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

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Rattan Lal is a professor of soil science at The Ohio State University and the 2020 World Food Prize laureate. Internationally recognized for his trailblazing work on developing and mainstreaming a soil-centric approach to increasing food production, Lal has received many other accolades, including the GCHERA World Agriculture Prize (2018), Glinka World Soil Prize (2018), Japan Prize (2019), and U.S. Awasthi IFFCO Prize (2019). Dr. Lal earned bachelor's and master's degrees at Punjab Agricultural University and the Indian Agriculture Research Institute, respectively, and a doctorate from The Ohio State University.

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

Ruben Echeverria, International Food Policy Research Institute (IFPRI)

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Executive Editor: Tom Thompson, Associate Dean and Director of CALS Global, Virginia Tech College of Agriculture and Life Sciences

Editor: Ann Steensland, Lead, Global Agricultural Productivity Initiative, Virginia Tech College of Agriculture and Life Sciences

Suggested reference Filling the GAPs: Expert Essays for the 2021 Global Agricultural Productivity Report. October 2021. (Thompson, T., and Steensland A. Eds.), Virginia Tech College of Agriculture and Life Sciences.

Please include the author's name in the reference.

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SOIL HEALTH AND GLOBAL AGRICULTURAL PRODUCTIVITY

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ABSTRACT

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

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

INTRODUCTION

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

