Innovation in Agriculture

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KEY MESSAGES

- Agriculture and land-use changes contribute as much as 25 percent of heat-trapping greenhouse gas emissions. However, agriculture can also be part of the solution to climate change, with the potential to offset and sequester about 20 percent of annual emissions through improvements in soil management.
- The combination of changing consumer needs and demands coupled with climate and environmental challenges is accelerating the transition to a new way of thinking about agriculture. Meeting these needs and challenges will require a whole-system approach, involving the sustainable intensification of agriculture to increase productivity while minimizing environmental impacts through increased resource-use efficiency.
- Advances in breeding technologies and tool development are allowing improvements for multiple traits in the context of overall crop productivity. The extension of these tools to underserved crops that are climate-resilient will be key to meeting future climate adaptation goals.
- The wealth of genetic diversity available in public germplasm repositories, including CGIAR genebanks, can provide the basis for improving existing crops, as well as developing new crops, to meet specific and local climate adaptation needs. This will allow a move away from reliance on a few intensively farmed grain crops for food security to a broader collection of climate-resilient crops that includes a greater representation of legumes for smallholder farmers.

- Capacity building for climate-smart agricultural practices will require incentives and innovative finance mechanisms to lower the upfront cost barriers to adopting new practices and minimize the risk exposure—real and perceived—of smallholders as they adopt new production systems.
- The successful implementation of these strategies will require inclusive policies that benefit women (who make up a majority of smallholder farmers) and youth.

> **The convergence of crises have made very clear that there is a link between climate shocks, food insecurity and poverty. 80% of the poor actually live in rural areas. When we talk about biodiversity, land, soil, sea life—these are the biggest assets for these poor rural small farm holders. Failure to conserve and to restore these assets will bring them into the brink of poverty. Small-scale producers, the rural poor community, need to be at the center of these adaptation efforts and of all our investments.”**
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> **Alvaro Lario**
> President, International Fund for Agricultural Development

INTRODUCTION

Agriculture is the foundation of lives and livelihoods in Africa. More than 60 percent of Sub-Saharan Africans are smallholder farmers, and nearly a quarter of Africa's GDP comes from agriculture. The Global Center on Adaptation (GCA) State and Trends in Adaptation 2021[1] report (STA21) sets out several key messages for the future prospects of agriculture in Africa in the face of climate change. It shows that agriculture is already being impacted considerably by extreme weather events, and that the severity of future challenges depends on the warming trajectory. While a 1.5°C trajectory provides some options for adaptation of African food systems, this will still require urgent action. A 3°C warming trajectory, however, will cause catastrophic disruption within 30 years.

Since the release of the STA21 report, the challenges for agriculture in Africa have only become more onerous. The continuing COVID-19 pandemic has exacerbated climate-driven challenges in the agri-food sector. In addition, there are emerging impacts from the Russia–Ukraine conflict on grain markets and global food security, including the impacts that undisrupted markets are having on global agro-biosecurity systems, impacts on availability for food aid, and reduced fertilizer availability.[2] More than ever, whole-food-system approaches will be needed to tackle the current challenges as well as anticipate and prepare for impending ones.

As the world's population continues to grow, food production is being challenged by slowing crop yield increases in many parts of the world as well as degradation of natural resources such as soils, water, and biodiversity. According to a 2020 report by the Food and Agriculture Organization of the United Nations (FAO),[3] the world is not on track to achieve Zero Hunger by 2030 (Goal 2 of the UN's Sustainable Development Goals). Instead there are likely to be more than 840 million classified as hungry. By 2050, the world will need to produce about 70 percent more food than at present to feed an estimated population of nearly 10 billion people.

The combination of changing consumer needs and demands coupled with climate and environmental challenges is accelerating the transition to a new way of thinking about agriculture. Meeting these increasing food needs will require sustainable intensification of agriculture to increase productivity

Photo: CTA ACP-EU

while minimizing environmental impacts through increased resource-use efficiency.

Financing agricultural adaptation is far more cost-effective than financing repeated crisis responses, disaster relief, and recovery efforts. Research synthesized in STA21 shows that for Sub-Saharan Africa, the cost of action on climate adaptation and food systems is less than a tenth of the cost of inaction: US$15 billion per annum compared with US$210 billion per annum.[4] Innovative approaches to climate change adaptation, however, will need to move beyond purely agricultural solutions into whole-food systems. Similarly, improvements to research and extension will need to be integrated into the whole agricultural chain. Innovation will also need to go together with use of local knowledge and systems as well as inclusive policies to achieve resilient and sustainable agricultural systems over the long term.

This chapter provides a detailed account of two trends in agriculture in Africa today that seek to drive the transformation required to enable agriculture and farmers in the continent to become more resilient in the face of climate change and its wide array of fallouts. The first is a timely convergence in thinking and policymaking about agriculture today, whether in the policy proposals of large multilateral institutions in the development or agricultural research space or in the agreements formulated at global forums like COP26, that emphasizes the need to take a holistic approach toward issues of agricultural productivity, sustainability, and technological innovation.

The second part of the chapter addresses a less widely disseminated subject, perhaps because it is more technical, but one that holds great potential for the future. This is the deployment of cutting-edge science in realms like plant breeding, genomic selection, pathogen resistance, and digital agriculture, often taking the form of collaborations between research organizations within and outside Africa. The goal is to devise and scale up innovative technological solutions to problems of soil health, crop productivity, genetic diversity, pest management, and lack of access to data and knowledge among smallholder farmers. Much of this work is highly specialized. But together, such solutions and emerging technologies can be combined into a very innovative and effective program of climate-smart agriculture (CSA) that addresses the challenges of the present and the coming decades.

CONVERGENCE ON THE CASE FOR A WHOLE-SYSTEM APPROACH

The need for an integrated approach to dealing with food security, climate change, and sustainability is a theme that connects several recent strategy documents, whether at global or regional levels. This section provides an overview of some of the most important of them.

In October 2015, the World Bank released the report "Future of Food: Shaping a Climate-Smart Global Food System," which examined ways to improve the productivity and resilience of the food system and to make agriculture part of the solution to climate change.[5] This report advocated for the widespread adoption of CSA to secure higher productivity, increased resilience to climate change, and lower greenhouse gas (GHG) emissions. The World Bank Group's "Climate Change Action Plan 2021–2025: Supporting Green, Resilient, and Inclusive Development"[6] recognized that building back from the COVID pandemic and the financial crisis will need to integrate climate and development strategies as well as align financial flows with the Paris Agreement.

The Koronivia Joint Work on Agriculture (KJWA), established at COP23, recognizes the unique potential for agriculture to tackle climate change and works to advance discussions on agriculture in the UNFCCC.[7] It addresses six inter-related topics: soil, livestock, nutrient use, and water management, as well as methods for assessing adaptation and the socioeconomic and food-security dimensions of climate change across agricultural sectors. The FAO supports its development and implementation. The COVID-19 pandemic has led to delays in implementation but its message of the need for climate adaptation and developing a wider network of partnerships is clear.

