Megatrends Shaping African Agriculture: Challenges and Opportunities

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Executive Summary

There is growing recognition of the role of soil health and increased use of both inorganic and organic fertilizers to achieve sustainable agricultural growth in Africa. This growing recognition is exemplified by the Africa Union Commission's plans to convene the Africa Fertilizer and Soil Health Summit in 2023. The purpose of this study is twofold: (i) to identify and highlight megatrends shaping the evolution of African food systems and efforts to improve soil health, fertilizer use, and sustainable agricultural growth in Africa; and (ii) to identify priority actions that are relevant to the Africa Union Commission's Africa Fertilizer and Soil Health (AFSH) Action Plan that will enable governments to effectively anticipate and proactively respond to the megatrends. .

The report emphasizes that in some cases, African policymakers may "bend the curve" of these megatrends, to mitigate adverse effects that would otherwise occur in the absence of proactive government action or avoided entirely through appropriate pre-emptive action. It concludes that African governments can more effectively insulate rural communities and consumers from incurring considerably greater social, economic and environmental losses in the future and at the same time hasten the continent's development by investing today in improved soil health and food systems resilience.

Key Recommendations

Strategies for improving soil health and fertilizer use must consider the current megatrends that are shaping the trajectory of Africa's agrifood system for them to be contextually relevant. In light of the six megatrends identified in this report the following actions are proposed for inclusion in the AFSH Action Plan:

1. **Prioritize raising farm yields and productivity on existing farmland rather than relying on expansion of cropped area as the main source of agricultural growth in Africa.** This will require investment in several areas:

    a) National governments prioritizing integrated soil fertility management (ISFM).

    b) Increasing the efficiency of fertilizer use on smallholder farms. Currently many smallholder farmers do not obtain enough additional crop yield to make it worthwhile for them to use fertilizers. This problem will worsen at least temporarily as fertilizer costs have skyrocketed in 2022. But the main point is that smallholder farmers will demand more fertilizer if they can utilize it profitably. Therefore, the following are the actions that will be needed to enable farmers to increase crop yield response to fertilizer use.

- Revive support for commitments already made by African governments: While almost all African governments have formally committed themselves to allocating 10% of national public expenditures to agriculture under the Comprehensive African Agricultural Development Program (CAADP) launched in Maputo, Mozambique, in 2003, only seven countries (out of over 50) have achieved this outcome. Ethiopia is one of the few African countries to substantially increase its spending on public agricultural research, which has more than tripled in real terms since 2000. Ethiopia also employs half of Sub-Saharan Africa's agricultural extension workers (Fuglie et al., 2020). Not surprisingly, Ethiopia has enjoyed the highest rate of agricultural growth of any country in SSA since 2000 at 6.0% per year (FAOSTAT, 2021; World Development Indicators, 2021).

- Increase or sustain long-term core donor support for the CGIAR and Feed the Future Innovation Lab (IL) systems. Greater weight should be put on ensuring that funds to the CGIAR directly contribute to strengthening the capacity of national partner agricultural institutions in developing countries. Involving national partner institutions as grant co-awardees and co-directorships would be some concrete first step in this direction. Doing so will require that CGIAR and IL prime awardees are rewarded and held accountable for building the capacity of national partners in addition to the achievement of shorter-term outcomes such as introducing a given number of new articles, varieties, or improved management practices generated under the award.

- Scale up and target investments in agricultural R&D initiatives that promote smallholder climate adaptation, sustainable intensification, or have dual benefits for crop yields and the environment. This could include increasing investments to scale up the sequencing and trait mining of genetic material to improve crop and animal varieties to help farmers improve their productivity and livelihoods. CGIAR holds around 10 percent of the world's germplasm – including seeds and other genetic material – in banks across the globe. This rich supply of germplasm is key to developing new crop varieties adapted to climate change, including the development of more productive, nutritious disease resistant local crops that communities rely on for their food security. In addition, greater investment in research on improved fertilizer management practices and viable alternatives to commercial fertilizers should also be considered. Additional R&D

investments to improve animal agriculture (health, nutrition, efficiency) are also essential to improving the nutrition and livelihoods of smallholders. Healthy animals also possess a lower carbon footprint and can support sustainability.

- Encourage developing country governments to make greater investments in their own agricultural R&D&E systems and strengthen the capacities and accountabilities of international, regional, and national agricultural R&D&E systems in developing countries. The responses will differ according to country readiness; Kenya and Ethiopia, for example, can build on strengthening their existing national institutions to achieve required responses, while many fragile states may lack such institutions entirely and thus have little ability to respond, at least in the near future. The latter category of countries may therefore rely more on regional approaches to mobilize R&D&E services for national constituencies. Several options can be considered:

    - Encourage international development partners to leverage developing country government investments in national agricultural R&D&E systems by offering matching funds for developing country governments to support their own national R&D and policy institutes.

    - In addition, donors can jointly establish with national governments accountability systems to encourage good performance for the use of greater funding of national R&D&E systems in developing countries. While increased funding for national R&D&E is an important requirement for developing climate-resilient local agricultural systems, simply calling for greater spending on agricultural research is unlikely to unlikely by itself to build national capacity for agricultural innovation (Lynam et al., 2016; Fuglie et al., 2020). Performance contracts and accountability frameworks led by national governments can generate greater accountability for the funds allocated for national climate adaptation efforts.

c) Promote diversification of agricultural production and value chains in areas where new crops have great potential to adapt to local agro-ecological conditions and thus improve resilience and sustainability.

d) Strengthen the performance of national and regional early warning systems and the coordination between them – work with international, continental and regional partners to strengthen climate information services and early warning systems.