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

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

ECO-FRIENDLY AGRICULTURE

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

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

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

TECHNOLOGIES FOR IMPROVING SOIL HEALTH AND INCREASING GLOBAL AGRICULTURAL PRODUCTIVITY

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

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

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

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

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

Figure 1: Innovating Agricultural Technology

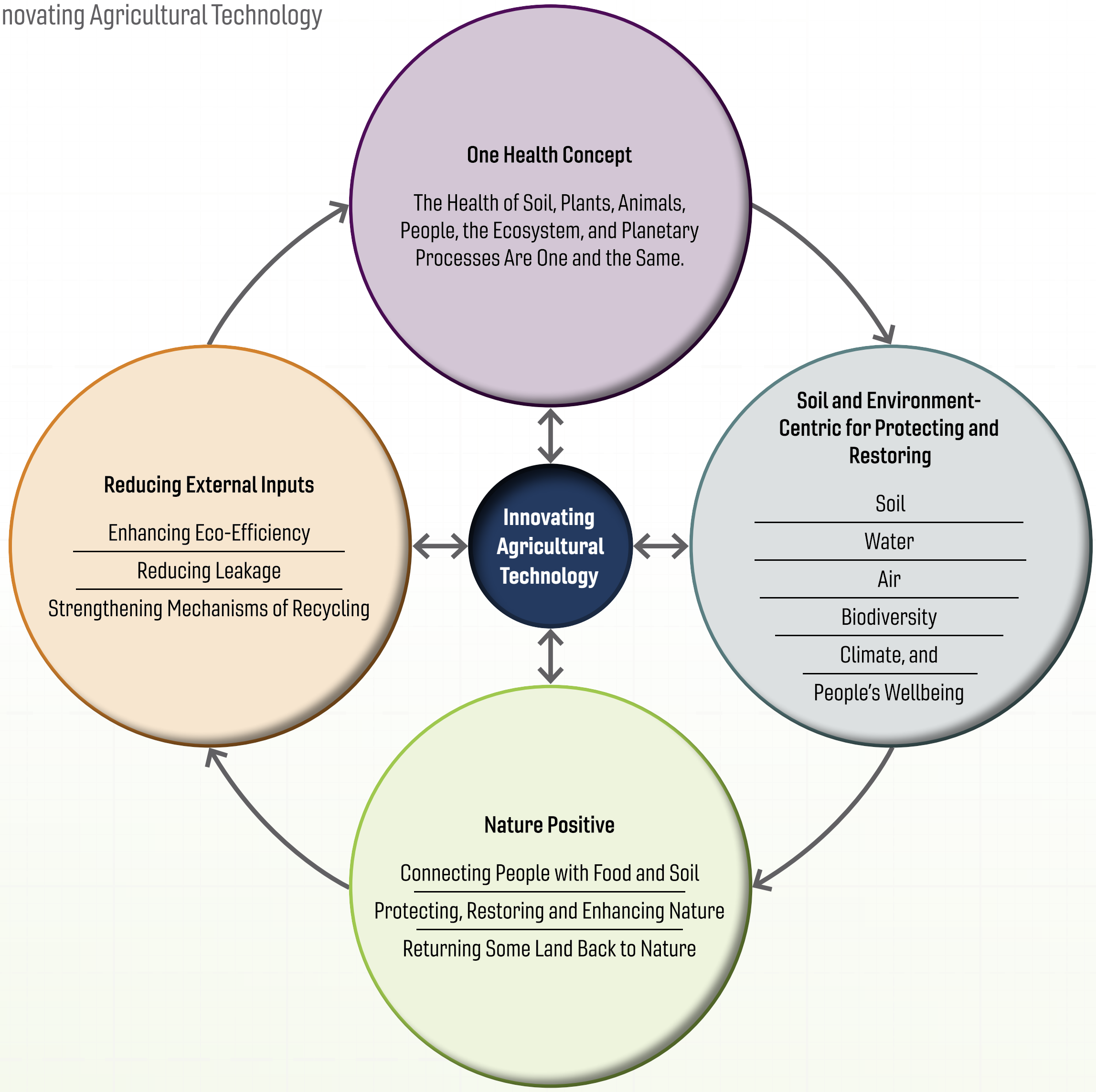

Table 1: Some Examples of Soil-Centric and Nature-Positive Agricultural Technologies for Food, Climate, and Environmental Security

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

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

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

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

CONCLUSIONS

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

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GAP REPORT® GLOBAL AGRICULTURAL PRODUCTIVITY REPORT®

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

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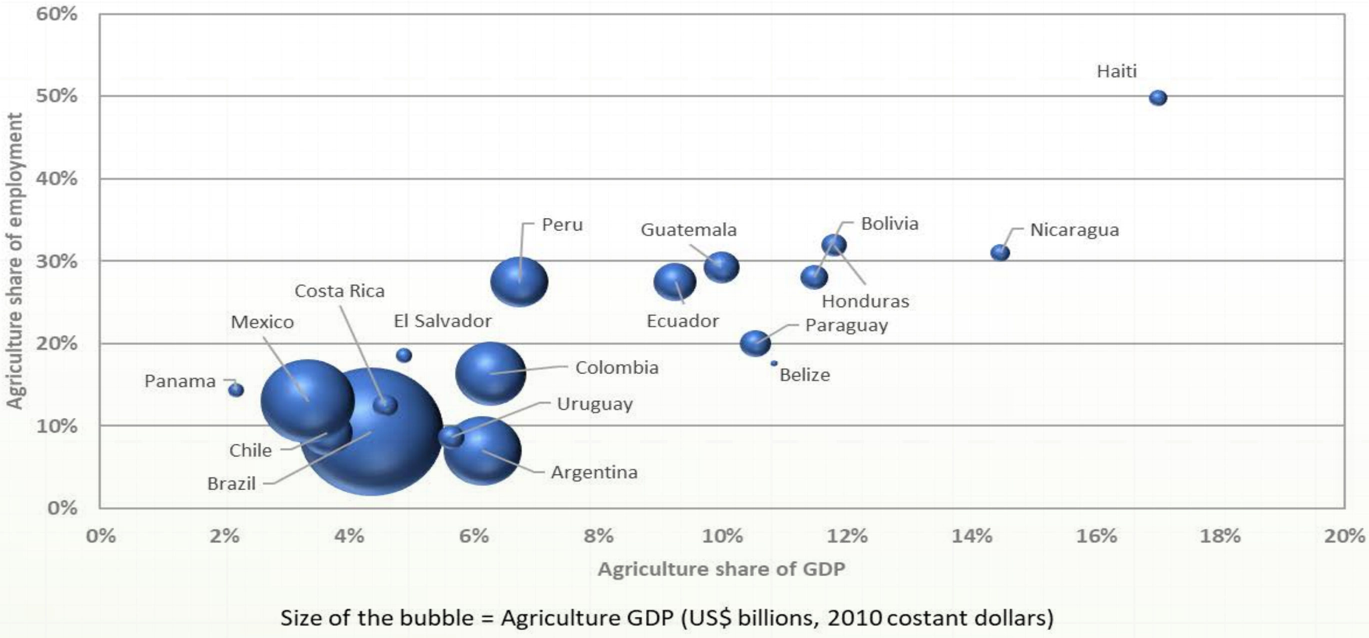
Rural societies and agri-food systems in Latin America and the Caribbean (LAC) face common and unprecedented challenges such as: improving the efficiency of food and agricultural systems; increasing the sustainability of agriculture; building the resiliency of communities, agriculture, and ecosystems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

