FEED THE FUTURE

The U.S. Government's Global Hunger & Food Security Initiative

# U.S. GOVERNMENT GLOBAL FOOD SECURITY RESEARCH STRATEGY

## Fiscal Year 2022-2026

Reducing global hunger, malnutrition and poverty through science, technology and innovation

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# THE U.S. GOVERNMENT'S GLOBAL FOOD SECURITY RESEARCH STRATEGY, 2022-2026

## Executive summary

Global food security is beset by myriad challenges, including the climate crisis, the ongoing COVID-19 pandemic, conflicts, and a lack of equity and inclusion. While this research strategy was being developed in response to the updated Global Food Security Strategy (GFSS), global food, fuel and fertilizer prices were increasing rapidly, posing major challenges to many low-income, food-insecure countries already experiencing high rates of malnutrition. At the time of the GFSS completion, Russia's war on Ukraine was further exacerbating the food-security and nutrition challenges facing the world's poorest people, and global food security was once again front-page news in the world press. Thus, as the U.S. Government's Global Food Security Research Strategy comes into effect, the food-security, nutrition, and resilience goals it is meant to help advance are gaining even greater urgency.

The Feed the Future initiative, with the generous support of Congress, guides a whole-of-government response to food-security challenges. The GFSS focuses on three major objectives: i) inclusive and sustainable, agriculture-led economic growth; ii) strengthened resilience among people, communities, countries, and systems; and iii) a well-nourished population, especially among women and children. The strategy gives attention to several cross-cutting issues, including climate change adaptation and mitigation to include co-benefits, increased equity and inclusion, and improved affordability of nutritious diets.

Agricultural research plays a significant and often underappreciated role in driving economic growth and incomes. This research enables agricultural productivity gains and reduces risks in ways that not only increase overall agricultural production to meet the needs of a growing global population but also are highly effective in reducing poverty and, in turn, contribute to improved food security and nutrition. Research is also critical to successful engagement with the complex systems where climate adaptation and mitigation, inclusive development, and nutrition gains must occur. Demand-led agricultural research can simultaneously address human (e.g., poverty reduction, food security, nutrition) and environmental goals, and historically, agricultural research investments have produced a seven- to tenfold rate of return.[1,2]

The U.S. Government and its partners provide global leadership in the multiple disciplines required for research that transcends traditional boundaries, integrating scientific disciplines, knowledge, methods and expertise to form novel frameworks to catalyze scientific discovery and innovation to enable convergence research. Prioritizing investments in climate-smart agricultural innovation is an urgent application of this approach that fosters knowledge and technologies that simultaneously enable the world to meet nutritional needs, increase agricultural productivity, reduce food loss and waste, improve livelihoods, conserve nature and biodiversity, build resilience to climate change, reduce future greenhouse gas (GHG) emissions, and sequester carbon.

This Global Food Security Research Strategy outlines the U.S. Government's science-based, convergent, demand-led, and inclusive approach to addressing food-security challenges, which will continue to span biophysical, socioeconomic and behavioral sciences. In addition to collaboration among U.S. Government agencies, the strategy emphasizes key partnerships with U.S. universities, including minority-serving institutions (MSIs) and those engaged with Feed the Future Innovation Labs; U.S. and international private business and nonprofit sectors; international agricultural research centers; and national research and extension systems in target countries—including government, universities, civil society and private-sector partners.

After a broad consultation with the global research community and interagency partners, several priority areas emerged. Feed the Future will support research activities that collectively represent three themes: i) climate-smart agricultural innovation, ii) nutrition and food systems, and iii) genetic improvement of crops and livestock. The strategy recognizes that research activities are most effective when they result from a sound prioritization process; directly engage community members and partners; bolster local participation and ownership; and are designed with market systems, risk reduction, and scale in mind.

## THE CONTEXT

There are nearly 800 million people who suffer from chronic hunger and 2 billion who suffer from micronutrient deficiencies in the world today.[3] An estimated 711 million people lived in extreme poverty in 2021, about 100 million more than projected in the absence of the COVID-19 pandemic.[4] Even without the pandemic, ending hunger and malnutrition were proving elusive goals. The world was off track to meet World Health Assembly targets on reducing wasting and stunting, and the pandemic and other crises are increasing the risk of reversing gains. Global estimates mask troubling regional disparities—one in five people in Africa were undernourished in 2020.[5] Globally, the gender gap has also worsened. The prevalence of moderate or severe food insecurity was 10 percent higher for women than men in 2020, as compared with 6 percent in 2019.[6] Much of this poverty, hunger, and malnutrition is concentrated in rural areas in developing countries, where most people rely on agriculture for their livelihoods.

These challenges are likely to worsen. For example, Russia's unjustified war in Ukraine is particularly alarming for African countries and low- and middle-income countries (LMIC) exposed to the war's effect on trade costs, commodity prices and financial markets.[7] An additional 40 million people are projected to become food insecure due to Russia's war on Ukraine. Food shortages and inflation-induced recessions are likely, particularly given the fragile state of the global economy and LMIC as a result of the COVID-19 pandemic. In addition, the global population is expected to swell from 7.7 to 8.5 billion by 2030 and again to 9.7 billion by 2050,[8] placing unprecedented pressure on food systems. Rising incomes will further increase demand for food—particularly animal-sourced foods that require more resources to produce. These changes, together with widespread environmental shifts and variability, will exert increasing pressure on the natural resources on which food production relies.

Addressing these interconnected issues lies at the heart of U.S. Government investments in global food security. In a world of increasingly integrated agricultural markets, where agricultural pests and pathogens easily cross borders and persistent hunger and malnutrition abroad can have geopolitical consequences at home, finding new and innovative ways to promote global food security does more than serve humanitarian goals—it is crucial to America's continued security and prosperity.

The U.S. Government launched Feed the Future[9] as a response to the 2007/2008 global food price spikes to reduce global hunger, undernutrition, and extreme poverty. Due to Feed the Future's impactful results and critical contributions to the U.S. economy, security and leadership, the initiative garnered broad bipartisan support. In response, Congress enacted the Global Food Security Act (GFSA) in 2016 and reauthorized it in 2018, allowing the work of Feed the Future to continue. The U.S. Government deployed the GFSS.[10]

In October 2021, the U.S. Government released a new GFSS.[11] The objectives of the strategy remain the same: i) inclusive and sustainable, agriculture-led economic growth; ii) strengthened resilience among people and systems; and iii) a well-nourished population, especially among women and children. However, the new strategy elevates new priorities. These include greater emphasis on enhancing climate adaptation and mitigation, including co-benefits, increased equity and inclusion, and more affordable high-quality diets. The U.S. Agency for International Development (USAID) Administrator Samantha Power introduced the overarching goal of the new GFSS at the United Nations Food Security Summit: contribute toward a 20 percent reduction in poverty and stunting over the next five years wherever Feed the Future works. Achieving this and other food-security goals requires science-based solutions. Recognizing the critical role that research plays in achieving food-security goals, the GFSA mandates that the GFSS "harness science, technology, and innovation, including the research and extension activities supported by relevant federal departments and agencies, including state partners, and Feed the Future Innovation Labs."[12]

## The critical role of research in sustaining and improving agricultural productivity, profitability, and resilience of food systems and agriculture

Agricultural productivity has long been understood as a powerful driver of growth that raises people out of poverty and contributes to overall economic development.[13] This is not surprising, as two-thirds of the world's extreme poor live in rural areas and derive their livelihoods from farming. In LMIC, growth in agriculture is up to four times as effective at reducing extreme poverty than growth in other sectors.[14] Thus, a 1 percent increase in agricultural gross domestic product (GDP) per worker yields roughly two to four times the impact on extreme poverty as comparable increases in labor productivity in industry or services.[15,16] This is largely because raising agricultural productivity creates inclusive economic growth, not only by increasing incomes for farmers, but also by creating more abundant and affordable food for the general population. This frees up household income for other kinds of expenditures and creates multipliers throughout the economy, including stimulation of nonfarm sectors and increased demand for locally produced goods and services, many of which can be provided by low-income and landless people.