2. **Improve policy and enabling environments** that incentivize the private sector (which includes millions of smallholder farmers and traders) to make climate-smart investments in the various stages of agri-food systems.

3. **Inter-ministerial coordination**, recognizing the multifaceted decisions required across many national ministries and departments to make sustained progress.

4. **Bolster programs that anticipate and respond to emerging new diseases and pests** affecting crops and animals, with a special focus on vulnerable regions increasingly affected by extreme weather.

5. Governments need to establish **enabling policy and regulatory environment** that makes it possible for technologies, innovations and management practices to be developed and adopted in the African agri-food food systems. There is a need for policies and regulations that balance public security concerns while encouraging and incentivizing innovation and entrepreneurship. Deliberate efforts are needed for creation and maintenance of an enabling environment that will accelerate the pace of investment in communications infrastructure and minimize the "digital divide", so as not to leave behind underprivileged members of society, especially the poor, elderly, women, handicapped and rural people who often lack or have limited access to information and communication technologies.

6. **Highly skilled human resource** is essential to developing and deploying new technologies and innovations to Africa's agriculture and other primary sectors which provide food, employ a larger proportion of the population and provide the largest export and foreign exchange earnings for the continent. There is a need to build the capacity of Technical Vocational Education Training (TVET), Higher Education Science and Technology (HEST), and R&D&E institutions to support the development of cutting-edge technologies and innovations. It is imperative to increase investment in tertiary education to strengthen the production of the required human resources at all levels (from vocational education graduates to PhDs) and through technological innovation. Higher education partnerships are also critical enabling mechanisms for African tertiary education institutions to share resources and experiences to fulfill the mandate for technological development.

7. **Establishment of an African-led climate change adaptation fund**. It is important to note that the focus on the global stage is more about mitigation, yet adaptation is more crucial for Africa, and, according to the IPCC's Sixth Assessment Report, Africa received only 3.8% of the global funding for climate research between 1990 and 2019. These facts support the need for a significant shift in climate financing for Africa; to increase financing and channel more of that financing to support climate change adaptation initiatives.

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Acronyms

AAP	The Alliance for African Partnerships
ACFTA	The African Continental Free Trade Area
AFAP	African Fertilizer and Agribusiness Partnership
AFS	Agrifood Systems
AFSH	Africa Fertilizer and Soil Health
AFSII	Africa Fertilizer and Soil Health Summit Project
GDP	Agricultural Gross Domestic Product
AGRA	The Alliance for a Green Revolution in Africa
AI	Artificial Intelligence
ANAPRI	Africa Network of Agricultural Policy Institutes
AUC	African Union Commission
AUDA-NEPAD	Africa Union Development Agency- New Partnership for Africa's Development
BMGF	Bill and Melinda Gates Foundation
CAADP	The Comprehensive African Agricultural Development Program
CAF	Central Africa
CGIAR	The Consultative Group on International Agricultural Research
CSA	Climate-Smart Agriculture
DRC	Democratic Republic of the Congo
EAF	East Africa
EC	The European Commission
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GE	Genetically Engineered
GIS	Geographic Information System
GMOs	Genetically Modified Organisms
GPS	The Global Positioning System
HEST	Higher Education Science and Technology
ICT	Information and Communication Technology
IFDC	The International Fertilizer Development Center

IFDC	International Fertilizer Development Center
IL	Innovation Lab
IPCC	Intergovernmental Panel on Climate Change
ISFM	Integrated Soil Fertility Management
LAC	Latin America and Caribbean
NARS	National Agricultural Research Systems
R&D	Research and Development
SAF	Southern Africa
SEA	South and Southeast Asia
SLM	Sustainable Land Management
SSA	Sub-Saharan Africa
TVET	Technical Vocational Education Training
UAVs	Unmanned Aerial Vehicles
UN DESA	United Nations Department of Economic and Social Affairs
UNCCD	The United Nations Convention for Combating Desertification
UNFCCC	The United Nations Framework Convention on Climate Change
USAID	The United States Agency for International Development
WAF	West Africa

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1 Introduction

African food systems are increasingly intertwined with the global economy and affected by a wide number of shocks and stressors arising from social, political, economic and environmental disruptions. African governments and development partners will therefore be compelled to anticipate emerging opportunities and challenges and respond proactively to them rather than reactively; doing so effectively will make African food systems and the 1.2 billion people dependent on them more resilient. It is on this basis that the African Network of Agricultural Policy Research Institutes (ANAPRI) and Alliance for African Partnership (AAP) undertook this study to identify and highlight the megatrends shaping the evolution of food systems in Africa. The overall objective was to identify priority actions that are relevant to the Africa Union Commission's Africa Fertilizer and Soil Health (AFSH) Action Plan that will enable governments to effectively anticipate and proactively respond to the megatrends, both to capitalize on the positive trends and in other cases to mitigate the potential adverse effects of some trends through appropriate pre-emptive action.

