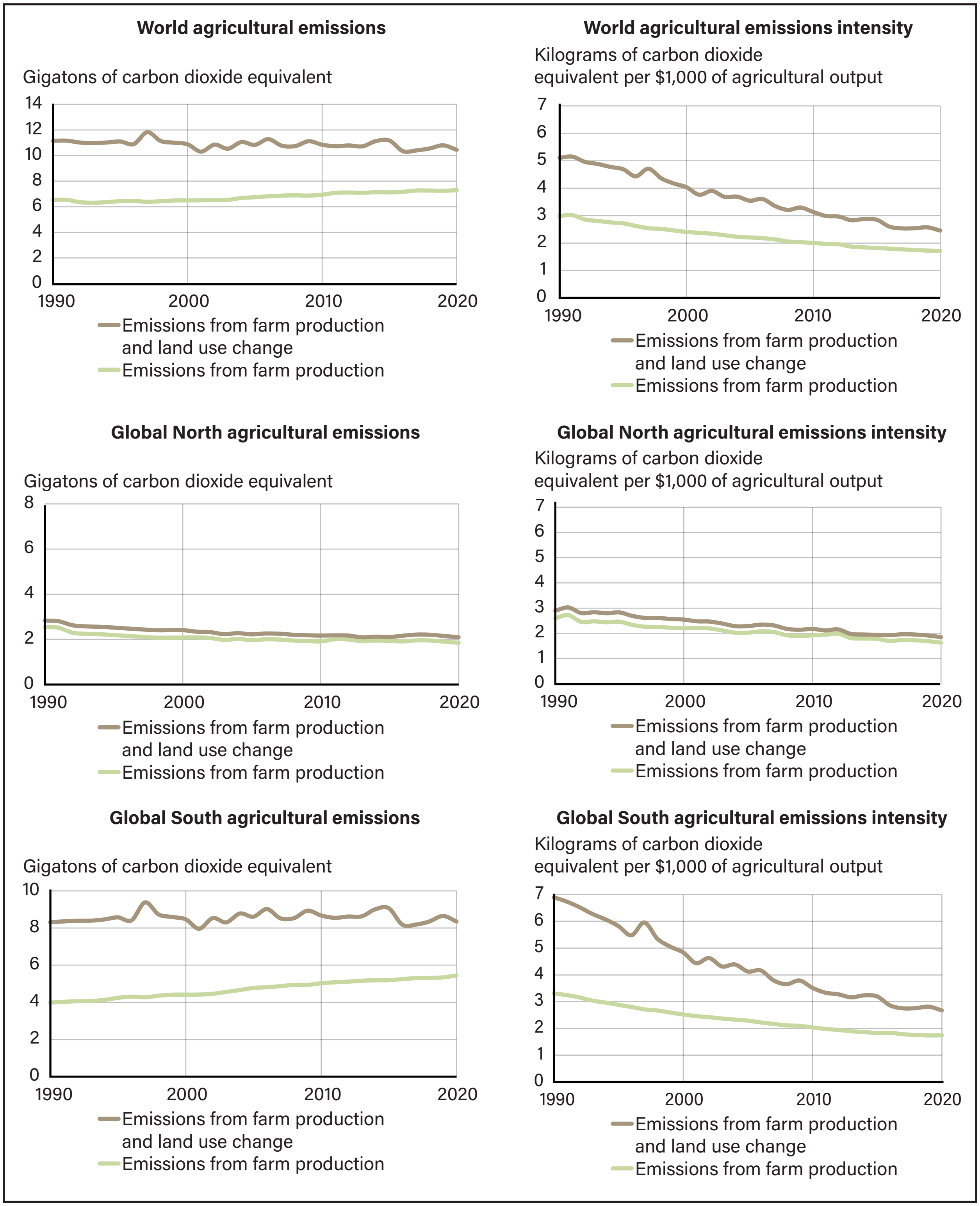
[2] Land-use change refers to a transition between the different activities that land is used for including cropland, pasture, forest use, among others.

equivalents (7.3 gigatons from farm production and 3.1 gigatons from land-use changes), or about 20 percent of total global GHG emissions. Preharvest and postharvest activities accounted for another 11 percent of total GHG emissions.