Historically, increased agricultural production depended on expansion of cultivated land alone. In the 20th century, agricultural productivity growth was achieved through increased use of water, fertilizers and other inputs, augmented by genetic and resource management advances. Today, most agricultural growth comes from farmers' abilities to produce more without increasing their use of inputs. This "total factor productivity" (TFP) lags in Sub-Saharan Africa (SSA), where growth in agricultural output continues to overly rely on expanding croplands and increasing input use. Recent analyses show that from 2001 to 2019, some 75 percent of increased crop production in SSA was due to area expansion rather than yield growth.[17] TFP growth is especially important for agriculture and its sustainability, given that the supply of land is inherently limited and further expansion has an enormous environmental footprint. TFP also encompasses investments of land, labor, time and capital, as well as reduced risks and losses, resource-use and market efficiencies, and value addition.

In addition to its poverty-reducing impacts on economic growth, agricultural productivity is one of several factors necessary for addressing malnutrition. Higher incomes and more affordable, safe, nutritious foods enable households to move to a more diverse diet that includes some animal-sourced foods and more fruits and vegetables, with less reliance on starchy staples.[18] Studies have shown that economic growth is correlated with reduced child stunting, but the strength of the relationship is not linear. Analyses have shown that for every 10 percent increase in GDP per capita, the rates of stunting decreased by 3 to 6 percent.[19,20] Unexplained variability exists in the effect of national income on stunting, requiring more research into how to protect children's growth and well-being through investments in the agriculture sector. [21,22]

Gains in TFP—and by extension, economic growth—come from the efficiency with which inputs are combined to produce output; this requires improved technology and practices. TFP is an integrative measure of growth due to the application of innovations such as improved seeds, crops, and livestock and improved production practices supported by better decision-making—all resulting from agricultural research and development (R&D). Moreover, this is sustainable—an increase in TFP represents a permanent expansion of the productive capacity of an economy, which also strengthens a country's ability to respond to and recover from economic shocks. The evidence is strong that sustained, long-term investments in agricultural research pay off. Social rates of return to agricultural R&D have averaged over 40 percent per year across developing countries, suggesting that the economy-wide benefits of research greatly exceed the cost.[23] TFP is a broad measure of economic performance but must be considered in the context of sound policy, environmental health, nutrition status, and other factors.

Recent studies of research investments under Feed the Future further strengthen the case for investment in public R&D. One study showed that research conducted by the Consultative Group for International Agricultural Research (CGIAR) has returned benefits tenfold.[24] Another study of innovations generated from U.S. university-led Feed the Future Innovation Labs, using different analytical approaches, showed five to nine times returns on investments over the lifetime of the programs assessed.[25] Both studies showed that benefits accrued to poor farmers and consumers and led to increased incomes and more affordable food (cost relative to income). Investment in agricultural research has long been a driver of prosperity and resilience and has never been more important, as food systems and agriculture around the world face existential threats like the COVID-19 pandemic, water insecurity, the climate crisis and conflict, including the unprovoked and brutal assault on the people of Ukraine.

## Affordable, nutritious diets for a well-nourished population

Russia's war on Ukraine will inevitably exacerbate the ongoing fallout from the COVID-19 pandemic, including increased food prices, negative impacts on trade, constrained purchasing power and limited access to or affordability of safe, nutritious food. A recent study estimated that the number of people who could afford a healthy diet before the COVID-19 pandemic was 3 billion, 2.5 billion of whom lived in 63 LMIC. That number is projected to have increased by 141 million in 2020, reaching 74 percent of these 63 countries' total populations, while the number of people who cannot afford a nutrient-adequate diet has increased by 220 million, reaching 43 percent of their populations (instead of 36 percent without the pandemic).[26] Infants and children in the critical age range of 6 to 23 months are particularly at risk, with a recent report estimating that in LMIC, only 16 percent of infants and young children receive a minimum acceptable diet, with stark socioeconomic disparities.[27] The war on Ukraine is already driving further food price inflation, which will have its greatest impact on low-income, net-food-importing countries, many of which have seen increased malnutrition in the face of pandemic disruptions.[28]

At the core of the Feed the Future approach to addressing malnutrition is a focus on affordable, healthy diets—meaning that family members, especially women and young children, have year-round access to affordable, safe, and nutritious foods. Increased availability and affordability of high-quality nutritious foods such as fruits and vegetables, legumes and animal-sourced foods (e.g., dairy, eggs, fish) are critical for improvement of diet quality.

## Research is essential for meeting the challenges of climate change

Climate change is already significantly affecting agriculture, threatening economic growth and food security, and it is expected to get worse. Climate change models predict a warming of 1-2 Celsius (C) from the preindustrial level by 2050, and for every 1-degree C increase, the global yields of the world's three major cereals—rice, wheat and maize—are expected to decrease by roughly 3, 6 and 7 percent, respectively.[29] The rural poor, who depend on agriculture for their food and livelihood, will be hit hardest. Projections suggest that a 1.5-degree C increase could result in an additional 530-550 million undernourished people, and a 2-degree C increase could result in an additional 540-590 million.[30] In addition, a deteriorating natural resource base reduces the resilience of the production system to climate variability and depresses future productivity.

The challenge will be to help agriculture meet the food demands of an expanding world population while decreasing its contribution to global GHG emissions. Growth in TFP is "green" growth, which results in reduced net global land conversion to cropland and, consequently, reduced GHG emissions. Without the TFP growth seen between 2001 and 2010, roughly an additional 125 million hectares more of land would have been needed for cropland, the conversion to which would have resulted in estimated emissions of 17 to 84 gigatons of carbon dioxide equivalent and substantial further declines in wild biodiversity. Without even higher TFP growth rates supported through agriculture R&D in the coming decade, the estimated need for cropland expansion is projected to reverse the environmental benefits accrued between 2001 and 2010.[31]

Additionally, a recent study found that if attainable yields were achieved globally and crops were grown where they are most productive, about half of the land currently used to grow food crops could be relinquished, likely decreasing GHG emissions and irrigation water requirements.[32] Another study estimated that the net effect of higher yields achieved through sustainable intensification has avoided emissions of up to 161 gigatons of carbon (GtC) since 1961, which corresponds to 34 percent of the total GtC emitted by humans between 1850 and 2005.[33] Many recent studies support the authors' conclusion that yield improvements compare favorably with other commonly proposed mitigation practices.

Support for agricultural R&D is critical for climate change adaptation and mitigation, as sustained investments in research provide a pipeline of innovations—from research through development, demonstration, and deployment—that address current and future crises. The U.S. Government has been investing in research to develop climate-resilient crops and livestock since the inception of Feed the Future and supports various research partners to develop technologies and practices that enable both adaptation—including resistance or tolerance to pests, diseases, and other stressors like heat and drought—and mitigation of carbon emissions from agricultural practices. Going forward, new research-based, climate-smart solutions must equip farmers, households, and communities to weather the climate crisis while supporting economic growth. This will require collaborative effort, including the engagement of institutions across the U.S. agriculture and food system.