Megatrends are generally slow yet overarching changes that fundamentally affect conditions, outcomes, and behavior of systems (Maggio et al., 2019). As such, they profoundly affect social, economic, and environmental systems in varied ways. Some megatrends shaping the development of agrifood systems in Africa may be slow moving but inevitable, and Africa must both anticipate and adapt to them. Other trends may activate more immediate effects – both positive and negative. In these cases, the challenge for African policy makers would be to institute policies and programmes that can mitigate the shocks and the adverse effects resulting from them – i.e., become more resilient – and to build on their positive impacts to increase the pace of food systems development. Still in other cases, African policymakers may be able to "bend the curve" so that adverse effects that will occur in the absence of proactive government action are mitigated or avoided entirely through appropriate pre-emptive action.

The ANAPRI and AAP study team undertook a review of literature together with interviews of key food systems experts to accomplish the objective of this study. First, through literature review and discussions with experts from ANAPRI and AAP, the study team identified a list of eleven trends (not necessarily megatrends) that affect in one way or another African food systems. Secondly, the team discussed and categorized this list of trends into two – megatrends or consequences of megatrends. This approach led to the identification of six "megatrends" shaping the trajectory of Africa's food systems: (1) rural population growth and associated rising land scarcity; (2) rapidly rising urban populations, fueling rapidly rising local demand for food and improved market access conditions for farmers in areas formerly considered remote; (3) economic transformation, whose main features include rising per capita incomes and associated changes in the demand for food as well as an accelerated tilt toward labor-saving agricultural technologies associated with rising agricultural wages; (4) climate change and increasing incidence of extreme weather events; (5) increasingly common global pandemics, regional conflicts, and economic disruptions; and (6) rapid advancement in technological innovation globally but with relatively little adaptive research, development and extension in SSA. Thirdly, after identifying these trends and drivers, the team conducted in-depth reviews of literature on each megatrend through developing an annotated bibliography and synthesizing the information from the bibliography. Fourthly, the team conducted interviews with experts in Africa's food systems on the megatrends for additional insights. Finally, the draft report was shared with four external reviewers with expertise in Africa's food systems to obtain their perspectives and for enrichment.

This report, therefore, provides critical insights and recommendations for identifying priority actions to be taken by African governments and partners to achieve the objectives of the AFSH Action Plan in light of the six megatrends. Sections 2 through 7 summarize the context, implications, and needed priorities for governments, donors, and other stakeholders for the megatrends.[10] The report concludes in section 8 with a list of priority actions for consideration in the AFSH Action Plan.

[10] The megatrends identified in this study has been utilized and referred to in the 2022 Africa Agriculture Status Report (AGRA, 2022).

Key terminology

Agrifood systems (AFS): *The totality of activities, people, institutions, and natural resources involved in supplying a population with food and agricultural products.*

Sustainability: *The capacity to preserve and enhance the livelihoods of both current and future generations.*

Resilience: *The capacity to dampen the impact of, and quickly recover from, shocks such as disease, conflict, and extreme weather; and to adapt flexibly in response to stressors such as climate change and rising land scarcity.*

Climate-smart agriculture (CSA): *the innovation of technologies, policies, and institutions such that agrifood systems become more resilient to the effects of climate change. CSA is defined by three principal objectives: 1) sustainably increasing agricultural productivity and incomes; 2) adapting and building resilience to climate change; and 3) climate change mitigation by reducing greenhouse gas emissions (FAO, 2013).*

Ecosystem services *are benefits that natural systems provide to people, such as clean air, pollination, marine life and seafood, genetic resources used in medicine and the development of new crops, recreation, and cultural heritage.*

Soil health *is the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health" (Doran and Zeiss, 2000).Source:*

2 Rural population growth and associated rising land scarcity

2.1 Africa's rural population will continue to grow, and agricultural land will become more scarce

Africa continues to experience a high rate of population growth. Between 1960 and 2020, the total population of SSA increased five-fold from 228 million to 1.15 billion. It is projected that between 2020 and 2050, the total population of SSA will increase by 90% to reach 2.1 billion. The rural population of SSA increased 3.4 times between 1960 and 2020 and is expected to rise by 40% to reach 909 million in 2050 (Figure 1). What is unique about SSA is that it remains the only region of the world where the rural population will continue to grow past 2050 (UN DESA, 2018). Moreover, Sub-Saharan Africa has the youngest population in the world, with 62% of the population under 25 years of age (Jayne *et al*., 2014). In most African countries, the number of wage jobs created will be outstripped by the number of youths entering the labor market, and because of this most Africans will remain engaged in agriculture and other jobs in agrifood systems (Jayne *et al*., 2014).