The FAO Strategic Framework 2022–2031,[8] released in October 2021, recognizes that food and agriculture hold the key to realizing the 2030 Agenda for Sustainable Development in an inclusive way that provides food security for all. CSA supports the plan for transformation of more efficient, inclusive, resilient, and sustainable agri-food systems to achieve the "four betters"—better production, better nutrition, a better environment, and a better life. The plan relies on innovative technological solutions to allow production of "more with less" and the implementation of systemic approaches across the whole food chain.

The COP26 Glasgow Climate Pact,[9] an output of COP26 in November 2021, focused on mitigation, adaptation, finance, and collaboration as a way to achieve its goal of keeping to the 1.5°C heating target set out in the COP21 Paris Agreement[10] in 2015. Notably, there was global agreement on an adaptation financing goal. While a substantial focus of these efforts was on the energy sector, it was also recognized that the natural environment will be an important part of the solution. For example, protecting and restoring ecosystems and managing land sustainably has the potential to reduce annual net GHG emissions by more than 7 gigatons by 2030. It was also recognized that while attention in the climate change space has been focused primarily on carbon dioxide emissions, methane is also a highly consequential GHG. Therefore, more than 100 countries signed up to the Global Methane Pledge at COP26 to reduce global methane emissions by 30 percent by 2030. Finally, COP26 also saw the launch of the Adaptation Research Alliance,[11] a global network of governments, businesses and local societies partnering to increase the resilience of vulnerable countries, placing indigenous knowledge and solutions at its core.

The Agricultural Innovation Mission (AIM) for Climate, a joint initiative led by the United States and the United Arab Emirates announced at COP26, focuses on enabling solutions at the intersection of agriculture and climate.[12] AIM for Climate seeks to address climate change and global hunger by uniting participants to significantly increase investment in, and other support for, CSA and food systems innovation over five years (2021–2025). At the heart of this initiative is the recognition that new technologies, products, and approaches will be needed to adapt vulnerable food systems. Increased investment is being attracted through "innovation sprints," aggregate self-financed investments from non-government partners to achieve an outcome in agriculture innovation and for CSA and food systems to be completed in an expedited timeframe.[13] The innovation sprints, which will be announced at COP27 in November 2022, focus on four key areas: Smallholder Farmers in Low- and Middle-Income Countries (LMICs); Methane Reduction; Emerging Technologies; and Agroecological Research.

The CGIAR 2030 Research and Innovation Strategy,[14] released in December 2021, refocuses CGIAR's efforts to achieve positive, measurable benefits across five interlinked impact areas, including climate adaptation and mitigation and environmental health and biodiversity. This strategy includes the transition to "One CGIAR" situating CGIAR in the evolving global context, which demands a systems transformation approach for food, land, and water systems. It aims to integrate CGIAR's assets and capabilities toward a new era of interconnected and partnership-driven research toward achieving the Sustainable Development Goals through a stronger, more relevant science agenda.[15] Its three action areas are systems transformation, resilient agri-food systems, and genetic innovation.

As the impacts of climate change increase, an increased alignment of different sectors on policy, financing, and strategy will be essential to successful implementation of CSA strategies to ensure the resilience of and sustainability of agricultural systems. The next section explains the nature and necessity of CSA in Africa today, and brings together a host of examples of such practice from the field today, collected under a series of broad themes, to give a sense of the possibilities of such an approach.

CLIMATE-SMART AGRICULTURE

CSA is an integrated approach to managing landscapes, including cropland, livestock, forests, and fisheries, that addresses the interlinked challenges of food security and climate change.[16] Agriculture and land-use changes contribute 25 percent of heat-trapping GHG emissions. Without interventions, this number will likely increase.[17] However, agriculture can also be part of the solution to climate change, with the potential to offset and sequester about 20 percent of annual emissions through improvements in soil management.[18] CSA aims to simultaneously increase agricultural productivity and enhance resilience while reducing GHG emissions. These improvements will require a full range of interventions, from innovations in crops and livestock to changes in management practices for soils, crops, water, livestock, forestry, and agroforestry, through systems approaches and enabling environments.[19] The World Bank Climate Change Action Plan 2021–2025 indicates that it will step up support for CSA across the entire agriculture and food value


Photo: CTA ACP-EU

chains, including the Blue Economy, via policy and technological interventions, using nature-based solutions where appropriate.[20] By taking an integrated approach, it is envisioned that productivity can be enhanced and resilience increased while reducing GHG emissions.

While the Green Revolution had positive impacts on food security, there were uneven outcomes for human nutrition, crop resilience, and the environment. As a consequence of the focus on staple grains and the adoption of expanded irrigation, the major benefits were in Asia, while Sub-Saharan Africa received fewer investments, particularly in orphan crops.[21] Going forward, achieving the necessary increases in plant productivity to meet growing food needs will require the development of climate-resilient crops tailored to local needs that can be grown sustainably. This will include leveraging naturally evolved traits as well as using new engineering strategies based on a mechanistic understanding. The efforts in research and development needed to effectively support agricultural adaptation to climate change are going to require not only an integrated approach across the whole food system, but the components will need to be tailored to local and regional preferences and needs, incorporate indigenous knowledge and practices, and be inclusive of women and youth. The focus of this chapter is on research and innovation with the potential for rapid scale-up and application for agriculture in Africa. Examples have been selected to illustrate specific regional issues, interventions, and drivers.

Genetic Strategies for Crop Adaptation

Genetic improvements have been a key component of the Green Revolution's success in increasing agricultural production, starting in the 1950s. Since then, there have been significant advances in the availability of basic biological information about potential targets for improvement and new sequence-based genomic tools that allow the acceleration of breeding strategies, as well as the modification of existing crop genes. These tools, including sequence-based trait mining and genomic selection, are allowing plant breeders to select and breed for specific traits in a more rapid and directed manner. Gene editing, using CRISPR-Cas9,[22] allows

Photo: Anne Wangalachi/CIMMYT

precise, targeted changes in genes within crops that might not be possible through traditional breeding approaches. The combination of these advances with the wealth of genetic resources contained within global genebanks opens up the possibility of using genetic diversity of crop germplasm for traits relevant to adaptation to abiotic stresses (drought, flooding, temperature stresses) and biotic stresses (pests, diseases) resulting from climate change.

One effort under way to address this critical topic, for example, is the AIM For Climate Innovation Sprint entitled "Fast Tracking Climate Solutions from Global Germplasm Banks."[23] This is a US$40 million initiative led by the CGIAR in partnership with the Foundation for Food & Agriculture Research and the Bill & Melinda Gates Foundation to unlock climate-resilient traits from CGIAR's global collections, expanding the utilization of high-value genetic diversity to benefit smallholder farmers. African "orphan" crops—those that have received little investment to date but are of local importance—may now be improved with respect to climate resilience as well as input use efficiency, yield, and nutritional content. These strategies will be most effective when used in conjunction with indigenous knowledge and expertise in growing and managing such crops in combination with new sensors and management techniques. Diversification of staple crops, use of indigenous knowledge, inclusion of women and youth, and integration into the whole value chain will be key to advancing CSA approaches toward more climate-resilient food production. The African Orphan Crops Consortium[24] is working to increase integration of orphan crops into African food systems through the development of sequence, genomics, and breeding resources for prioritized crop species. Intended outcomes of this strategy include providing quality planting material for farmers, improved nutritional content of crops, better value and remuneration for farmers, as well as new value chains, markets, and products.