## Institutional strength and diversity of the U.S. agriculture and food system

U.S. institutions have exceptional capacity to support country partners in generating solutions. The U.S. Government will continue to lead research for development efforts through collaborative research partnerships that share advances in science, generate science-based solutions, and increase the abilities of countries to make informed decisions on the utility and role of new technologies.

The U.S. agriculture and food system, which comprises federal, state, and private-sector actors, benefits from the innovations generated by researchers at U.S. universities, including those supported by Feed the Future. More than 70 U.S. colleges and universities, including 22 MSIs, are engaged in partnerships with Feed the Future Innovation Labs, generating innovations that deliver mutual benefits for food-insecure developing countries while strengthening U.S. food systems and agriculture. "Win-win" outcomes emerge from the Innovation Labs and other Feed the Future-funded research partnerships, which can help strengthen U.S. food systems—for example, through gains in heat tolerance or against emerging pests and diseases. More broadly, Feed the Future promotes science- and evidence-based approaches that help partner countries grow their agricultural and wider economies in ways that expand demand for U.S. exports. This enhances the potential for mutually beneficial private-sector investment in food systems and agriculture, which increases productivity and incomes and helps reduce malnutrition.

## Advancing diversity, equity, inclusion, and accessibility (DEIA)

Recent research has highlighted the need for a more nuanced view of social issues embedded in food systems if poverty reduction, food security, nutrition, and resilience objectives are to be achieved. It is well established that identities (including gender) shape trait preferences, underscoring the value of demand-led approaches in R&D. As this thinking matures, researchers are moving away from homogenous comparisons of men and women to asking, "which men?" and "which women?" to consider how broader social identities and household characteristics (such as age, ethnicity, race, location, and poverty level) interact with gender in food system participation and the ability to benefit from agricultural innovations.

Structural vulnerabilities render marginalized groups (including inequalities related to gender, age, ethnicity, sexual orientation or identity, or disability) the most likely to experience poverty, food insecurity, and malnutrition, and these circumstances are further exacerbated under climate shocks and economic disruption, as the COVID-19 pandemic has so tragically demonstrated.[34] This research strategy's focus on reducing extreme poverty and ending malnutrition mandates inclusive R&D to benefit these marginalized groups where poverty and malnutrition occur.

The U.S. Government is committed to prioritizing and advancing DEIA throughout the federal workforce, in partnerships, and in programming both at home and abroad (Box 1). Feed the Future research activities will embrace these basic principles from conception and throughout implementation. The U.S. Government will work with a broad and diverse partner base, including more MSIs and organizations with people of diverse backgrounds in key leadership positions.

### BOX I. DIVERSITY, EQUITY, INCLUSION, AND ACCESSIBILITY

Supporting DEIA is a U.S. Government policy for the federal workforce,[35] and these tenets should translate to U.S. Government engagement with research implementing partners and stakeholders. This approach includes:

- Addressing equity and inclusion in partner staffing and partnerships, enabling country leadership, including local STEM talent when and where possible, and listening to local voices.
- Assessing diversity staffing using tools, such as the African Science and Technology Initiative (ASTI),[36] among USG partners and local institutions to address support needed for increasing diversity in the workplace.
- Engaging new partners and a more diverse partner base, both in the U.S. and partner countries, while addressing potential barriers and constraints.
- Supporting local leaders including women, men, people of other gender identities, youth, persons with disabilities, indigenous people, LGBTQI+ people and locally marginalized groups.

## THE APPROACH

Smallholder farmers face a complex mix of challenges (e.g., land degradation, extreme weather events, scarce resources, pre- and post-harvest losses). Trans- and multidisciplinary approaches are necessary to address this complexity, achieve objectives across biophysical (e.g., increased productivity, decreased environmental impact, increased resilience) and socioeconomic (e.g., increased incomes, greater gender inclusion and equity) domains, and leverage synergies across food systems and agriculture. This is especially true in diversified farming systems involving crop, livestock, and horticultural enterprises.

### Convergence research

Building on the principles of inter-, trans-, and multidisciplinary research, convergence research is a framework that merges diverse areas of expertise to solve complex and specific societal challenges. As defined by the National Science Foundation (NSF), convergence research "entails integrating knowledge, methods, and expertise from different disciplines and forming novel frameworks to catalyze scientific discovery and innovation."[37]

The convergence research needed to achieve GFSS objectives requires a greater understanding of the behavior, needs, preferences, and constraints of various actors in the agriculture and food systems, including the differences facing females, males, and youth. This understanding will lay the groundwork for more effective theories of change. Moreover, addressing these complex and interrelated needs requires novel and creative partnerships across science disciplines, which often necessitates a shift from traditional organizational structures. Leveraging research funding from multiple donors and across multiple U.S. Government agencies—including those outside of the GFSA mandate, like the National Institutes of Health (NIH) and the National Aeronautics and Space Administration (NASA)—can address gaps in programming and foster new collaborations to address food-security challenges. These U.S. Government agencies are committed to engaging in local partnerships and with leaders to the extent possible and to foster the development of capacity over time (Box 2).[38]

A convergent approach requires, at every stage of the research and scaling process, consideration of the agriculture and food systems in which food insecurity, malnutrition, and poverty occur. Long-term solutions

### BOX 2. AGRICULTURAL RESEARCH CAPACITY DEVELOPMENT

Stable and sustained local investment in agricultural R&D—and a transition from doing things "for" to doing things "with"—is critical for agricultural development, job creation, and poverty reduction, but there is underinvestment in agricultural R&D in many Feed the Future countries. Additionally, increasing capacity of diverse research institutions increases the ability to incorporate convergence research principles. Opportunities for investment agricultural research capacity development include:

- Strengthening of local research systems, with a more diverse cadre of host-country scientists, including women and people from groups who are not well-represented based on country context.
- Enhancement of research infrastructure, including laboratory space and equipment, information and communications technology, and resources for research trials.
- Expansion of human capital, as large numbers of agricultural researchers approach retirement. This includes developing the skills and competence of local scientists and organizations, including through local Master of Science and PhD training and mentorship programs, particularly for women and underrepresented groups.
- Linking of research actors to other innovation system stakeholders (e.g., business, extension, and policymakers through innovation platforms and brokers) to support more effective commercialization and scaling.
- Supporting regional and sub-regional bodies, networks, and mechanisms structured around shared agro-ecological conditions in neighboring countries to optimize scarce R&D resources.

to food-security challenges can only be realized when innovations are considered in the context of social parameters (e.g., numbers of extreme poor; socioeconomic context of marginalized groups; prevalence of chronic malnutrition, especially as evidenced by child stunting and micronutrient deficiencies), which are made more complex by vulnerability to climate impacts. While these systems are multifaceted and diverse across partner countries, key constraints may be common, and a convergent mode of research will be needed to transform food systems and agriculture to simultaneously increase TFP and smallholder profitability, improve nutrition outcomes, adapt to and mitigate climate change, and achieve social equity objectives. Diverse and inclusive teams of researchers (locally led to the extent possible) connecting disciplinary expertise across traditional boundaries can expose key constraints; identify tradeoffs; produce demand-led, context-appropriate innovations; and guide approaches to facilitate smallholder adoption.