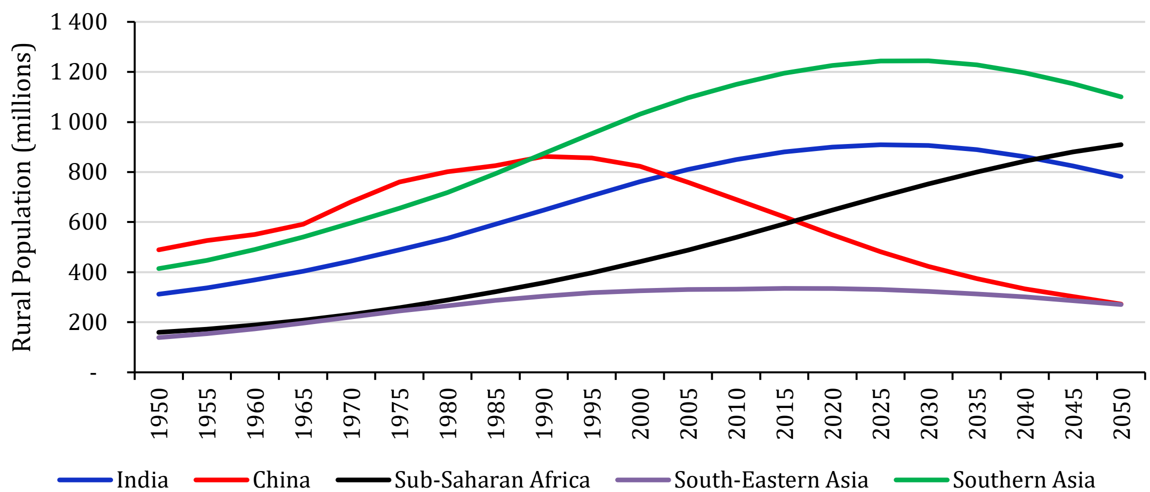


Figure 1: Trends in rural population in selected developing regions, 1950-2050 (medium scenario)

Source: UN, DESA (2018)

Rapid rural population growth in SSA implies continuing growth in demand for agricultural land. This increased demand for agricultural land will occur against the backdrop of a growing class of middle- and high-income urban-based Africans with an interest in commercialized farming, which is intensifying the demand for agricultural land. Meanwhile, there has been a rising global interest in African farmland (Schoneveld, 2014), with the possibility that tenure insecurity in the customary land systems in many countries may enable land to be taken away from smallholder farmers under these conditions. These forces have combined to create conditions of land scarcity, and with it, explosive increases in land values (Jayne et al., 2021). Land scarcity is leading to institutional changes paving the way for land transfers (Abay et al., 2021; Jayne et al., 2021). Many national governments have enacted or are enacting land laws to extend state power into customary lands. Chimhowu (2019) reports that between 1990 and 2017, 32 new land laws were enacted in SSA with most of them designed to wrest control of land allocation from customary authorities.

2.2 Implications of rising rural population and attendant land scarcity

Rising rural population pressure and attendant land scarcity is leading to (i) the shrinking size of most smallholder farms over time; (ii) a shift away from long fallow periods, which contributes to land degradation and unsustainable forms of agricultural intensification that will render inorganic fertilizer use less profitable or unprofitable unless smallholder farmers have access to and can utilize improved land management practices; and (iii) the rise of land rental and purchase markets and changes in land allocation institutions. Continued rural population growth combined with increased commercial demand for land is likely to both legitimize and greatly expand the use of land purchase and sales markets, with major changes in the structure of land ownership and associated distributional effects unless governments take active steps to constrain the development of such markets. Already a new class of relatively wealthy people are gaining access to land through both open and clandestine land sales markets, expanding the importance of “emergent” African farmers, many of whom are relatively commercialized in their operations and farming between 5 and 100 hectares of land (Brohms, 2020; Jayne et al., 2016; Omotilewa et al., 2021; Yaro et al., 2021). Increasingly acute land scarcity and the commodification of land is creating challenges for African governments to ensure equitable access to land for the next generation of rural youth to ensure broad-based and inclusive forms of agricultural development. In some cases where land titling has been explored as a conduit for tenure security for farmers, agricultural production has sometimes been found to decline since households reallocate their labour from farming to non-farm activities once their claim to the land is secured by the title deed (Agyei-Holmes et al., 2020).

There remains substantial arable land in SSA, but as much as 90% of the region's unutilized arable land is in nine countries,[11] leaving most SSA countries with limited potential for agricultural area expansion (Jayne et al., 2014). Moreover, there is a huge environmental cost of converting natural forest and grasslands to farmland (van Ittersum et al., 2016). This puts the emphasis squarely on raising yields and productivity on tens of millions of smallholder farms in SSA, especially in areas where expansion of cultivated area is no longer feasible.

[11] These countries are: Democratic Republic of Congo (DRC), Angola, Congo, Zambia, Cameroon, Mozambique, Central African Republic (CAR), Gabon and Sudan (including South Sudan).

3 Urban population growth

3.1 Africa's urban population is rising rapidly

Africa's urban population is rising even faster than its rural population. Projections in Figure 2 show that sub-Saharan Africa's urban population will increase nearly three-fold, from 459 million in 2020 to 1.26 billion by 2050 (UN DESA, 2018). This means that the urban population will expand by about 800 million people over the next 30 years and will surpass rural population by 2040. Approximately 58% of SSA's population will live in urban areas by 2050.

The SSA's urban population growth is driven by two key factors, namely, (a) natural population growth, and (b) reclassification of rural areas into peri-urban centers due to increases in population densities (Potts, 2017). Much of Africa's urban population now reside in secondary and tertiary towns, which act as service centers for rural areas (Yeboah and Jayne, 2018). Connectivity and linkages between farming and agrifood systems in secondary/tertiary towns and the rural economies they service will likely play an increasingly significant role in off-farm employment growth and rural livelihood outcomes (Christiaensen and Todo, 2014). The strengthening rural-urban connectivity is associated with improved access to finance, inputs, information services, physical (e.g. roads) and communication infrastructure and social networks connecting farmers to markets, which are important enablers of improved rural livelihood outcomes (De Bruin *et al*., 2021). However, if the region cannot succeed in achieving sustainable agricultural productivity growth and the multiplier effects resulting from it, the proliferation of secondary and tertiary towns may increase poverty along with increased urbanization (FAO, 2022).