The report next focuses on relationships between agricultural TFP and agriculturally related GHG emissions (i.e., emissions from farm production and land-use changes, but not preharvest and postharvest activities). Figure 23 shows trends in total agricultural and farm GHG emissions and emission intensity for the world, the Global North, and Global South over 1990–2020 (the difference between agricultural and farm emissions is emissions due to land-use change). Globally over 1990–2020, emissions from farm production were rising but emissions from land-use change declined, which kept the total agricultural GHG emissions stable over this period. However, since agricultural output nearly doubled over these three decades, agricultural GHG emissions per volume of agricultural output fell by half between 1990 and 2020, respectively, from 5.1 kilograms to 2.5 kilograms of carbon dioxide equivalents per $1,000 of agricultural output.

Virtually all the GHG emissions associated with agricultural land-use change occurred in the Global South. Due to improved farm production and declining rates of land-use change, GHG emissions intensity in the region fell by over 60 percent between 1990 and 2020. However, average agricultural GHG emissions intensity in 2020 was still higher in the Global South compared to the Global North (2.7 kilograms carbon dioxide equivalents per $1,000 of output versus 1.8 kilograms carbon dioxide per $1,000 of output), but most of this difference was attributable to land-use changes. By 2020, the average emissions intensities of farm production were approaching similar levels across the two regions.

Figure 23
Agricultural GHG emissions and emissions intensities, 1990–2020



Note: Agricultural GHG (greenhouse gas) emissions are measured as kilograms of carbon dioxide equivalent and include emissions from farm production and land-use changes. Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. Global North includes Europe, Canada, the United States, Japan, South Korea, Taiwan, and Oceania.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data; and Food and Agriculture Organization of the United Nations. (2023a). *FAOSTAT* [database]. Food and Agriculture Organization of the United Nations.

The resource use intensities shown in figures 21–23 obscure large variations among countries and regions. Resource use intensities and how fast they are changing are determined not only by rates of agricultural output and TFP growth but also by the extent of land-use changes, the commodity composition of agricultural output, and farm production methods. Table 5 breaks out average annual agricultural resource use intensities in 2016–20 for land, water, GHG emissions, and nutrient loadings for major subregions in the Global North and Global South. For land in the Global North, high-income countries in Asia have the lowest resource intensity, only 0.13 hectares per $1,000 of agricultural output, while Oceania has the highest land resource intensity at 6.32 hectares per $1,000 of output. This reflects the high average yield of agricultural land in Asia's high-income countries, where most land is in irrigated cropland, whereas Oceania has vast agricultural areas in pastures and rangelands. In the Global South regions, the lowest GHG emissions intensity in 2016–20 was achieved in Northeast Asian countries, while the highest emissions intensity was in Sub-Saharan Africa. During this period, Northeast Asia had curbed land-use changes and achieved relatively high agricultural yields, Northeast Asia also had a relatively small number of ruminant animals, which account for a large share of methane emissions in agriculture through enteric fermentation, a digestion process that produces methane as a byproduct. On the other hand, Sub-Saharan Africa (SSA), which has a large land area and cattle herd numbers relative to agricultural output, was still converting significant natural areas to agricultural production each year. Conversely, SSA had the lowest nutrient loading intensities of any of these regions due to low levels of synthetic fertilizer use. In fact, phosphorous loadings in SSA were, on average, negative in 2016–20, indicating soil nutrient mining was taking place as more phosphorous was being removed in crop harvest than was being replenished through fertilization.