The Sustainable Intensification Assessment Framework (SIAF)[39] is a demand-driven, systematic method for putting this trans- and interdisciplinary approach into practice. Researchers compare experimental results across productivity, environmental, social, individual (e.g., nutrition), and economic domains. The framework allows researchers to compare a proposed innovation to the status quo (Figure 1), explore tradeoffs and synergies of different intensification pathways, and guide monitoring and evaluation of development efforts. The SIAF identifies keystone elements of a system critical for guiding prioritization, moving the research community from conceptual goals to quantitative evaluation of agricultural development pathways across the five domains of sustainability. Analysis can be conducted at various scales (e.g., plot, farm, household, and landscape) and tailored to the specific local agro-ecological zone, farming system, cultural preferences, institutions, and policies.

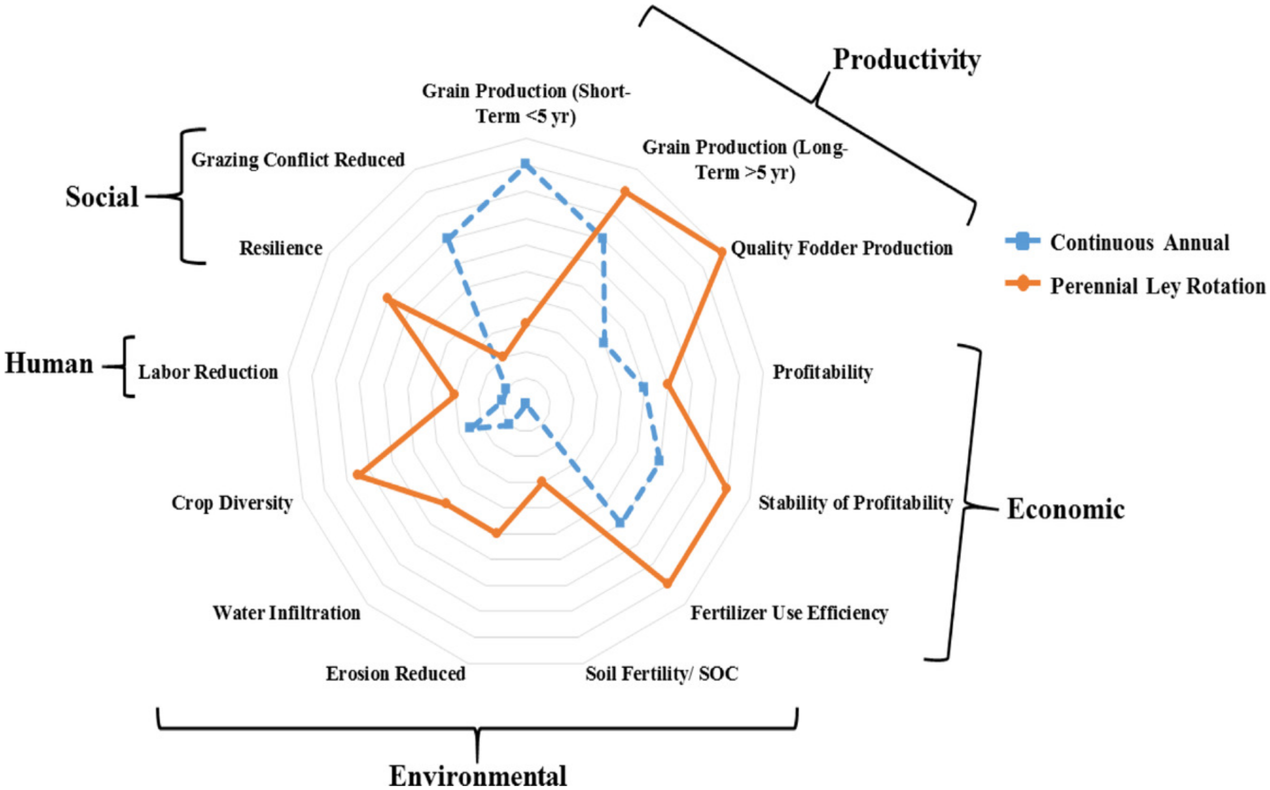


**Figure 1. Sustainable Intensification Assessment Framework (SIAF).** The SIAF was used to compare the status quo practice of continuous annual cropping to an innovation—annual cropping rotated with ley perennial grass—in agro-pastoral farming systems[40]. This radar chart depicts each approach as a polygon of connected data points. The data points are situated along axes representing the five domains of sustainability.[41] A data point far from the center of the chart indicates good performance within a given domain, and when connected, the data points associated with overall better performance form a comparatively large polygon. Perennial ley rotations have greater system benefits, but there are trade-offs that may be key barriers to scaling of the technology (e.g., short-term grain production and grazing conflicts) and the intended impact. Adaptation of the technology or pairing the technology with other methods would be essential for overcoming this barrier to improve adoption and impact.

## Integration across biophysical, socioeconomic, behavioral, and policy research

A convergent systems approach requires communicating and integrating across disciplines without sacrificing depth and rigor in domain-specific expertise. Traditional research domains should not limit integration of perspectives on food systems and agriculture from various disciplines relevant to the specific ecological, agronomic, social and economic context. Fostering integrative research is one of ten core Feed the Future research principles (Box 3).

### BOX 3. CORE RESEARCH PRINCIPLES

The Biden-Harris Administration is strongly committed to "protecting research security and maintaining the core values behind America's scientific leadership, including openness, transparency, honesty, equity, fair competition, objectivity, and democratic values."[42] In line with these ideals, shared core operating principles will continue to guide Feed the Future investments in hypothesis-driven, rigorous research activities implemented with scientifically validated methods.

- **Embrace purpose-driven research**. Research should ultimately maximize development outcomes in Feed the Future partner countries. Upstream research should facilitate early identification and targeted acceleration of demand-driven technologies. Downstream research should prioritize the generation, piloting, adaptation and scaling of technologies relevant in the geographies and associated farming systems where poverty and malnutrition are most concentrated.
- **Recognize that local leadership and ownership are essential.** Locally led development is the process in which local actors—encompassing individuals, communities, networks, organizations, private entities and governments—set their own agendas, develop solutions, and bring the capacity, leadership and resources to make those solutions a reality.[43] National and subregional strategies can help guide this effort. Local leadership and ownership are essential for fostering sustainable results across development and humanitarian assistance work, including research. Mentoring and training the next generation of local agricultural leadership will help sustain locally led development.
- **Encourage research integrity.** GFSS research collaborations will encourage research integrity by promoting values of openness, transparency, reciprocity, and merit-based competition. Openness and transparency are critical because they support reproducibility of results, promote accurate interpretation of findings, and foster appropriate disclosure of conflicts of commitment or interest. Reciprocity helps all parties mutually benefit from contributing to the research. Merit-based competition provides support to the best ideas.
- **Foster integrative research.** Few human endeavors touch as many disciplines as agriculture, and integration across disciplinary boundaries and across sectors is urgently necessary to meet the multiple objectives required for agriculture to transform food systems. Agricultural research must be tailored to assess and address the needs of low-income smallholder farmers and their communities across multiple domains of sustainability. Through every stage, research must achieve greater inclusion of women, youth, and other marginalized groups in co-developing, targeting, and validating innovations and elucidation of barriers to their participation in agricultural value chains more generally. Inclusive ex ante assessments must identify the needs driving individual, household, and community decision-making and to project biophysical and socioeconomic factors for successful adaptation, validation, and scaling. Modeling must consider complex scenarios and discover potential tradeoffs, obstacles, and synergies that may obstruct or incentivize adoption of innovations in specific agricultural, social, economic, and policy contexts, including input and output markets, trade, finance and regulatory frameworks for biotechnology, plant and animal protection, and food safety.
- **Strengthen agricultural innovation systems.** Research investments cannot simply generate research outputs that researchers see as valuable. To achieve desired outcomes, research investments must be made

with input from a network of actors and in the context of supporting institutions and policies to bring innovations into use.