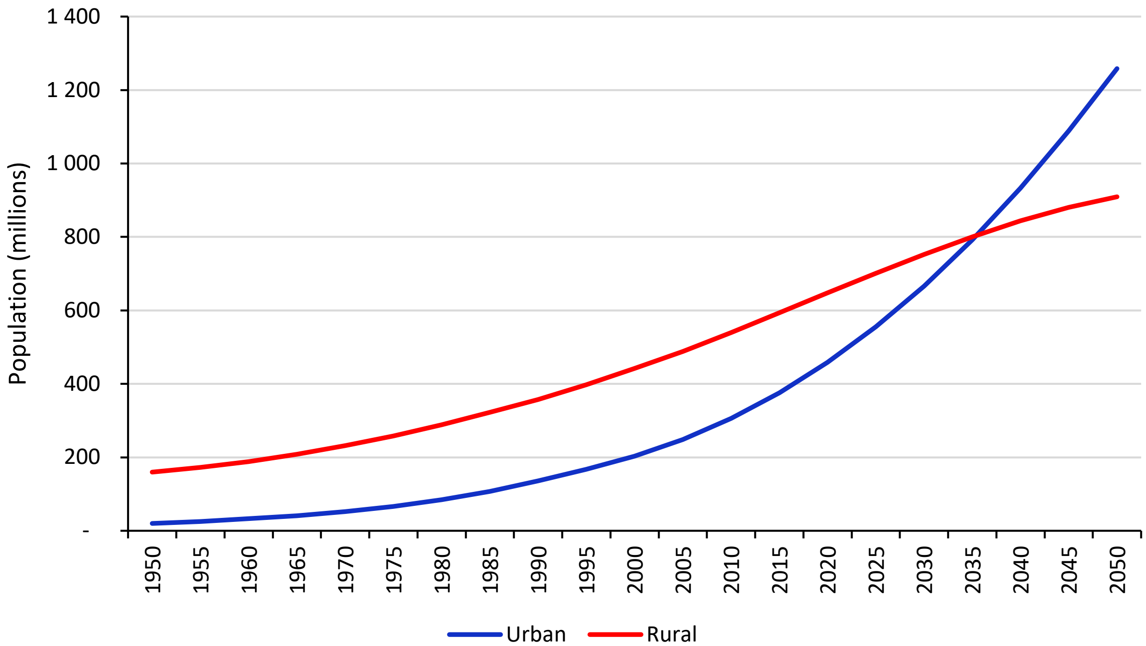


Figure 2: Urban and rural population trends in sub-Saharan Africa, 1950-2050

Source: UN, DESA (2018)

3.2 Rapidly rising urban populations and rising per capita incomes will fuel a stable and constantly increasing demand for food amid competing uses of land

Rapid urbanization is converting some high potential agricultural lands into residential real estates. In cities like Bamako, Nairobi, and much of the West African coastline, the conversion of accessible farmland with good commercial agricultural potential to real estate for residential, commercial or industrial use is shifting the locus of commercial farmland (Kiita, 2013; Picard and Selod, 2020). These changes in land use are accompanied by changes in land tenure, where land held under traditional customary arrangements are sold to new urban residents, often with formal/statutory property rights (Picard and Selod, 2020). The co-existence of formal and informal land uses under customary land rights (i.e., legal pluralism) have often led to land dispossession and fragmentation (Picard and Selod, 2020).

The combination of growing urban populations and rising incomes are leading to growing food markets and rising, diverse and changing food demand (i.e., high value and processed products), which is generating a downstream modernization of food systems – from informal to more structured formal market linkages (De Bruin *et al*., 2021; World Bank, 2021; Ogwu, 2019).

The increasing food demand amidst rising land scarcity strengthens the case that Africa must significantly raise yields on existing farmland to satisfy the continent's rapidly growing demand. Otherwise, the continent will rely on farmland expansion through conversion of forests and natural grasslands, which will entail major destruction to its stock of natural capital and associated ecosystems services and/or increasing dependence on the global market for its food supplies (van Ittersum et al., 2016; AGRA, 2022. Currently, Africa imports roughly US$45 billion in food from global markets (AGRA, 2022). Recent global shocks have underscored the costs and risks of heavy dependence on global markets (see section 1.5). Additionally, Africa will lose potential employment and income multiplier effects that promote economic transformation if an increasing share of its food supply is produced, processed, and distributed from outside the continent (Yeboah and Jayne, 2018). Most of the other stages of African food systems (e.g., input supply chains, aggregation, farm storage, wholesaling, transport) cannot grow unless the production base also expands; there is a symbiotic relationship between expanded production of domestically produced food and new investments in agri-input supply, agricultural advisory services, local crop assembly and wholesale trading, rural processing, agricultural finance and insurance, etc. For these reasons, sustainable intensification and the role of improving soil health on millions of smallholder farms becomes an urgent priority. Africa's agrifood system will also need to focus on initiatives that reduce food loss and waste in the supply chain, improve nutritional value of foods and promote the generation and use of renewable energy.

In areas of Africa experiencing rapid economic transformation, farm wage rates will rise over time, encouraging farms in the region to utilize labor-saving farm technologies such as mechanization and herbicides use, and the use of labor-saving management practices to improve soil health and productivity. By contrast, in areas of Africa with slow rates of economic growth, population growth will likely increase faster than economic growth, leading to a reduction in agricultural wage rates and less incentive to use labor-saving farm technologies. In both cases, there are major implications for the priorities of international and national R&D&E systems.