Table 5

Agricultural resource-use intensities by region, 2016–20 annual average

		Agricultural land	Cropland	Irrigation water	Nitrogen loadings	Phosphorous loadings	GHG agricultural emissions	GHG farm emissions
Quantity		Hectares	Hectares	Megaliters	Kilograms of nitrogen	Kilograms of phosphorus	Kilograms of carbon dioxide equivalent	Kilograms of carbon dioxide equivalent
Region		(natural resources per $1,000 of agricultural or crop output, constant 2015 prices)						
Global South	SSA	3.60	1.20	0.18	9.28	-4.77	7.82	3.56
	LAC	1.28	0.57	0.33	21.85	2.93	4.50	2.25
	NE Asia	0.60	0.20	0.24	33.24	4.25	0.82	0.82
	SE Asia	0.43	0.54	0.74	24.36	1.61	4.25	2.51
	South Asia	0.39	0.56	0.95	59.42	5.51	1.89	1.87
	CWANA	1.99	0.62	1.00	25.87	1.05	1.16	1.15
Global North	Europe	1.15	1.01	0.13	32.80	1.50	1.94	1.79
	Canada-U.S.	1.09	0.83	0.30	28.02	-0.98	1.78	1.41
	Oceania	6.32	1.55	0.29	29.34	6.25	3.39	3.34
	HI Asia	0.13	0.30	1.37	33.65	11.39	1.25	1.17
Global South		1.06	0.52	0.51	32.21	2.69	2.72	1.74
Global North		1.34	0.93	0.25	30.70	1.02	1.92	1.70
World		1.14	0.62	0.45	31.84	2.29	2.50	1.73

SSA = Sub-Saharan Africa. LAC = Latin America and the Caribbean. NE Asia = Northeast Asia. SE Asia = Southeast Asia. CWANA = Central and West Asia and North Africa. HI Asia = High-Income Asia (i.e., Japan, South Korea, and Taiwan).

Note: Agricultural land and greenhouse gas (GHG) emissions intensities are per $1,000 of agricultural output; cropland, irrigation water, and nutrient loading intensities are per $1,000 of crop output. "GHG agricultural emissions" includes emissions from farm production and land-use change. "GHG farm emissions" includes emissions from farm production only. Global South includes Asia (except Japan, South Korea, and Taiwan), Africa, and Latin America and the Caribbean. Global North includes Europe, Canada, the United States, Japan, South Korea, Taiwan, and Oceania.

Source: USDA, Economic Research Service (ERS) using USDA, ERS, October 2022 International Agricultural Productivity data; and Food and Agriculture Organization of the United Nations. (2023a). *FAOSTAT* [database]. Food and Agriculture Organization of the United Nations.

Overall, the data presented in this section showed that agricultural resource use intensity of land, water, nutrient loadings, and GHG emissions intensity have declined sharply over time, especially after 1990 when TFP growth, rather than farm inputs, became the major source of growth in world agriculture. Between 1990 and 2020, the amount of cropland used and the GHGs emitted for a given volume of agricultural output fell by half, irrigation water intensity fell by nearly 40 percent, and nitrogen loading intensity fell by 35 percent. The rate of growth in use of natural and environmental resources in agricultural production sharply slowed, or in some cases declined, even as agricultural output continued to grow at approximately 2 percent per year. The growth in agricultural TFP contributed to a significant decoupling of agricultural growth from the use of natural and environmental resources.

Summing Up: Implications for Sustainable Agricultural Growth

Over the six decades from 1961 to 2020, world agriculture was reshaped in fundamental ways. The volume of production (i.e., total crop, livestock, and aquacultural output) increased by a factor of 4.2, while world population grew by a factor of 2.6. As productivity improved and food and other agricultural products became more abundant, agricultural prices fell by approximately one-third in real terms (Fuglie et al., 2020). A larger proportion of the world's population could afford a richer and more diverse diet, although about 1 out of 11 people in the world still lacked sufficient calories for normal daily activities in 2020 (FAO, 2022).

One fundamental change in world agriculture over this period was a shift from resource dependent growth to productivity-led growth. The adoption of new technologies, farming and husbandry practices, specialization, and other efficiency improvements enabled farmers to increase the total productivity of the land, labor, capital, and material inputs at their disposal. Over the past three decades (1991–2020), TFP increases accounted for most of the output growth in world agriculture.