- **Orient research efforts to support technology scaling.** Research efforts only generate global food-security gains if they are broadly adopted and utilized in partner countries. Consideration of adoption pathways, beneficiaries, and both public and private scaling partners must occur at the onset of a project to meet local needs, preferences, and market demands.
- **Promote empowerment and equitable participation in science.** The U.S. Government seeks to increase the participation and empowerment of host-country women, youth, and disadvantaged minority groups in all levels of scientific research and innovation.
- **Leverage data to accelerate research impacts.** Coordination across U.S. agencies and local research partners allows efficiencies of scale and leveraging of complementary skills and resources, particularly by aggregating, analyzing, and applying insights from larger data sets more rapidly than ever before. The sharing of analytical tools including machine learning, linkage between disparate data sets through internationally recognized metadata, and widespread application of data analytics to inform farm-to-national decision-making promise to make global agriculture more precise, productive, resilient, profitable, and inclusive by facilitating service delivery, geospatial analysis, digital financial services, engagement of youth, inclusion of people with disabilities, and open access to data.[44]
- **Generate and sustain global public research goods.** To maximize the long-term impact of research, investments will primarily emphasize the generation of global public goods. When applicable, the U.S. Government will seek to play a facilitating role to catalyze private-sector investment and leverage co-investment that generates food-security research outputs with the potential to lead to broad benefits.
- **Continuous learning, adaptation, and communication through monitoring and evaluation.** Tracking the long-term performance of public research investments is inherently challenging. The research strategy offers an opportunity for U.S. research funding agencies to better understand and communicate the long-term, interrelated impacts of their collective research investments.

From the use of advanced genomic tools in laboratories far from farmers' fields to the on-farm research identifying and validating management practices needed to meet the challenges of specific environments and user needs, biophysical research can address key constraints critical for continued agricultural productivity growth. Biophysical research outputs must be designed for integrated production and market systems, which necessitates an understanding of social, behavioral and economic factors along interconnected value chains and across food systems. Innovations resulting from biophysical research are typically used most effectively in combination with other innovations (e.g., growing improved crop varieties using practices that improve soil and water conservation). These improved innovations and packages are most transformative when developed using socioeconomic information through which consumers' preferences and farmers' demands are more accurately identified (e.g., developing dual-purpose sorghum that provides human food and livestock feed) and by which more-inclusive outcomes are achieved (e.g., more appropriately designing field equipment better fit for women's use). Innovations must also mitigate risks from multiple complex challenges such as the transmission of zoonotic disease, the loss of forest cover, and the degradation of natural ecosystems. Convergence research can support more sustainable, inclusive, nutrition-sensitive, and biodiverse food systems and agriculture, effective natural resource and landscape management, and policies that anticipate and address diseases and other risks to human health such as food safety issues and ecosystem degradation.

The full potential of agricultural R&D to help reduce poverty and malnutrition remains unrealized, due in part to limited adoption of the innovations generated by researchers. Socioeconomic and behavioral sciences can offer insights into the complex but rational reasons why farmers and households often do not adopt innovations, as well as offer an opportunity to build into innovations, incentives, or co-benefits that address obstacles or downsides (e.g., increased risk, low return on investment). Because the challenges facing smallholder farmers are complex, research around agricultural innovations and their adoption must be demand driven and confront the intersectionality in farmer age, sex, years of farming experience, and socioeconomic status for adoption in a specific farming system.[45] Innovations must address the needs of farmers, key private- and public-sector partners, and market forces to drive sustainable intensification leading to TFP growth in the face of increasing challenges such as pests, diseases, and extreme weather events. Particularly considering the disproportionate stresses induced by the COVID-19 pandemic on people already in vulnerable situations—conflict, water insecurity, and increasing frequency of disruptive climate events—food security, malnutrition and poverty must be understood through a policy lens sensitive to equity and inclusion. Multiple disciplines must contribute to a concerted effort to meet emergent goals around poverty, nutrition, environment, climate and inclusion.

The One Health approach—recognition of the interconnected, interdependent nature of the health of humans, animals and ecosystems[46]—involves convergent approaches that recognize, solve and prevent complex health challenges at the human-agriculture-ecosystem interface. Feed the Future federal partners (e.g., USAID, U.S. Department of Agriculture [USDA], U.S. Department of Health and Human Services, and others) have pioneered One Health approaches for many years to reduce the risk of epidemics. For example, in Malawi, USAID's Africa RISING [47] research program helps smallholder farming families learn agroforestry practices that integrate trees with crops and maintain a year-round green cover on the land. This allows farmers to improve food security and nutrition while increasing soil fertility, tree canopy and wildlife habitat. The practice also reduces deforestation, which in turn reduces flooding that can destroy farmers' crops and damage their health and nutrition. Programs like this demonstrate that it is possible to limit encroachment on wild lands while still helping food systems deliver on nutrition and smallholder incomes.

A convergent approach is also necessary to identify and address the distinct and intersectional needs of women and girls. In addition to considering gender in all stages of research and product development, data and evidence generated from the Women's Empowerment in Agriculture Index (WEAI)[48] provide project-level analysis tools that can evaluate not only whether hypotheses about gender were validated during the adoption of improved agricultural practices and technologies, but also whether adoption led to unintended effects in specific contexts.[49] In Africa, farmers' abilities to take advantage of improved practices is positively correlated with access to extension and information; participation in farmer groups; and access to credit, land size, livestock assets, off-farm and overall income, wealth, and secure land tenure.[50] These factors, which vary among groups, affect farmers' abilities to take on the risk and time demands of changing established practices to adopt innovations, and they present barriers to marginalized groups benefiting from agricultural innovations and economic growth. Food system innovations that rely on knowledge-intensive value chains and market systems, for example, may achieve greater impact through information and communications technology. Digital literacy is often critical for success, as it can break down barriers in communications, extension, and service provision, increasing opportunities for off-farm income. This impact, however, may be unevenly distributed if existing digital divides, which tend to be greatest among women and other marginalized groups, are not taken into consideration.

## Strengthened and expanded access to markets and trade

To achieve economic and nutrition objectives and improve resilience, it is critical that policies and infrastructure are in place to link smallholder producers and consumers to markets and trade in an efficient and inclusive manner. This leads to greater movement, availability, and affordability of agricultural inputs, goods, services, and safe, nutritious foods. Substantial Feed the Future research has demonstrated the important role of markets in increasing resilience and improving nutrition.[51]

Additional research that aims to address market risks, including risks to animal and plant health and food safety, would provide more evidence of systemic approaches to address poverty, hunger and malnutrition. Improved infrastructure is necessary to physically connect producers and rural and urban consumers, but other barriers exist to market participation and associated benefits (especially to women and other marginalized groups). There is evidence that as small- and medium-sized enterprise (SME) value chain actors arise to provide inputs and knowledge to small-scale producers, they are not currently providing information about practices that would improve environmental impacts, gender equity or resilience to climate change.[52] SMEs and other community and public market actors play varying roles in the sharing and scaling of technologies and information, both in the presence and absence of monetary incentives. Interaction across markets can lead to intra- and inter-regional trade that meets safe food demand, as well as long-term trade relationships among partner countries and/or with the United States. With growing interest in the role of agricultural systems as potential carbon sinks, producers in some contexts might also benefit from linkages to carbon markets or results-based climate finance payments, which could become a supplementary income source while reducing emissions and/or sequestering carbon.