3.3 Priority response actions to rapidly rising rural and urban population

Raising productivity on existing farmland is a strategic priority for Africa. This will need to be achieved in ways that are sustainable (socially, environmentally and economically), resilient to climate and other shocks, inclusive of vulnerable groups such as women and youth, and improve nutrition.

While there tends to be a positive relationship between rural population density and fertilizer intensification, the fact that SSA is experiencing very slow yield growth and low yield response to fertilizers – particularly for the major staple crops that account for the majority of area under cultivation in the region – implies that farmers are facing circumstances that limit their ability to sustainably intensify crop production (Josephson et al., 2014; Headey and Jayne, 2014). This challenge requires policy and programmatic interventions to manage land constraints, such as addressing tenure security which provide farmers with the necessary incentives to make long term investments in soil health improvement, including adoption of complementary inputs and soil fertility management practices that would make inorganic fertilizer more efficient, and boost crop yields and incomes. Further, by proactively anticipating and responding to the challenges faced by acute land scarcity, SSA governments may promote sustainable transformation processes that impose less painful adjustments on rural people (especially rural young people) who will not be able to inherit land or enter farming as previous generations have. Among the priority responses will be:

i) Strengthening the education system and promoting access to quality education by youth to enable them to effectively take up and succeed in off-farm and non-farm employment opportunities. Here, attention should be paid to an educational system which emphasizes -hands-on training and vocational skills underpinned by ethics and good attitude to work. Besides, it will be necessary to promote investments in manufacturing and service sectors as well as rural infrastructure and services to increase employment opportunities for the educated youth.

ii) Strengthening the capacity of national agricultural research, development and extension systems to effectively perform their mandate of technical innovation and deployment of technologies and management practices for sustainable agricultural productivity growth. With increasing land scarcity, agricultural research systems will need to emphasize land-saving technologies, innovations and management practices. These include ways to raise crop yield response to external inputs, especially inorganic fertilizers, and promotion of sustainable land management technologies that address land degradation and promote environmental conservation. In addition, there will be need to diversify the range of crops and animal products to which R&D&E services are directed, from the current mostly small number of staple and industrial cash crops, to include high-value fruits and vegetables, dairy, poultry and livestock, and other crops with increasing commercial potential. Pluralistic extension system (i.e., involving public and private extension agents) to meet the needs of the diverse categories of farming communities will be needed.

Refocusing of adaptive research and extension priorities will require several actions. First, the Consultative Group on International Agricultural Research (CGIAR) system will need to make substantive reforms to its programs in Africa to focus more on building the capacities of local agricultural research systems in Africa, and to assist these systems develop and implement their own locally led research and extension priorities, rather than CGIAR developing separate priorities, which may weaken CGIAR's efforts to assist African R&D&E systems to achieve their own objectives. Therefore, the CGIAR will need to (i) emphasize joint partnerships with NARS and regional agricultural research organizations, (ii) substantially increase its resources dedicated to capacity building and empowering the African R&D&E organizations to take the lead in priority setting and adaptive crop research, trials & testing and (iii) shift its focus from leading research activities in Africa to supporting African research organizations to take the lead in setting research priorities.

Secondly, stronger capacity building linkages between the CGIAR and African R&D&E systems also need to be accompanied with sustained commitments by African governments to provide the resources necessary for their own national systems to develop. Therefore, African governments will need to increase funding for and strengthen the organizational capacity and effectiveness of African national agricultural research and extension systems. The governments will need to commit resources beyond payment of salaries for agricultural research scientists in African institutions, to deliberately commissioning relevant research and paying for them. In addition, there is need to build and strengthen the capacity of research scientists in African institutions in areas of data science and advanced analytics.

iii) Establishing and adopting land tenure arrangements that protect local communities' rights to land while at the same time enabling the transfer of land to relatively productive users who can generate greater growth linkage effects to the wider economy resulting from higher levels of farm productivity. Access to and secure rights over use of land are critical to farmers' investments in technologies and innovations that improve productivity and thus accelerate agricultural transformation.

4 Economic transformation

4.1 Evidence of economic transformation, whose main features include rising wage rates and per capita incomes

Economic transformation is a fundamental driver of improved living standards, resilience, and self-reliance. In most sub-Saharan African countries, agriculture and the broader agri-food system are the primary sources of employment and incomes for large parts of the population. Therefore, agriculture is critical in achieving economic transformation. Economic transformation is linked to two development processes, namely (i) structural change, which is the shift of workers and other resources from low-productivity sectors (e.g., subsistence agriculture) to high-productivity sectors (i.e., manufacturing and services), and (ii) faster productivity growth within the various sectors (Filmer and Fox, 2016).

In sub-Saharan Africa, economic transformation has been uneven across countries, with the greatest progress being made by lower-middle-income countries, and least progress by resource-rich and fragile countries (Jayne, *et al*., 2021). Countries such as Malawi, Mali, Tanzania, Rwanda, and Zambia, have seen at least a 10% decline in the proportion of the labor force in self-employed and wage-employed farming. In such countries, off-farm employment, both in and outside the agri-food system, is expanding rapidly, but from a low base (especially the agro-processing sector) – with rural-based growth outperforming urban growth (Yeboah and Jayne 2018). The improvements in agricultural labor productivity over the past two decades have been remarkable, though they remain low when compared to the rest of the world. Recent studies suggest that relying on labor-saving and relatively affordable mechanization technologies coming from India and China could be a game changer regarding productivity improvement in many areas of SSA (Agyei-Holmes, 2016).