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

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

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

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



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

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

INNOVATION AND PRODUCTIVITY

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

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

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

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

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

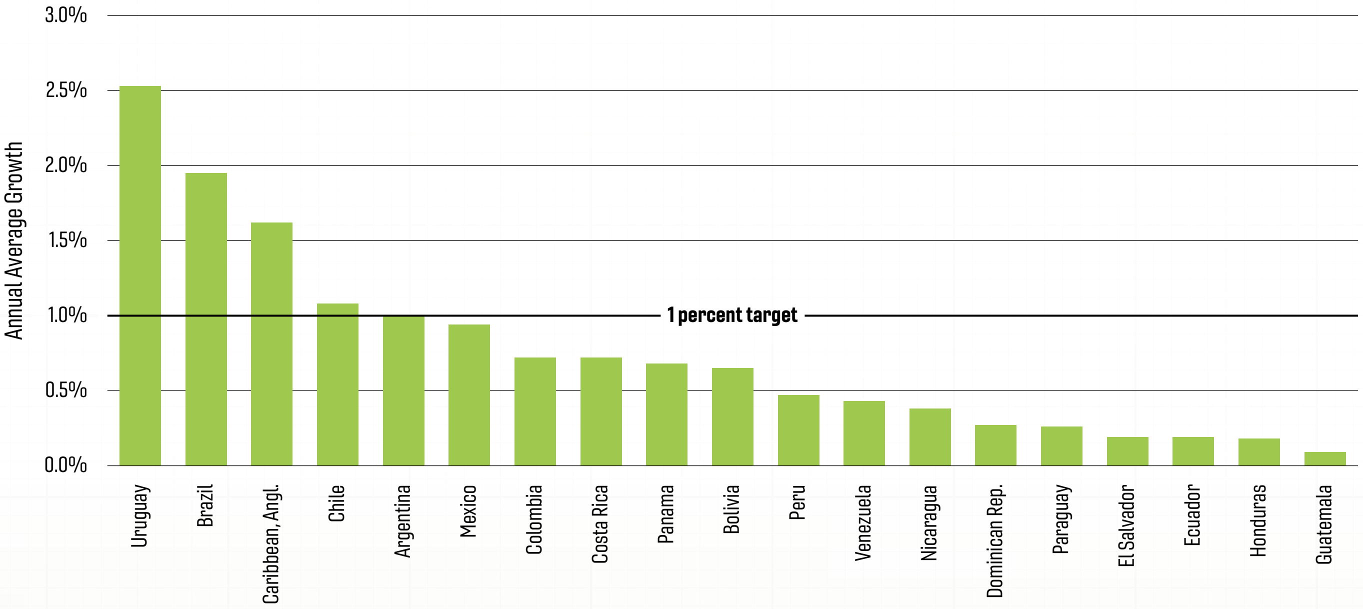
Greenhouse gas emissions increased much faster in crop production (3.4 percent) than in livestock production (0.8 percent), although emissions from livestock are six to eight times higher than crop emissions. Most of the emissions from agriculture come from enteric fermentation in ruminants and manure.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

THE NEED FOR MORE SIGNIFICANT INVESTMENT IN INNOVATION

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

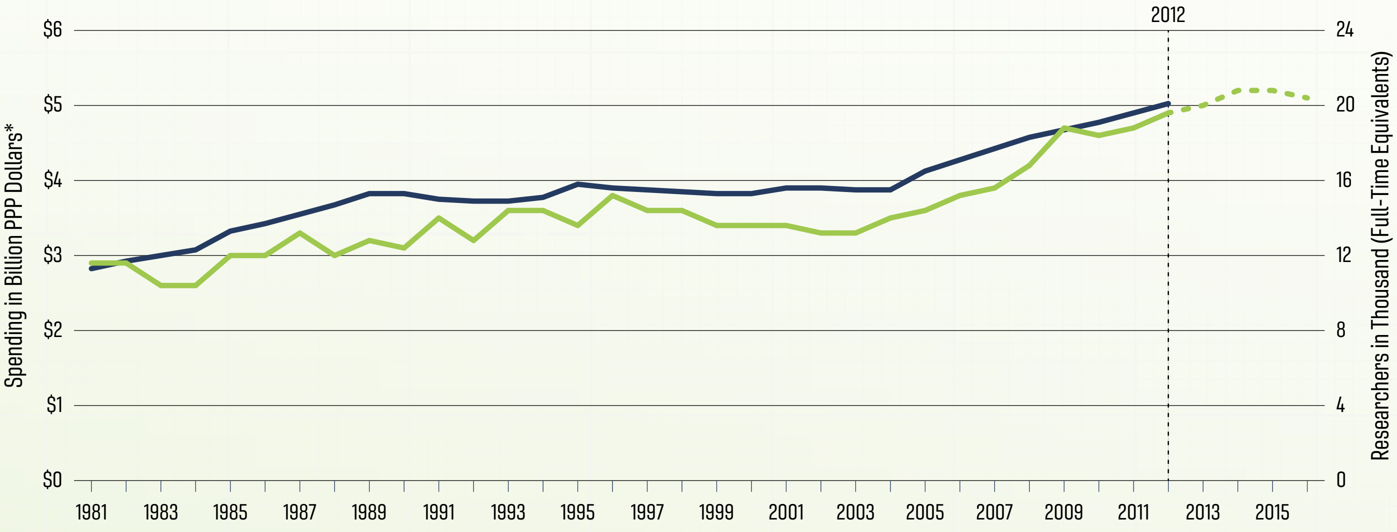
Furthermore, most of the research investment is focused on staple crops. Only a few countries have national research systems with high civil society participation and the private sector in the region.[9] The public sector employed more than half of agricultural researchers in the mid-2000s, the higher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