## Interagency

The GFSA mandates the alignment and leveraging of U.S. strategies and investments across science, technology and innovation.[53] This includes coordination with GFSA-authorized, U.S. research funding agencies, as well as engagement with non-GFSA agencies (e.g., NSF, NIH, Environmental Protection Agency, NASA) and is paramount to the success of this research strategy. The focus on a convergence research approach, coupled with the increased scope for synergy related to global challenges in climate, One Health, and reducing/reversing cropland expansion into fragile, carbon-, and biodiversity-rich environments, requires deliberate coordination among experts from federal agencies and their traditional stakeholders.

Coordination advances broader research gains with mutual benefits to GFSA research and the interagency. These gains could include strengthening partnerships for sharing samples and expanding collections; facilitating research across different scales; targeting geographical areas to prevent/address a hazard; promoting U.S. research values and building public trust in science; connecting with U.S. Government experts for scientific input; and aligning agency efforts toward open, secure, and inclusive data ecosystems through coordinated implementation of the U.S. Digital Government Strategy[54] and associated agency strategies, like those of USAID[55] and USDA[56]) and partnership with international Open Data[57] and FAIR initiatives.[58]

## Key partners

In addition to U.S. research funding agencies, Feed the Future will leverage key partnerships with U.S. universities, including MSIs and those engaging with Feed the Future Innovation Labs; U.S. private business and nonprofit sectors; commodity groups; international agricultural research centers (e.g., CGIAR); and national research and extension programs in partner countries, including government, universities, civil society, and private-sector partners. Feed the Future can also draw on the expertise of the Board for International Food and Agricultural Development in convening university and research communities broadly to increase information sharing in a systematic manner. A hallmark of this research strategy is using the capacity of U.S. institutions to support country partners and strengthen relationships through shared advances in science, generation of science-based solutions, and an increase in countries' abilities to make informed decisions on the utility and role of new technologies.

Technology transfer and research translation can accelerate innovation by making existing scientific advances available to a wider range of actors, as in the international transfer of plant and animal germplasm through methods such as embryo transfer as well as participatory plant and animal breeding at the community level. Technology transfer should be done by properly considering the management of intellectual property, the appropriateness of the innovation for the target context, and the assurance that the recipient has sufficient technical capacity to move the innovation forward.

## RESEARCH THEMES

Feed the Future will support research activities across three themes that collectively address the food systems and agriculture transformation constraints identified above: i) climate-smart agricultural innovation, ii) nutrition and food systems, and iii) genetic improvement of crops and livestock. While these categories are familiar, the degree to which researchers are called on to collaborate across boundaries—academic disciplines, marginalized communities, local experts and researchers—is the hard work of convergence research. Each theme is necessary, but not sufficient, to generate the innovation needed to achieve GFSS strategic objectives. Examples of opportunities for integrative research within these themes are provided below.

### Climate-smart agricultural innovation

Today's problems demand solutions that simultaneously address the interrelated challenges of global food insecurity and the climate crisis, enabling the world to sustainably increase agricultural productivity and incomes, meet food and nutritional needs, improve livelihoods, conserve biodiversity, build resilience to climate change, reduce GHG emissions, and sequester carbon. Recognizing the essential role of agricultural research in meeting the challenges of climate change, the U.S. Government is coleading the Agriculture Innovation Mission for Climate (Box 4), which aims to create a surge of innovations to address the climate crisis.

One foundational way to achieve sustainable, resilient, and climate-smart agricultural production systems is to improve soil health, which is at the core of unleashing the economic returns to fertilizer, improved crop genetics, and water inputs. Modeling studies indicate that improving soil health can lead to multiple benefits, including a doubling of the global annual grain yield, a 50 percent reduction in total fertilizer use, and a 30 percent decrease in the land area under cultivation by the year 2100.[59] Furthermore, soil is an enormous carbon sink, giving it the potential to slow the increase of atmospheric carbon and associated global climate change—and potentially support smallholder livelihoods through connections to climate change mitigation innovations.

### BOX 4. AGRICULTURE INNOVATION MISSION FOR CLIMATE (AIM FOR CLIMATE)[60]

AIM for Climate is a joint initiative by the United States and the United Arab Emirates, which seeks to address climate change and global hunger by uniting participants to significantly increase investment in, and other support for, climate-smart food systems and agriculture innovation over five years (2021-2025) in the following areas:

- Scientific breakthroughs via basic agricultural research through national-level government and academic research institutions.
- Public and private applied research, including through support to international research centers, institutions, and laboratory networks.
- Development, demonstration, and deployment of practical, actionable, and innovative products, services, and knowledge to producers and other market participants, including through national agricultural research extension systems.

Climate-smart agriculture requires practices and technologies that facilitate adaptation, reduce emissions intensity, or sequester carbon, while offering opportunities to meet resilience, nutrition, and economic goals. Research opportunities in carbon and soil health include greater understanding of the biophysical, chemical, and microbial interactions among soil organisms and plants; the development of methods to harness soil microbes to improve soil structure, carbon storage, and yields; improved methods for nutrient management; and new tools for monitoring soil health while increasing diversity and productivity of agricultural lands. Viewed through this lens, productivity includes the entire system in which agricultural activities take place and demands appropriate technologies like mechanization and connection to advisory services. These research opportunities must be informed by related considerations of women's empowerment and inclusive and equitable access to climate-smart innovations, including improved methods for facilitating adoption.

Innovative and integrative approaches for systemic understanding are also needed to better and more directly address the energy and water dynamics of agriculture in a landscape context; increase resource use efficiency; decrease environmental impacts; improve soil and water conservation; improve pasture and range management, particularly in pastoral systems where climate change is increasing the frequency of extreme weather events like drought;[61] expand mechanization to decrease labor needs; reduce pre- and post-harvest losses and food waste; and bring integrated approaches to effectively prevent, manage, and control evolving threats from pests and pathogens, which share an ecosystem with plant, animal, and human hosts. Research that advances understanding of these integrated systems and considers competing hypotheses for diversification, productivity, profitability, environment, gender equity, inclusion, and multiple facets of nutrition will advance the multiple goals of this strategy. Where large data sets are available, machine learning tools can enhance analytical and modeling insights.

Many proven technologies are not widely adopted by smallholders because their applicability is context-specific, and farming systems—and farming households—vary tremendously. Digital tools offer opportunities to overcome this barrier at multiple levels. Connecting remotely sensed information with both researcher-generated and user-sourced inputs allows researchers to leverage these and other large data sets and machine learning insights for additional research and hyper-localize cropping and land use management recommendations.[62] The climate crisis necessitates a shift from reactive to proactive strategies, including improved climate forecasting, so that research can be ahead of the crisis curve rather than behind it. Improved weather forecasting also supports better decision-making by farmers and other food system actors, enabling more informed decisions—for example around planting and field operations, storage, transport, and climate-related pest risks and early warning. Combining these two concepts, the cellular bandwidth currently available in partner countries could combine weather forecasts with local data (including real-time soil and vegetation monitors) to support smallholder farmers through a digital decision support system.[63] Digital and other tools could also enhance linkages among diverse smallholder farmers, their communities, markets, and market actors. Many Feed the Future programs are advancing the applications and utility for digital decision support tools and contributing to the digital innovation evidence base. Simultaneously, digital tools should be developed and deployed in an ethical, equitable, and accessible manner.