Another fundamental change was that—for the first time in recorded history—the absolute size of the world's agricultural labor force began to shrink. After peaking at 1.1 billion people in 2003, by 2020 more than 200 million workers had left agriculture. Meanwhile, land and capital available for those remaining in agriculture increased, with mechanization increasingly replacing manual labor in farm work. As a proportion of total global employment, agriculture's share declined from about 61 percent in 1961 to 26 percent in 2020.

A key characteristic of agriculture that did not change over the 1961–2020 period was the continued dominance of family-operated farms. The vast majority of the world's 600 million farms are family-operated and largely employ family labor. This has proven to be a more successful and enduring farm structure than experiments with large-scale collectives or cooperative farms. Generally, corporate plantations have only been successfully sustained for a limited number of crops, mainly those that require close coordination between harvesting and processing (i.e., cases where harvested crops rapidly deteriorate in quality if not processed immediately), such as sugar, banana, oil palm, and tea. Even in these cases, family-operated operations can compete successfully so long as coordination issues can be solved, such as through contracting arrangements between producers and processors. However, in the past decade or so there has been some corporate farming expansion into grains, oilseeds, and confined animal production, aided by new technologies that have standardized farm practices and simplify workforce monitoring.

However, the dominance of family farms has not prevented farms from becoming large. Instead, families manage large farms primarily by employing more capital per worker (i.e., through mechanization). In this way, they continue to rely mainly on their own labor rather than hiring a large pool of workers, although hired labor may be used for certain operations where work performance can be easily monitored, such as paying fruit pickers by the amount of fruit picked rather than by hours worked. The movement toward larger farms evolves organically in an economy as wages rise so long as land markets are allowed to operate freely. Land may not necessarily be owned by the family but instead rented, leased, or sharecropped. But because scale economies are generally not large in agriculture, small and large farms often coexist even in a high-wage economy, so long as families operating small farms can find off-farm work to supplement their income from farming. In some countries, growth in farm size may sometimes be constrained by agricultural or land policies that restrict land markets or otherwise support small-sized farms.

Another important dimension of agriculture is that it has a major impact on the environment. Agriculture is a significant user of freshwater resources for irrigation, a source of greenhouse gas (GHG) emissions, and runoff or leaching of chemicals, fertilizers, and manure from cropland to the detriment of surface and groundwater quality. However, agricultural TFP improvements have led to significant reductions in agricultural resource use intensity (i.e., natural and environmental resources used per unit of agricultural output). Over the three decades from 1990 to 2020, the amount of agricultural land needed to produce $1,000 in agricultural output fell by about one-half. At the same time, GHG emissions and phosphate loadings per $1,000 of farm output fell by more than half, and nitrogen loadings and irrigation water withdrawals per $1,000 of agricultural output declined by at least one-third. The close association between agricultural TFP growth and improved economic and environmental performance suggests that TFP-led growth can be leveraged for sustainable and resilient agricultural intensification (Coomes et al., 2019).

However, at the global level, improvements in agricultural TFP have not been sufficiently rapid or universal to make a significant dent in the total impact of agriculture on the environment. This is especially true in regions of the world where agricultural productivity remained low or stagnant. In fact, it appears that global agricultural TFP growth is coming under severe strain. During the decade from 2011 to 2020, world average agricultural TFP growth was about half the rate of the previous decade, with most of the slowdown in TFP growth occurring in regions of the Global South. Agricultural TFP growth has significant implications for global food security and environmental resource conservation. A prolonged slowdown or stagnation in agricultural TFP will make food more scarce and more expensive, encourage expansion of agriculture into more natural lands, and make it increasingly difficult to achieve global aspirations for a food secure and environmentally sustainable world.

The main policy lever influencing agricultural TFP is investment in agricultural research and development (R&D) and—to a lesser but still important degree—agricultural extension. Since agricultural technologies and practices are sensitive to climate, soil, and social conditions, they often need to be developed and adapted locally. Thus, most countries have invested in national agricultural R&D systems, and overall, the total world spending on public agricultural R&D increased by 76 percent between 1991 and 2016. But many national agricultural research and extension systems, particularly in some of the lowest income and most food insecure countries, remain underdeveloped and underfinanced. This limits the prospects for achieving and sustaining productivity-led agricultural growth worldwide.

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