Individual research initiatives as well as multinational collaborations have benefited from an expansion of the availability of web-based tools for plant breeders. The Breeding API (BrAPI) project[25] is an effort to enable plant-breeding databases to talk to each other. BrAPI is a web-based programming

Box 1. Online Breeding Tools and Resources

The goals of the CGIAR Excellence in Breeding (EIB) platform[28] is to empower breeding programs in the developing world to develop more resilient, nutritious crop varieties and livestock, faster and with greater relevance to local farmer communities. Its vision was developed by leaders and researchers from CGIAR in coordination with select National Agricultural Research Systems (NARS), funders, and private sector partners.

The Genomics Open-source Breeding Informatics Interface (GOBii),[29] funded by the Bill & Melinda Gates Foundation, is the first large-scale public-sector effort with the goal of systematically applying detailed mapping information to the breeding of staple crops in the developing world. The initial focus is on rice, wheat, maize, sorghum, and chickpea in South Asia and Sub-Saharan Africa. Its outputs will include decision-support tools for breeders. It collaborates with international partners, including the CGIAR (the International Maize and Wheat Improvement Center [CIMMYT], International Rice Research Institute [IRRI], and International Crops Research Institute for the Semi-Arid Tropics [ICRISAT]).

interface for communicating plant-breeding data that is open to anyone interested in plant-breeding data management. It covers a spectrum of data types including germplasm management, field trials, and genotyping, which can be used individually or in combination. It builds on established community data standards and can be used with any modern program language. Its partners are located worldwide and include Breedbase, CGIAR centers (IRRI, ICRISAT, International Center for Agriculture Research in the Dry Areas [ICARDA], International Potato Center [CIP], and CIMMYT), NextGen Cassava, AfricaYam, and DivSeek. This project is an essential building block connecting the use of germplasm collections to generate and test new varieties in the field and its architecture promotes collaboration. Its utility for African breeders would be expanded by internet availability in the field, bypassing the need to collect data and upload later when an internet connection is available.

A critical component of these breeding efforts focused on African crops will be the concomitant training of African breeders as well as provision of resources for them to be able to continue their work domestically and train others. The African Plant Breeding Academy[26] is a professional development course established by the University of California, Davis, in 2013 to teach the latest principles in plant breeding to Africa's top plant breeders. The courses are offered at the World Agroforestry Center (ICRAF) in Nairobi in partnership with The African Orphan Crops Consortium and the New Partnership for Africa's Development (NEPAD).[27] The course covers current approaches in plant breeding, quantitative genetics, statistics, and experimental design. It also includes accurate and precise trait evaluations, development of appropriate strategies to integrate genomics into breeding programs, and experience in identifying and utilizing genomic data and DNA-based markers in breeding programs.

Box 2. Genomic Selection Tools to Increase Maize and Wheat Yields

Researchers at CIMMYT are using genomic selection to increase the yield of maize and wheat varieties. In genomic selection, breeders use information about a plant's genetic makeup along with data on its visible and measurable traits, known as phenotypic data, to "train" a model to predict how a cross will turn out without having to plant seeds, wait for them to grow, and physically measure their traits. In this way, they save time and costs by reducing the number of selection cycles. The Accelerating Genetic Gain in Maize and Wheat for Improved Livelihoods (AGG) project, a partnership between Cornell University and CIMMYT, identified an optimal genomic selection strategy for maize using the EiB and GOBii. Over the last five years, CIMMYT's African maize breeding program has used genomic selection with the "test-half-and-predict-half" strategy, and has already reduced operational costs by 32 percent relative to traditional selection methods.[30]

Soil and Plant Health

Increasing basic knowledge about biological processes in plants, animals, and microbes, coupled with genome-scale analyses, is driving innovation in the development of biological solutions to CSA needs. Plants grow in a complex relationship with other living organisms as well as the environment around them. Advances in our understanding of the signals and receptors involved in communication across multiple organisms have enabled the development of new approaches to dealing with plant pathogens as well as fostering beneficial new associations. Biological approaches such as these can capitalize on and adapt existing pathways without many of the harmful environmental impacts brought about by chemical amendments, and they have the potential to avoid unintended consequences such as pathogen resistance. While some of these approaches are still at the proof-of-concept stage, they offer the possibility of sustainable long-term impact in Africa at scale, especially when used in concert with indigenous knowledge and advanced management approaches.

It has been estimated that 40 percent of the soils in Sub-Saharan Africa are low on nutrients.[31] Degraded soils do not just reduce the potential for food production but can also lead to desertification and erosion, while healthy soils contribute to resilience to flooding, nutrient cycling, and carbon sequestration.[32] Improving soil health requires both detailed knowledge of the specific regional issues as well as science-based management information.[33] The Alliance of Bioversity International and CIAT, the Plant and Soil Laboratory of University of Antwerp, and the Artificial Intelligence for Smart Agriculture Unit at the Leibniz Centre for Agricultural Landscape Research (ZALF) have synthesized more than one thousand primary studies to assess the impacts of different agricultural practices and climatic factors on soil health.[34] Their findings indicate that management practices, lack of diversity of crops grown, and the types of input applied can have negative impacts on the fungal components of soils.

Healthy soils comprise four major components: minerals, water, air, and organic matter. The living component of soils is a complex mixture of microscopic organisms such as bacteria, algae, and fungi, as well as nematodes, microarthropods, earthworms, and insects. These organisms play a critical role in soil fertility. Loss of, or alterations to, soil microbial communities can negatively impact soil health and consequently the productivity of crops it supports. Mutually beneficial associations ("symbioses") between flowering plant roots and a class of fungus (arbuscular mycorrhizal fungi) have been shown to be important for plant mineral uptake, including phosphorus.[35]

Another symbiosis important for plant nutrition and soil health is the association of legumes with nitrogen-fixing bacteria (for example, *Rhizobia* species). These symbioses lead to biological nitrogen fixation within the plant, which provides nutrition for the plant host and also enriches the surrounding soil. However, application of nitrogen fertilizers can decrease biological nitrogen fixation within legume crops, along with additional factors such as the crop cultivar, strain of nitrogen-fixing bacterium in the symbiosis, and additional environmental conditions. The N2Africa project,[36] a large-scale, science-based "research in development" project, has focused on putting nitrogen fixation to work for smallholder farmers in Africa. In this strategy, scientific research is linked with capacity building that engages actors along the whole chain, from farmers to traders, extension workers and NGOs, with an emphasis on training, women's empowerment, and input/output market access though public–private partnerships. The project, which is funded by the Bill & Melinda Gates Foundation, has been active in 11 African countries and focuses on common bean, chickpea, cowpea, fava bean, groundnut, and soybean. N2Africa optimizes plant genotypes, *Rhizobia* strains and management approaches and by testing with a wide range of farmers, it is tailoring and adapting legume technologies to specific sites and farmer needs. By 2017, N2Africa had already reached more than 600,000 smallholder farmers with improved technologies for grain legume production.