4.2 Implications of economic transformation

Economic transformation in Africa is associated with a rising middle class, an increasing share of the labor force moving partially or completely out of farming, rising per capita incomes and purchasing power, and changing patterns of food demand toward more processed and livestock-based foods (Christiaensen and Todo, 2014; Tschirley et al., 2015). These developments are creating challenges and opportunities for African food systems in at least two ways. First, increasing non-farm business opportunities and rising wages pull labour out of farming. These in turn put upward pressure on agricultural wage rates and drive farmers to adopt labor-saving technologies and practices, such as mechanization and use of herbicides. Evidence indicates that farm labour use tends to decline in areas with relatively strong economic growth (Michler, 2020) and that the proportion of the national labor force employed in non-farm occupations and the rate of agricultural growth are strongly correlated (Yeboah and Jayne, 2018). Secondly, the growing number of relatively rich Africans interested in entrepreneurial farming has increased the demand for farmland in proximity to urban areas, changing the characteristics of farmers in such areas (Jayne et al., 2022).

4.3 Priority response actions to economic transformation

African governments and development partners can support R&D&E systems to produce and deliver to farmers labor-saving technologies and management practices that improve soil health and increase the profitability of using inorganic fertilizers.

African governments will also need to provide a conducive environment for development of mechanization rental markets, for example by reducing the cost of spare parts of agricultural equipment through tariff rates reductions. Governments will also need to promote the business environment for local production of labor-saving technologies for small-scale agro-processing, for example as has happened in China and India.

As suggested earlier, there will be need to provide a policy environment broadly perceived as equitable, by protecting land rights of local communities (including women and youth) while at the same time facilitating access to land for productive entrepreneurial farmers with the wherewithal to invest in soil health and sustainable agricultural intensification.

5 Climate change

5.1 Increasing incidences of extreme weather events

Climate change is a major global environmental problem that continues to affect life on earth, with particular challenges for agriculture. Climate change and variability and livelihoods are closely linked in regions where a significant share of the population work in climate-exposed sectors. Africa is the epitome of such regions. The sixth Intergovernmental Panel on Climate Change report (IPCC, 2022) suggests that 55 – 62 percent of the workforce in sub-Saharan Africa (SSA) is in agriculture and that 90 – 95 percent of cropland in Africa is rainfed. With such a large share of people employed in a climate sensitive sector, SSA is significantly exposed and vulnerable to climate hazards - increased temp, flooding, shorter seasons, drought and variable rainfall. Without inclusive economic growth, nearly 40 million Africans are projected to be extremely poor by 2030 because of climate change (Hallegatte et al., 2016). Africa's dependence on rainfed agriculture makes the sector a primary impact channel for climate change on the continent.

Temperature and rainfall are primary indicators through which climate change affects agricultural production. According to the latest IPCC report, increases in frequency, intensity and severity of droughts, floods and heatwaves, and continued sea level rise will increase risks to food security (IPCC, 2022). The report further states that there is a strong likelihood that Africa will experience average temperature rise this century. The drier subtropical parts will warm more than the moist tropics by the middle to end of the century relative to pre-industrial levels. Specifically, a rise in mean temperatures by 1.7 °C and 2.7 °C by the year 2030 and 2050, respectively, is expected under the current emissions trajectory (Figure 3). Average annual rainfall will also increase but parts of southern, western, and northern Africa will experience reduced rainfall amount by 2050 (Girvetz et al., 2018).

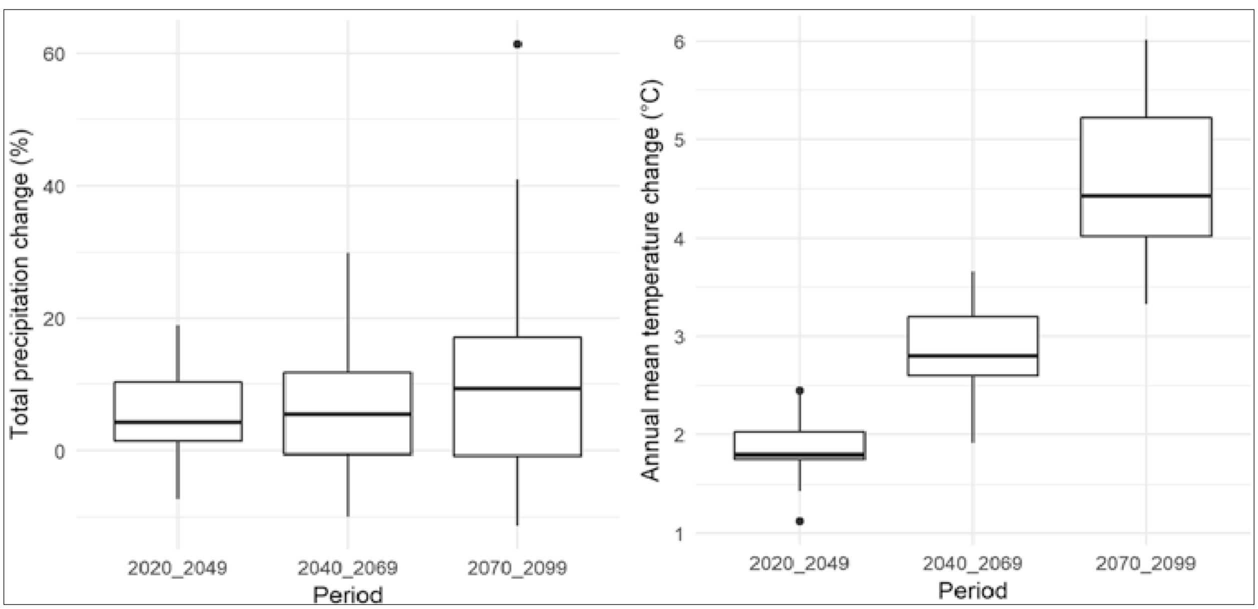


Figure 3: Projected changes in total annual precipitation (in percentage) and annual mean temperature (°C) for Africa