## Nutrition and food systems

As many LMIC now face a triple burden of malnutrition—undernutrition (underweight, stunting, and wasting), overweight and obesity, and micronutrient deficiencies—understanding the role of food systems in influencing population health has never been more important. Food systems are changing rapidly due to globalization, urbanization, demographic shifts, and climatic conditions. Moreover, the COVID-19 pandemic has exposed the systemic weaknesses and fragility of food systems, pointing to an urgent need for rigorous research on cost-effective strategies that make safe and nutritious food affordable year-round for all people. More recent increases in staple food prices place a further constraint for the very poor, whose limited incomes cause them to shift increasingly to cereals and away from more expensive, high-quality nutritious foods, leading to declines in nutritional status, especially of women and children.

Undernutrition of mothers, infants, and children is the cause of 45 percent of deaths of children under five years old, and those children who survive undernutrition in early life often face associated suboptimal cognitive and physical development, undermining their future health and potential.[64] An estimated 2 billion people worldwide suffer deficiencies in one or more micronutrients and upward of 800,000 deaths annually of children under five years old are due to micronutrient malnutrition.[65] A major contributor to these outcomes is a lack of access to affordable, safe and nutritious food year-round.

A food-systems lens shows multiple entry points to advance diet and nutrition outcomes through diversifying the local farming system, eliminating loss and waste, improving hygiene, and improving the food safety and nutrient profiles of final products. The inclusion of women and youth is particularly important to improving nutrition outcomes through demand-led research and access to information about healthy diets. These factors influence the cost of a healthy diet in target geographies across the year.

Many of the most nutritious foods like fresh fruits, vegetables, and animal-sourced foods are perishable, limiting their year-round availability. These foods are also at increased risk of contamination (e.g., pathogenic bacteria), and the associated food-safety issues are linked with increased morbidity and mortality and reduced economic growth and may exacerbate malnutrition — particularly for those in the most vulnerable situations, including women, adolescent girls, and children. Feed the Future will continue to emphasize research on effective, practical food-safety solutions to such contaminants and their risk pathways.

Research opportunities include identifying processing options with the potential to overcome economic, social, and behavioral barriers to food security and malnutrition for the marginalized; innovating cost-effective technology to monitor the origin and quality of ingredients and products within the food system to reduce losses and improve food safety; facilitating inclusive (and disaggregated) dietary data collection using individual intake metrics; conducting food environment and diet cost analyses in local markets; identifying alternative uses for unsafe food and agriculture products, supporting circular economy principles, and reducing food loss and waste; developing alternative sources of healthy protein, including for animal feed; and identifying sustainable methods to increase diet adequacy, particularly for women and children.

Integration of livestock into farming systems allows diversification into animal-sourced foods for improved nutrition and can also offer household and community resilience. This diversification may be limited by the availability of feedstock, fresh water, or other constraints such as insufficient veterinary services or medicines. Research opportunities include the adoption of improved, dual-purpose crops to address this bottleneck. Diversification into animal-sourced foods or fruits and vegetables brings the need for better information on food and environmental safety, such as hygienic practices.

In addition to increasing the food supply and improving nutrition, the elimination of food loss and waste lowers economic costs for stakeholders throughout the food system and reduces pressures on natural resources and the environment, including the lowering of GHG emissions.[66] Research opportunities include pest-tolerant and pathogen-resistant plant varieties, proper drying and storage, cold chains for highly perishable food products, moisture control and measurements, reappropriation of discarded food toward feed, standards for certification and traceability, and other policies and national strategic plans for food loss and waste reduction.

## Genetic improvement of crops and livestock

A continuous pipeline of improved plant and animal varieties and breeds remains the cornerstone of agricultural innovation and allows smallholder farmers to adapt to dynamic markets, shifting production conditions, and emerging threats. Breeders and researchers must choose which crops, varieties, breeds and traits to prioritize while balancing consideration for gender roles in crop cultivation, soil health impacts, opportunities for dual-purpose cultivation systems, gender-specific nutrition impacts, climate adaptation and/or mitigation, food safety and human health impacts, and market access. This requires a product life cycle (PLC) approach (Figure 2), using inclusive, disaggregated methods to measure smallholder farmer demand profiles for agricultural inputs including improved genetics, small-scale mechanization, and value addition as well as consumer demand.

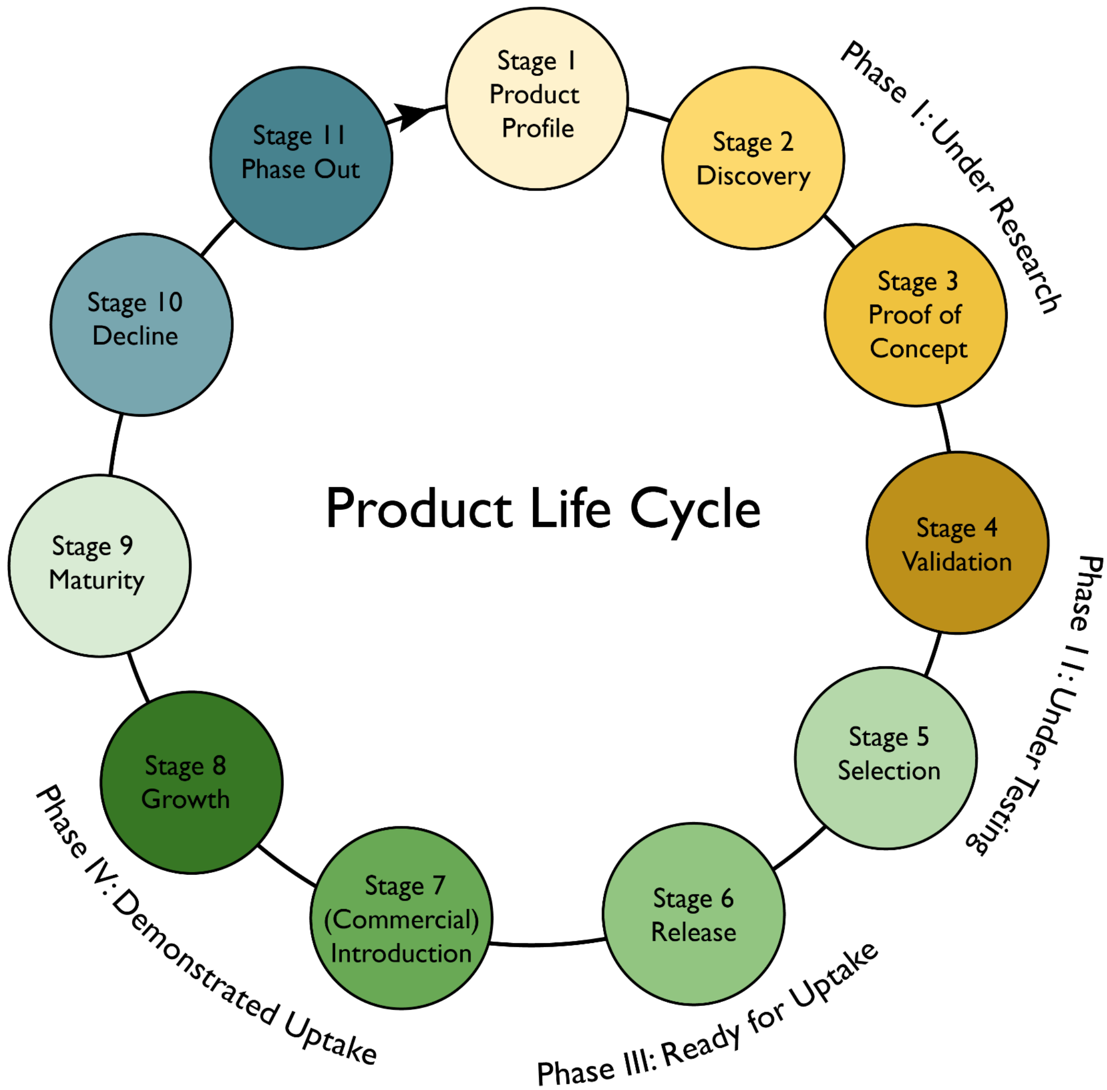


**Figure 2. The Product Life Cycle (PLC).** The PLC process identifies the threshold criteria for technology advancement along a defined scaling pathway and the downstream partners who must be engaged at each stage. The stages of product development are grouped into four phases: i) under research; ii) under testing; iii) ready for uptake; and iv) demonstrated uptake.