The reduction in biological nitrogen fixation efficiency in many grain legumes compared to wild relatives is likely to be, at least in part, a consequence of genetic changes that occurred during domestication. There is a wealth of legume genetic diversity in the world's plant diversity collections, including the CGIAR collections, that can serve as a source of useful traits, and analysis of wild relative genomes can allow restoration of genes required for establishment of robust symbioses as well as increased rates of biological nitrogen fixation. The transition to CSA would be greatly enhanced by reduction of, or removal of, the need for nitrogen and phosphorus fertilizers. While the use of organic management practices is one component of this strategy, its impacts could be significantly increased by transfer of the ability to form symbioses to enhance phosphorus and nitrogen availability in a wider range of plants. Recent advances in our mechanistic understanding of how these symbioses are established indicate that there are a relatively small number of genes necessary to confer biological nitrogen-fixing capabilities in non-legumes.[37] While this is almost certainly a longer-term approach, it would increase the options for African farmers to manage plant nutrition in a more sustainable and reliable way and reduce reliance on expensive and potentially environmentally harmful chemical fertilizers.[38] In the interim, management practices can accelerate the transition to sustainable practices. For example, a decade-long study shows that the management of placement and timing of nitrogen fertilizer on maize crops using conservation agriculture practices maintains productivity.[39]

There has been a movement toward using soil amendments such as biochars (charcoals) and microbial fertilizers and there is growing private-

Photo: S. Kilungu/CCAFS

sector activity in this area. However, there is a need to evaluate the interactions of these components with respect to different soils and environments so that treatments can be standardized and optimized.[40] Modern breeding tools have enhanced and accelerated the ability to breed and gene-edit crops with enhanced use efficiencies for water, phosphorus, and nitrogen. However, the complex inter-relationships between plant processes, architecture and productivity will necessitate an integrated approach to developing climate-resilient crops rather than a gene-by-gene or trait-by-trait approach.[41]

Adaptation to Biotic Stresses

The impacts of plant pests—any species, strain or biotype of a plant, animal, or pathogenic agent injurious to plants—are already being exacerbated by climate change. Warming temperatures can expand the range of plant diseases as well as facilitate the establishment of new invasive species.

Plant disease resistance genes were early targets of breeding efforts, conferring race-specific resistance to adapted pathogens. However, while these genes are effective individually at conferring resistance, the resistance quickly breaks down under field conditions as the pathogen mutates into new resistant forms. Efforts to incorporate multiple resistance genes is time-consuming, technically more challenging, and can result in a reduction in yield because the plant has to divert resources to express the resistance pathways.[42] However, this approach is more durable in the field than single resistance genes and the 2Blades Foundation has been introducing between three and five resistance genes to confer wheat stem rust resistance.[43]

Advances in next-generation sequencing methods and the availability of high-density marker platforms have enabled mapping of quantitative trait loci (QTL) for broad-spectrum resistance to multiple variants of the same disease in crops where these resources are available. These broad-spectrum disease loci comprising major and minor contributing genes have been identified in several crops (such as sorghum[44] and rice[45]) but they have not yet been used extensively in crop production, perhaps because of associated reductions in yield.[46] The challenge for many African crops is that sequence and marker resources are often insufficient or unavailable. Where these are available, there has been significant progress in developing varieties with disease resistance that holds up under field conditions. The availability of sequence data and molecular tools for crop plants have enabled advances in understanding the basis of disease resistance and development of potential solutions. New multi-parent crop plant populations contain many of the desired traits sought by plant breeders, and they have attributes that make them suitable as a basis for breeding programs. Low-cost, sequence-based genotyping has become a highly cost-effective and efficient tool for a wide range of crops.[47]

Rice cultivation in Africa has increased significantly over the past two decades and during this time there has been a significant increase in rice bacterial blight caused by *Xanthomonas oryzae pv. Oryzae (Xoo)*. This disease is expanding to new rice production areas and results in losses of up to 50 percent, threatening food security. The most effective way to control the disease is through use of resistant germplasm.[48] New genetic populations have been used to map resistance loci for two major rice diseases, bacterial leaf streak and bacterial blight, caused by *X. oryzae* variants, some conferring resistance to multiple disease variants. Controlling these diseases is very important in Sub-Saharan Africa, where there are no sources of disease resistance in the lines that are currently deployed, and the new populations can serve as a source of new disease resistance loci in breeding programs.[49] Gene editing is an effective tool for creating resistance loci when there is knowledge of a pathway and potential targets. Cassava (*Manihot esculenta*) is believed to have been introduced to Sub-Saharan Africa by the Portuguese during the 16th century and is now a major source of calories in this area. Cassava's ease of vegetative propagation and resilience to abiotic stresses allows it to grow in a wide range of agroecological zones where many other crops cannot thrive.

However, as a staple crop, cassava has several drawbacks, including the poor protein content in tubers as well as low levels of vitamins A and E, iron, and zinc. Vegetative propagation under poor phytosanitary conditions also makes it susceptible to devastating viral diseases, including cassava mosaic disease (CMD) and cassava brown streak disease (CBSD), as well as additional viral and bacterial diseases.[50] CMD results in mottled and deformed leaves; infected plants are often stunted and produce few tubers. CMD resistance has been obtained using genetic approaches. In contrast to CMD, CBSD has few distinct leaf symptoms and can take a long time to become established, but it eventually results in necrosis of the tubers, making it difficult to screen plants for infection or resistance. There is no resistance against the viruses causing CBSD in African cassava varieties, and all of the common landraces and improved varieties eventually succumb.

However, there are sources of resistance in South American germplasm held at CIAT and these have been screened through the NextGen Cassava partnership using a new, fast-forward screening method developed to identify resistant crosses.[51] This strategy has resulted in identification of seedlings that carry both CMD and CBSD resistance and the CBSD resistance is a dominant trait.

Cassava is also susceptible to multiple bacterial diseases, including cassava bacterial blight (CBB). Four resistance genes have been isolated from cassava for the one strain and shown to mediate resistance in cassava, opening up the possibility for breeding strategies.[52] The cassava germplasm collections are likely to contain additional sources of resistance that could be introduced into breeding programs with the availability of the appropriate tools and resources.[53]

Box 3. NextGen Cassava

NextGen Cassava, funded by the Bill & Melinda Gates Foundation and the UK Foreign, Commonwealth and Development Office (FCDO), brings together 13 partners, including CGIAR, across eight countries on four continents. Its activities are organized around three primary divisions: breeding, research, and survey. Its breeding programs incorporate disease-resistant cassava germplasm from South America into the breeding populations and implement genomic selection strategies to accelerate the breeding cycle. The NextGen Cassava varieties are focused on quality traits including increased yield and improved disease resistance, traits identified through research surveys as of utility for smallholder farmers and cassava processors. Its work has been accelerated by development of a third generation HapMap for cassava, whole genome sequencing, a collection of 1,273 cassava clones, 20 million single nucleotide polymorphism (SNP) markers and genotyping of over 42,000 cassava accessions. Genomic selection approaches have shortened the breeding cycle time by more than half. NextGen Cassava also trains the next generation of cassava breeders and works closely with NARS.