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



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

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



*inflation=adjusted; 2011 prices

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

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

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

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

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

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

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

ENDNOTES

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

[2] For a recent comprehensive review of agrifood systems in the region, see Díaz-Bonilla, E. and R.G. Echeverría (2020). Duality, urbanization, and modernization of agri-food systems in Latin America and the Caribbean. In K. Otsuka and S. Fan (eds.) World Development. New Perspectives in a Changing World. IFPRI: Washington DC.

[3] Berdegué, J. & Fuentealba, R. 2011. Latin America: The State of Smallholders in Agriculture. IFAD, Rome.

[4] Nin-Pratt, A., Falconi, C., Ludena, C.E. & Martel, P. 2015. Productivity and the Performance of Agriculture in Latin America and the Caribbean: From the Lost Decades to the Commodity Boom. IDB Working Paper Series. Inter-American Development Bank. Washington DC.

[5] Nin-Pratt, A. & Falconi, C.A. 2019. Agricultural R&D Investment, Knowledge Stocks and Productivity Growth in Latin America and the Caribbean. IFPRI Discussion Paper 01730. Washington DC.

[6] Parra-Peña, R.I. et al. 2021 (Una hoja de ruta para el aumento de la productividad agropecuaria de Colombia: desafíos y oportunidades. Fedesarrollo, Colombia) show a 0.6 percent annual growth rate of agricultural total factor productivity in Colombia for 2001-2016, one of the lowest in the region (1.8 percent average during that period according to the author). Similar low productivity figures for Colombia are reported for agricultural labor productivity for the same period, with an estimated average value added per farm worker of $5,086 (2010 constant dollars) compared with a $5,990 average for the region. Although those figures represent less than 7 percent of the US farm labor productivity, they are close to Mexico's figures ($5,107) and higher than Argentina's ($2,809) and Peru's ($2,184), although lower than Chile ($9,266) and Brazil ($7,661).

[7] During the period 2012-2016, only one country showed an average growth rate of 4.0 percent (Guatemala), followed by Bolivia (3.8 percent), Mexico (3.1 percent), and the Dominican Republic (2.9 percent). The fastest-growing countries in the earlier period are now growing at rates of 2.4 percent (Paraguay), 1.1 percent (Brazil), and 0.3 percent (Uruguay). Crop production continues to be the fastest-growing subsector in the fastest-growing countries, with growth rates of 4.6 percent in Guatemala, 5.4 percent in Bolivia, 5.4 percent in Mexico, and 4.7 percent in the Dominican Republic. (Nin-Pratt and Falconi, 2019)

[8] Hyland, J. 2017. A record year for agtech activity in Latin America? SVB Financial Group. Available at https://www.svb.com/blogs/jackie-hyland/record-year-for-agtech-activity-in-latin-america

[9] Gert-Jan Stads, N. Beintema, S. Perez, K. Flaherty and C. Falconi, 2016. Agricultural Research in Latin America and the Caribbean. A cross-country analysis of institutions, investment, and capacities. ASTI and IDB, Washington DC.

[10] World Bank, CIAT, CGIAR & CCAFS. 2018. Bringing the Concept of Climate-Smart Agriculture to Life: Insights from CSA Country Profiles across Africa, Asia, and Latin America. World Bank. http://ciat.cgiar.org/wp-content/uploads/COP_CSA_Synthesis_ToPrint.pdf

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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