Feed the Future will focus breeding investments on crop and livestock species that maximize food-security impacts across the geographies and farming systems where GFSS beneficiaries are concentrated. Research opportunities span a wide range of innovative methods that can accelerate breeding for crops and livestock. Genomics-enabled molecular breeding, coupled with high-throughput genotyping and phenotyping and improved computational approaches, will enable data-driven decision-making and improve both precision and efficiency of genetic improvement programming. Emerging precision-breeding technologies, including genome editing, will leverage inexpensive, high-quality genome sequencing to further increase the range and speed of genetic improvement efforts. Where appropriate, genetic engineering and synthetic biology can make novel traits available, expanding the range of potential development solutions to address food-security challenges in GFSS priority countries.

Breeding efforts will increase yield, quality, and nutritional content of crops (for food, feed, fodder, fuel and fiber) and livestock—with an emphasis on satisfying local market preferences and production contexts, as informed by complementary socioeconomic, gender, biophysical and policy research. Enhancing climate resilience will be a critical, cross-cutting emphasis of genetic improvement efforts, along with careful attention to the inputs and labor available to women and youth in specific farming systems and market expectations. Improved resistance or tolerance to pests, pathogens and abiotic stressors will also remain a key priority, complemented by improved diagnostic and surveillance approaches for emerging agricultural threats and opportunities for climate mitigation. Ultimately, the success of these breeding investments will be measured not only by generation of breeding outputs but also by the degree of inclusion in the research process and the successful transfer and adoption of new breeds and varieties benefiting marginalized populations over the medium to long term.

## ENHANCING IMPACTS FROM RESEARCH INVESTMENT

Research activities are most effective when they result from a sound prioritization process, directly engage community members and other partners, bolster local participation and ownership, and are designed with scaling and adoption in mind.

### Prioritization

A structured, transparent, evidence-based and coordinated system for setting research priorities is necessary for success in achieving GFSA objectives. Feed the Future research investments should be informed by i) the likelihood of advancing practices, policies, knowledge, or technologies; ii) the value to society of the outputs generated from successful research; and iii) the existence of a unique and compelling need for the U.S. Government to fund the research.

Consultations with scientists can offer insights for advancing knowledge or technology; however, more formal economic analysis is also needed to evaluate tradeoffs among research investments. Combined, scientists' judgments and formal analyses can identify the research portfolio that has the best chance of generating the largest impact on GFSA goals and objectives. Likewise, consultations with stakeholders, including innovation and technology end users, help craft a demand-driven strategy with higher likelihood of technology uptake. Formal research priority-setting undertaken in collaboration with partner countries and other donors offers the U.S. Government an opportunity for more coordinated, integrated, and effective research.

Best practice principles for optimizing research resource allocation emphasize undertaking broad stakeholder engagement and expert consultation. These principles also emphasize the need for at least an informal assessment of potential research impact, and where feasible and practicable, formal assessment of research costs versus potential research benefits. These include:

- Economic value of commodities: The Parity Model is an example of how economic analysis has been used to inform research priorities in crop improvement research.[67] The concept is to allocate research resources in proportion to the economic value of the commodities of interest. This model offers a good starting point for discussions about research prioritization. Importantly, departures from the parity rule should be given explicit justification. The Parity Model should be weighted to reflect nutritional, healthy (e.g., using disability-adjusted life years), inclusive, scalable, environmental, and other desired outcomes specific to smallholder farmers
- Benefit-cost analysis: This analysis involves making judgements about the cost of the R&D needed to develop and disseminate new knowledge or technologies; the time it will likely take to move from initiation of research to full adoption and utilization; the size of the welfare benefits likely to be achieved from technology or knowledge adoption; and the underlying assumptions of poverty and nutrition impacts to women, youth, and other marginalized groups as well as climate and other environmental impacts.
- Rate of return studies: Evidence on returns to past research may be used as an indicator of potential returns to new research in an area when inclusive measures of return are used, including environmental and nutritional impacts weighted towards target groups.

## Engagement with community members and research and scaling partners

Partnerships allow the U.S. Government to bring together governments, regional organizations, multilateral development institutions, international donors, civil society, the global research community, U.S. universities including MSIs, faith-based organizations, and the private sector to leverage collective capabilities to address food security and climate challenges and promote resilience and nutrition. Beyond formal partnerships, direct engagement with community members and other actors is critical for research outputs to reach end users.

Research-for-development is best positioned to deliver sustainable results when local actors are involved in agenda-setting and decision-making. Thus, the U.S. Government is taking a locally led approach and encouraging partners to do the same.[68] Feed the Future research activities are increasingly designed through a cocreation process to bolster local participation and ownership. Likewise, Feed the Future research activities should support local capacity strengthening, which may include strengthening local research systems, developing the skills and competence of local scientists and organizations, and linking research actors to other innovation system stakeholders (Box 2). Increasing the inclusive participation of local actors also includes gathering and, if needed, translating research reports conducted by local, national and regional organizations (gray literature) that would otherwise be unavailable to and unrecognized by the wider research community.

## Scaling and adoption of innovations

The successful development, transfer, and adoption of agricultural technology is a proven contributor to inclusive economic growth. Research-for-development activities focus on generating innovations that increase the efficiency and productivity of farming systems to lower input and labor costs, increase food supply, lower food costs, and generate smallholder farmer income. Facilitating technology adoption requires a good fit between product and market as well as coordination among many actors. Such coordination may be facilitated by coordination hubs linking research activities with local scaling partners—and thereby linking researchers to demand information. In developing markets, adoption failures can stem from a poor understanding of market demand, failure of the technology to address end-user needs, delayed regulatory approval, inadequate delivery systems (e.g., weak seed systems), inadequate packages of practices surrounding an innovation, and insufficient incentives to motivate private-sector actors. SMEs respond to changes in the micro- and macroeconomic context, including adoption incentives. Product development must be inclusive and country- and demand-led, utilizing local STEM [science, technology, engineering, math] talent when and where possible and consulting with and seeking to benefit women, youth and other low-income potential adopters.

Scaling of innovations requires a dynamic, integrated, and informed value chain/market system. As a step toward achieving a pathway to market for Feed the Future innovations, USAID adopted a PLC framework. The PLC (Figure 2) is an end-to-end management tool that advances products based on fit and identifies downstream actors who must be engaged at each stage as a product advances. PLC management is an industry standard that helps align new technologies with farmer, processor and customer needs and secure a pathway to market. While large companies can often work across the entire value chain, USAID focuses on strengthening markets that are less mature and connected. The PLC helps many small producers and businesses link together to engage in production and commercialization. Adoption may be facilitated by conceiving and promoting innovations within integrated packages that are appropriate to each targeted farming system.

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