One example of a new NextGen Cassava variety is Gamechanger, bred by IITA and the National Root Crops Research Institute in Nigeria.[54] Gamechanger cassava is resistant to CMD, cassava anthracnose disease (CAD) and cassava mealybug with moderate resistance to CBB, and tolerance for cassava green mite (CGM). It has improved processing qualities including high dry matter and yield and is suitable for making high-quality flour.


Photo: Nikada/istock

Photo: Ollivier Girard/CIFOR

Plant insect pests also pose increasing challenges as their ranges move with a changing climate and outbreaks become more frequent. Conventional genetic modification approaches are still yielding useful outcomes in the field; for example, in generating crops that are resistant to pests. *Maruca vitrata*, the Maruca pod borer, is a pantropical pest of legume crops, including pigeon pea, cowpea, mung bean, and soybean. In cowpea, there are no known resistance genes for this pest. Cowpea genetically modified with *Bacillus thuringiensis* (Bt) protein is resistant to *M. vitrata* and shows yield increases over non-Bt varieties.[55]

Parasitic nematodes are also devastating pests that kill the roots of susceptible plants, preventing the uptake of water and minerals. Impacted crops include potatoes, tomatoes, beans, bananas, and yams. There are over 4,100 species of plant-parasitic nematodes, which collectively cause an estimated US$80–125 billion in annual damage to crops.[56] The most economically significant of these species are those that target plant roots of major production crops, which make up about 15 percent of all known nematode species. For example, wheat, which is a staple food for 40 percent of the world's population, suffers significant reductions in yield when infected by the cereal cyst nematode (*Heterodera* spp.) Rice, another of the world's primary staples, also suffers from nematode infestations and approximately 10–25 percent of global annual yield loss in rice is attributed to the more than 100 species of nematodes. One of these species, *Meloidogyne graminicola*, may reduce yields in affected fields by up to 80 percent. Sweet potatoes, the world's sixth most important food crop and fifth most important in LMICs, are subject to approximately 10 percent annual yield loss due to plant-parasitic nematodes worldwide.

Unfortunately, chemical control of nematodes is expensive, environmentally damaging, and of limited utility. While genetic strategies have been successful in some cases, these do not necessarily transfer successfully to other hosts/nematode races. Basic studies of the signaling pathways that nematodes use to find plants has yielded a potential nature-based strategy. Plants release small molecules into the soil and nematodes have receptors that can detect these molecules and use them to locate potential hosts. Synthetic versions of these molecules could potentially be used to treat fields in place of older chemical treatments, which are deleterious to the environment.[57]

A number of companies have been established to develop biologically inspired pest and pathogen treatments. This type of strategy is consistent with sustainable agricultural practices and, with appropriate partnerships, could be extended to crops where genes for genetic resistance to nematodes are lacking.

Controlling the Impacts of Parasitic Weeds

Parasitic weeds in the family *Orobanchaceae*, and especially those in the genus *Striga*, are serious pathogens of cereals crops (corn, sorghum, rice, sugarcane) that are widespread across parts of Africa, Asia, Australia, and North America. *Striga*, also known as witchweed, is an obligate parasite and cannot complete its lifecycle without a living plant host to trigger germination and support the early stages of development. The impacts of *Striga* on subsistence farmers can be devastating because it causes serious yield reduction and symptoms include stunting, wilting, and chlorosis. *Striga* species are major constraints to agriculture throughout semi-arid Sub-Saharan Africa. Over 50 million hectares of arable farmland under cultivation with cereals and legumes are infested with one or more *Striga* species.[58] Many African countries, including Tanzania, Kenya, Malawi, Madagascar, Botswana, Zimbabwe, Gabon, Nigeria, Ethiopia, Niger, Togo, Benin, and Burkina Faso, have high levels of parasitic weed infestation.[59] In South Africa, *Striga* remains the single highest biological constraint to cereal grain production. In total, African smallholder farmers are losing more than half a million tonnes of rice a year because of *Striga*.[60] The FAO estimates more than US$7 billion is lost due to *Striga* across Africa every year, adversely affecting over 300 million people on 50 million hectares of *Striga*-infected croplands.[61]

Striga is particularly difficult to control because each plant can produce anywhere between 90,000 and 500,000 tiny seeds, which can remain viable in the soil for 10 years or longer. Germination is triggered by detection of chemicals (strigolactones) secreted by host plant roots. The parasitic seedling finds and attaches to the host roots. After a one-to-two-month development phase, the parasitic seedling flowers and produces seeds. Because the seeds are readily distributed by wind, water and in the soil as well as through human activity, and much of the lifecycle occurs underground, *Striga* is very difficult to control. Climate change will be likely to exacerbate the problem since crops grown under poor moisture and low-fertility conditions are especially susceptible, and plants that are growing under phosphorus-poor conditions release increased amounts of strigolactones.

Despite concerted efforts to develop methods of *Striga* control, to date there has been no single effective solution.[62] Control of *Striga* using chemical, biological and management strategies have met with limited success, in part because they are too expensive and/or too knowledge-intensive.[63] For smallholder farmers, this can mean having to abandon infected land, so new, sustainable solutions are urgently needed, especially as the impacts of climate change increase soil degradation and soil temperatures, creating more favorable conditions for the spread of *Striga*. Mapping [64] and modeling[65] are under way to understand the extent of potential impacts in different African regions.

Breeding of *Striga*-resistant varieties using crop genetic diversity is being explored to evaluate whether there are sources of resistance genes in major impacted crops.[66] *Striga* attachment host plant resistance traits, but these do not necessarily hold up against different *Striga* strains, and resistance has been found to break down in some cases.[67]

Another complementary strategy that has been used to generate *Striga* resistance is physical mutagenesis. A recently completed International Atomic Energy Agency Coordinated Project (D25005) enabled experts from 12 countries to identify novel sources of *Striga* resistance in cereals. A total of 64 induced mutants were identified with resistance and/or tolerance to two major *Striga* strains in sorghum, maize, and upland rice. At least three of the verified mutants for each crop were advanced to field evaluation for possible release in the participating countries (Burkina Faso, Madagascar, and Sudan) and capacity building provided in the form of training.[68]

The use of synthetic versions of strigolactones that mimic the growth signals *Striga* picks up from crops is being explored to pre-germinate and kill parasitic plant seeds prior to planting crops in the field.[69] The Japanese Institute for Transformative Bio-molecules (ITbM)[70] at Nagoya University has developed and is testing the efficacy of small molecules based on strigolactones.[71] These small molecules could be sprayed on a vacant field to germinate all the *Striga* seed, and once the plants had died off because they failed to find a host, the field could be potentially usable again for farming. This strategy is attractive because the small molecules are based on a biological understanding of the mechanism of strigolactone action, they are effective at low concentration, and would provide much-needed control strategies when genetic resources are not sufficient or available.

Adaptation to Abiotic Stresses

Climate change is already impacting African agriculture, causing reductions in maize and wheat yields in Sub-Saharan Africa and an estimated 34 percent reduction of agricultural production since 1961. The Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) sets out the irreversible consequences of global warming beyond 1.5°C for Africa, including shortened growing seasons and increased water stress.[72] The report flagged drought as a major driver for food insecurity and reduced crop yields.

Climate change exerts a range of impacts through multiple environmental changes, with downstream impacts on a range of crop attributes, including physiology, nutritional content, and yield.[73] An increase in average temperature during the growing season leads to greater energy use in plants for respiration and maintenance, and reduced growth. Reproductive cycles are shorter and yields lower, with accompanying impacts on nutritional content. Higher nighttime temperatures can impact seed set and yields of grain crops such as rice. Changes in the average amounts of rainfall, timing and intensity will work synergistically with temperature changes leading to increased moisture stress. These impacts will be severe for rainfed agricultural systems, and especially those with degraded soils. Shifting planting seasons and extreme weather events will make it difficult for farmers to determine the best times to plant.

Adaptation to the changes in plant growth ranges resulting from climate-induced changes in temperature and rainfall will necessitate better use of genetic resources, inputs, and management tools to continue to sustain crop production. At the same time, sustainable intensification will be needed to meet growing food needs while minimizing environmental impacts. Since the Green Revolution, mainstream agriculture has focused on a few key crops using controlled genetics alongside application of fertilizers and pesticides to maximize production.[74] The FAO "Save and Grow"[75] model for sustainable production and intensification calls for "greening" of the Green Revolution approach through the use of high-quality seed of diverse, well-adapted varieties with good agroecological practices to maintain soil health along with integrated pest management. Technological improvements can be part of building this kind of strategy when integrated into a whole-chain approach. Current efforts are focused on partnerships that integrate local knowledge, traditional practices, and new technologies to bring the needed innovations to the field.

Three of the Feed the Future Innovation Laboratory for Crop Improvement Centers funded by USAID are based in Africa: The East African Center of Innovation for Finger Millet and Sorghum (CIFMS) in Uganda, the Center for Innovation for Crop Improvement for East and Southern Africa (CICU-ESA) in Malawi, and Crop Innovation in West Africa (CIWA) in Senegal.[76] These

regional hubs, which represent partnerships between Cornell University in the US and African scientists on the ground, are working to accelerate improvement of crops essential for food security in a wide range of environments and cropping systems, with a focus on community needs. A goal of the hubs is to empower smallholder farmers, especially women and youth, to move from subsistence farming to food and nutritional security using interventions across the whole food chain. For example, CIFMS is breeding new varieties of sorghum and finger millet resilient to biotic and abiotic stresses as well as containing improved protein and micronutrient content, using gene and molecular marker discovery for novel traits.

The CGIAR system plays a central role in the development of genetic resources for African farmers with support from the platforms for Excellence in Breeding (EiB), genebanks, and Big Data for Agriculture. As part of the One CGIAR reform, the Global Science Group on Genetic Innovation will implement a crop breeding and seed system project for key crops, including groundnut and millet, across western and eastern African countries.[77]

This whole-chain system includes conservation of genetic resources in genebanks and facilitating and expanding their use by stakeholders, as well as accelerating crop improvement through precision genetic tools and enabling tools and technologies.

A new project led by CIMMYT under One CGIAR, called Accelerated Varietal Improvement and Seed Delivery of Legumes and Cereals in Africa (AVISA),[78] will focus on increasing the productivity, profitability, resilience and marketability of grain, legume, and cereal crops. It will take a whole-system approach, strengthening networks to modernize crop breeding by CGIAR and national program partners and public–private partners to strengthen seed systems. The project is currently working in Burkina Faso, Ethiopia, Ghana, Mali, Nigeria, Uganda, and Tanzania. A CGIAR initiative entitled “Building Systemic Resilience Against Climate Variability and Extremes” (ClimBeR)[79] also takes a whole-food-systems approach to dealing with the poor climate adaptation preparedness of food and agricultural systems in low- and middle-income countries, including Kenya, Senegal, and Zambia. ClimBeR builds on prior investments, proposing clear pathways to improving the lives of 30 million smallholder farmers in six countries by 2030. It aims to transform the climate adaptation capacity of food, land, and water systems with the goal of increasing resilience of smallholder production systems to withstand climate impacts such as drought, flooding, and high temperatures. The focus

Photo: Cinoby/iStock

on adaptive transformation tackles the root causes rather than immediate causes of vulnerability, and the intended impacts extend beyond technology and solutions to integrate social equity, environmental quality and protection, and technical aspects, domains that are key to long-term success.

Livestock

Livestock is an important component of any climate-resilient agricultural strategy, accounting for 40 percent of the global value of agricultural output and directly supporting the livelihoods and nutritional security of 1.3 billion people.[80] More than 500 million pastoralists worldwide depend on livestock as a means of income, food security, and asset storage. These pastoralists are among the most vulnerable to climate change. Conversely, the livestock sector emits an estimated 7.1 gigatons of CO_2 equivalent per year, representing 14.5 percent of human-induced GHG emissions. Improving the efficiency and resilience of livestock supply chains is key to both limiting the growth of GHG emissions and protecting the food security and livelihoods for billions.

Many strategies exist to both minimize the climate impact of livestock and to improve climate adaptation of the livestock sector. Enteric methane produced by livestock is a significant source of GHG emissions. Work to mitigate the sector's emissions is under way through the development of technological solutions, developments in feed additives, and genetic efforts to develop lower methane-producing livestock breeds. Meanwhile, livestock animals are particularly at risk from pests and diseases whose ranges are expanding with climate change. Advances in vector control, vaccines and antimicrobials, and veterinary epidemiological monitoring systems are all under way to help mitigate these emerging threats.

Box 4. Bracharia, a Perennial Forage Grass for Soil Rehabilitation and Improved Livestock Feed

Arable land is being lost at an unprecedented 30–35 times the historical rate. Unsustainable management practices and intensive agriculture are eroding soils, having significant impact on the sustainability of food systems. Today about 25 percent of the world's soils are degraded and about 3.2 billion people are impacted by land degradation, especially rural communities and smallholder farmers. Sustainable, regenerative agricultural practices, including the use of more diverse crops, can instead allow agriculture to contribute to soil rehabilitation and land restoration. CGIAR is developing new crops as part of this effort.[81]


Photo: Vinicius Abe/Shutterstock

In Tanzania, Bracharia, a leafy perennial forage grass that originated in this area, is being used to increase soil carbon and reduce nitrous oxide emissions. Bracharia increases stable carbon storage through its deep roots and also releases a secondary compound into the soil than inhibits nitrification. Its tolerance of extreme climatic conditions as well as ability to grow in low-fertility soils make it a useful component of CSA systems.

In addition to its value for soil remediation and stable carbon capture, Bracharia is also valuable as an animal feedstock.[82] The Climate-Smart Bracharia program at the BecA ILRI Hub in Kenya provides technical support to NARS, non-governmental organizations, and the private sector on Bracharia grass production and forage biosciences.
Its research includes disease management, development of a Bracharia-legume cropping system for soil fertility management, African Bracharia seed production niches, and the use of plant-beneficial microbes to enhance resilience and production of Bracharia grass in Sub-Saharan Africa.

Tools and Data for Decision-Making

More than 60 percent of Sub-Saharan Africans are smallholder farmers, and nearly a quarter of Africa's GDP comes from agriculture.[83] However, most crops are not currently reaching full yield potentials and the impacts of climate change are only likely to reduce productivity further. For example, 50 percent of the droughts caused by anthropogenic climate change between 2001 and 2011 took place in Africa. The use of digital data for agriculture ("digital agriculture") and Artificial Intelligence (AI)–driven decision tools built on large data sets can enable farmers to better manage inputs such as water, fertilizer, and pesticides, as well as predict and manage the impacts of extreme weather events to improve and maintain productivity.[84]

A 2022 report from the FAO and the International Telecommunications Union (ITU)[85] reviewed the status of digital agriculture in 47 Sub-Saharan African countries. It is clear that different countries are at varying levels of digital transformation, but with almost 60 percent of the population under the age of 25, active engagement of youth in agriculture is essential, along with training for women and youth. A major barrier to expanding digital agriculture is the lack of investment in rural agricultural infrastructure as well as insufficient investment in research and development, agro-innovation (for example, in sensor development),[86] and agricultural entrepreneurship, which are essential drivers of digital agriculture transformation.

Expansion of broadband internet availability is needed to support data collection, forecasting, and dissemination of real-time information. In the short term, prioritization of connection of Sub-Saharan African countries to undersea cables is needed to improve broadband access for coastal and landlocked countries. These modalities could be complemented with available terrestrial backbones to link urban and rural areas.[87] In the longer term, satellite internet could have significant impacts on the coverage and speed of broadband access. A new range of low-power, sensor-to-satellite terminals and modules was recently announced that make it possible to connect agricultural sensors anywhere in the world, where there is no alternative coverage.[88]

A fourth agricultural revolution is under way, encompassing the application of smart technologies such as AI, biotechnology, the internet of things (IoT) linking sensors to the internet, big data, and robotics, to increase agricultural productivity and sustainability.[89] According to a 2019 report issued by the Technical Centre for Agricultural and Rural Cooperation,[90] more than 400 different digital agricultural solutions were reported to be in use in Africa among 33 million registered farmers across the Sub-Saharan region. More than a third of the participants said that they used at least one connected technology, such as field sensors, unmanned aerial vehicles (UAVs or "drones"), big data, or data analytics. Together these tools can assist farmers with data-driven management of irrigation and fertilization of their crops. Farmer advisory services are providing weather and planting information by SMS or smartphone, as well as market and supply chain information. These tools are already leading to yield improvements and accompanying increases in income for farmers. However, there are still significant gaps in uptake, particularly in young women who, according to the report comprise 40 percent of the agricultural labor force yet make up only one quarter of the registered users of digital services. Women have been reported to be 13 percent less likely to own a mobile phone.[91]

Digital services are being developed in both the public and private sectors. Africa Agriculture Watch (AAgWa)[92] developed by AKADEMIYA2063, an African non-profit organization, is a web-based platform that links to a technical model that uses machine learning and remote sensing data to predict agricultural yields and production of crops across Africa. African digital farming services are growing at nearly 45 percent per year, and Sub-Saharan Africa now has over 400 apps and platforms.[93] For example, Farmerline,[94] launched in Ghana in 2013, and the DigiFarm[95] app, which was launched in Kenya in 2017, provide access to business intelligence, quality inputs and access to financial services. AKILIMO,[96] an agronomic advisory service developed for and with smallholder farmers, is employing state-of-the-art analytics to provide site-specific recommendations that optimize productivity and profits. To date, its recommendations have been validated by more than 5,000 smallholder growers and used by over 200 partner organizations.

While the reach of digital services is growing quickly, more than half of the solutions are headquartered in East Africa and nearly two-thirds of registered farmers are based in East Africa, with the majority in Kenya.[97] Uptake of apps is limited by lack of internet access, as 3G networks only cover about 40 percent of Sub-Saharan Africa's rural areas, and half the region's population had no access to electricity as of 2020.[98] There are intermediate solutions—for example, the publicly funded apps PlantVillage Nuru[99] for disease diagnosis and CubicA[100] for weather and agricultural information, which do not require an internet connection. One critical area where digital tools can have a significant impact is in irrigation.[101] The majority of African farmland is rainfed, and the dependence on unpredictable rainfall makes food production seasonal and vulnerable to climate change. Irrigation can be costly and potentially detrimental to the environment and currently only 6 percent of cultivated African farmland is estimated to have access to reliable irrigation. In the private sector, SupPlant[102] is working with about half a million, mostly female smallholder maize farmers in Kenya using sensorless technology to gather hyperlocal climatic, plant, and irrigation data, while SunCulture[103] manufactures and distributes affordable solar-power irrigation solutions to meet smallholder irrigation needs.

Some of these digital solutions have led to the development of new tech start-up companies serving African agriculture. There are agri-tech companies covering almost every aspect of the agricultural chain, including financing, insurance, weather data, water and fertilizer inputs, disease tracking, cold storage, and market data. These solutions are critical for African farmers to be able to implement CSA in the face of technological constraints. An enabling business environment is fundamental to attracting investment to create a favorable business environment, especially start-ups.[104]

Box 5. PlantVillage Nuru

PlantVillage Nuru is a publicly developed and supported app that uses an AI-trained digital assistant to help farmers diagnose crop diseases in the field without an internet connection. For example, the app uses more than 200,000 annotated images of identifying and classifying diseases and uses these to train the digital assistant. The initial primary focus was cassava, although resources are now available for other crops, including rice and wheat. Partners include the CGIAR (CIP, CIAT, IITA, CIMMYT and IFPRI) as well as Penn State University, West African Virus Epidemiology for food security (WAVE), and the FAO. The project was a CGIAR Platform for Big Data in Agriculture Inspire Challenge 2017 pilot project and 2019 scale-up winner.[105]

Smartphone tools are also being developed to assist farmers with mechanization. The Hello Tractor app,[106] which won the 2021 Agtech IOT Platform of the Year award, connects farmers with tractors, matching supply and demand and maximizing profit and social outcomes. The app lets tractor owners rent their vehicles to smallholders in their area and allows farmers to pool efforts to rent a vehicle at affordable rates. Its innovative route optimization tool uses GPS data from the tractors to monitor supply locations and attributes, as well as weather forecasts to generate a monthly plan of activities. Hello Tractor, which operates in 13 countries, including Nigeria, Kenya, and Tanzania, has been described as "Uber for tractors." Since its launch in 2014, Hello Tractor has served more than half a million farmers and 55 percent of the customers were using the app for the first time.

The African Soil Information Service (AfSiS), funded by the Bill & Melinda Gates Foundation, provides detailed information that can be used to determine the best use of inputs such as fertilizers and other management practices.[107] Its activities are supported by close scientific, operational, and implementation partnerships with the Agriculture and Food Security Center (AgCenter)[108] and the Center for International Earth Science Information Network (CIESIN) at Columbia University in the United States,[109] ICRAF in Kenya, the International Food Policy Research Institute (IFPRI) in the United States,[110] ISRIC

World Soil Information in the Netherlands,[111] and Rothamsted Research in the United Kingdom.[112]

Innovation in internet-linked sensor development could help to fill in gaps in forecasting and management data. For example, low-cost sensors built from off-the-shelf hardware can be used to measure and transmit diverse soil characteristics,[113] monitor environmental conditions,[114] as well as trap and identify insects.[115] Initially formed as a start-up company, ThirdEye[116] supports farmers in Mozambique and Kenya through its drones, which carry spatial sensors as well as sensors capable of detecting crop stresses before they are visible to the human eye.[117] These data allow farmers to make data-driven decisions about where and when to apply inputs (water, fertilizer, seed, and labor). This program was initially established using support from the Securing Water for Food program funded by USAID, the Swedish International Development Cooperation Agency (SIDA), and the Dutch Government Department of Foreign Affairs. iSDA Africa is investing in near-infrared handheld sensors to enable low-cost, farm-level measurement of soil properties, the nutritional content of crops, feeds and manures, and soil health diagnostics. iSDA partners with multiple organizations, including ICRAF and Rothamsted Research, and its soil data is hosted on the Amazon Web Services (AWS) registry of open data along with associated metadata. Where broadband internet access is not available, this kind of agronomic information is being made available through text messaging services. For example, Precision Agriculture for Development (PAD), a non-profit organization based in the United States, provides information to African farmers tailored to local soil, weather, and marketing conditions. In the private sector, Zenvus[118] and AgrCenta[119] provide similar kinds of services.

Open access to data will be important to sustaining the growth of digital resources for African farmers. The Global Open Data for Agriculture and Nutrition (GODAN)[120] is a partnership of more than 374 entities from national governments, non-governmental, international, and private-sector organizations that supports proactive sharing of open data to make information about agriculture and nutrition available, accessible, and usable. While there are existing policies for digital information and communication technologies, these are not aligned to existing agricultural policies, which hinders the process of digitization in the agricultural sector. The FAO/ITU report recommends the development of national strategies that support the digital transformation of agriculture. Digitization should encompass the entire value chain and be fostered at the government level. Increased collaboration among countries, international organizations and the private sector will be needed to create a set of public goods in agriculture that are sustainable and scalable.[121]

Box 6. Seeds for Needs

Climatic uncertainty means that smallholder farmers need to have more confidence in the seeds they use. Therefore, the CGIAR Research Program on Water, Land and Ecosystems (WLE) and The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) have launched a Seeds for Needs program targeting these farmers with a diverse range of seeds that are able to thrive in a changing climate.[122] Along with the seeds, they provide additional support to help farming communities adapt to climatic and other shocks, directly addressing their vulnerability to food insecurity. Seeds for Needs interventions include support for farmer selection of appropriate germplasm and cropping systems, as well as information about nutrition and conservation. The farmers are invited to be part of on-farm experimental trials of selected seed varieties. A Seeds for Needs program launched in 2011 by CGIAR in partnership with the Ethiopian Biodiversity Institute (EBI) with a focus on female farmers, has been implemented for wheat and barley in collaboration with local research institutes. The Seeds for Needs approach has also been used by other organizations in Ethiopia, including the Integrated Seed Sector Development Program (ISSD), which has distributed 280 varieties of 17 different crops to 20,000 farmers.


Photo: V. Atakos/CCAFS

RECOMMENDATIONS

As this chapter has demonstrated, capacity improvements are needed across the whole agricultural value chain if the challenges of climate change are to be met. However, there are some key intervention points that could have immediate impacts on existing strategies:

- Advances in breeding technologies and tool development are allowing improvements for multiple traits in the context of overall crop productivity. The availability of these tools needs to be expanded to underserved crops that are climate-resilient, including the diverse germplasm available in public genebanks.
- A major barrier to expanding digital agriculture is the lack of investment in rural agricultural infrastructure as well as insufficient investment in research and development, agro-innovation (for example, in sensor development)[123] and agricultural entrepreneurship. Expansion of broadband internet availability is needed to support data collection, forecasting, and dissemination of real-time information.
- Filling in gaps in digital data for areas like soils will be important for farmers to be able to access more precise forecasts and solutions to potential climate-related challenges.
- Bundling of digital services is needed so that farmers can receive information as well as possible courses of action, such as sources of seed, fertilizers, and funding.
- Improved networking is needed for stakeholders on the research side with downstream users, from extension agents to farmers. As climate-related challenges intensify, the existing tools will need to be adapted and improved to include the information that farmers need to make decisions about what to plant, when to plant it, and what inputs will be needed.
- There is a need for regional networks of scientists, (for example, plant breeders) to share knowledge, tools, and equipment, as well as innovative approaches for sharing resources.
- Increased alignment of different sectors on policy, financing, and strategy will be essential to successful implementation of CSA strategies to ensure the resilience of and sustainability of agricultural systems as the impacts of climate change increase.
- Incentives will be needed to promote adoption of new climate-resilient strategies. Fostering an enabling environment for the update of these strategies will prove to be a critical step, with a conscious effort needed to link climate-resilient policies, science, and food security within national agricultural implementation schemes.[124]
- Effective capacity building will also require a focused gender lens. Women account for about half of the world's smallholder farmers and grow 70 percent of Africa's food. As they are the majority food producers on the continent, research and innovation must keep women as the primary target audience. Any mechanism designed to improve capacity through climate-resilience practices and investments or through the wider enabling environment must prioritize their needs and preferences. Implementation efforts, likewise, must ensure gender-equitable access to new technologies and products to avoid exacerbating gender-based inequalities.
- Innovative finance mechanisms are another area for innovation to help farmers and businesses adopt climate-smart practices and technologies. Often the upfront costs, real and perceived, of new practices can prove a roadblock to adoption and implementation while risk mitigation remains a major concern both for businesses and farmers. Finance mechanisms, like innovative insurance or credit programs, that build onto existing financing arrangements with producers will aid in end-user adoption of climate-smart practices and tools.[125]
- Lastly, advisory services play a critical role in educating farmers and producers on use and adaptation of new technologies. As such, expanded capacity is needed among climate-smart advisory services as a key intervention to help farmers in their transition to more resilient practices and systems.[126] Effective capacity building among climate-smart advisory services in turn allows for the effective distribution of the climate-smart practices and technologies discussed above and is a requisite step in ensuring effective uptake of these innovations and practices by end users.