Source: Girvetz et al., 2018

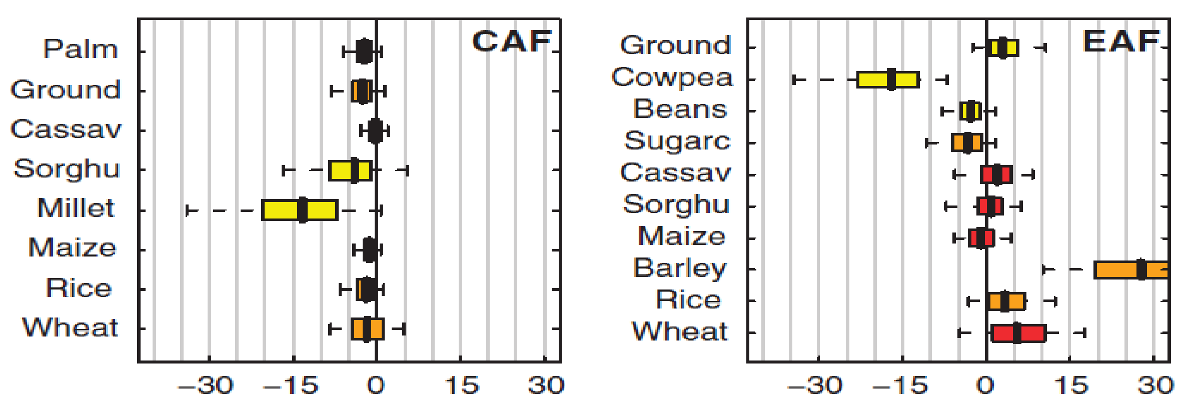
The IPCC lists the following manifestations and effects of climate change for the African region: high mean temperatures and hot extremes above the trend explained by natural climate variability in all land regions of Africa; a faster rate of increases in surface temperatures in Africa compared to other regions of the world; a greater frequency of heat waves than cold-extremes; and a greater frequency of marine heat-waves, which affect wind directions through a variety of mechanisms that generate extreme weather events (IPCC, 2022). For instance, in early 2022, Ethiopia, Kenya and Somalia were all undergoing severe multi-seasonal drought conditions, which were exacerbated by the lowest March - May rains in 70 years, and severely threatened food security of millions of people in the region (FEWS NET, 2022). Climate change is already lowering the speed of farm technical innovation and agricultural productivity growth in SSA compared to other regions, especially when combined with historically low public spending on agricultural research, development, and extension. As a result, SSA still relies heavily on land expansion and extensification as its main agricultural growth drivers.

Designated as climate change hotspots, West and southern Africa have had large negative physical impacts of climate change. It is suggested that the Sahel region of West Africa will be the hardest hit by global climate change, which will be exacerbated by a depleted and diminishing natural resource base and rapid population growth (Sissoko *et al*, 2011). Climate change and dwindling natural resource bases are widely thought to be fueling regional conflicts over scarce resources such as productive land, water and pasture.

5.2 Implications of climate change to agricultural production

Climate change can have severe impact on agriculture by increasing the frequency, severity, and intensity of climate extremes such as flooding, droughts, heat stress, and dry spells (IPCC, 2020). Climate change and variability also adversely affect soil structure and function, which results in reduced agricultural output (Chan, 2011; Brevik, 2013). Africa's predominantly rainfed agriculture is vulnerable to extreme weather events, such as droughts that occur early or late in the cropping season and affect crops development and yield (FAO, 2015; Mugwe & Otieno, 2021). Besides, climate change is altering the geographic distribution and life cycles of pests, which in turn are expected to change pesticide application trends (FAO, 2020b). As a result, plant pests and diseases trigger yearly losses estimated at 20 to 40 percent of the global world crop production (FAO, 2022).

Although the effects of climate change on agriculture will vary by crop and livestock types and by region, major cereals and staple foods are projected to be the worst affected. Global estimates suggest that maize and wheat yields may already be 3.8 percent and 5.5 percent, respectively, lower than they would have been without the effects of climate change during the last three decades (Lobell et al., 2011; Lobell & Field, 2007). Each degree Celsius increase in world mean temperature will diminish global wheat yields by 6.0 percent, rice yields by 3.2 percent, maize yields by 7.4 percent, and soybean yields by 3.1 percent without CO_2 fertilization, effective adaptation, and genetic improvement (Zhao et al., 2017). For maize in SSA, each degree day above 30°C reduces yield by 1 and 1.7 percent under optimal rainfed and drought conditions, respectively (Lobell et al., 2011). Even with global warming of less than 2°C by the 2050s, crop production in sub-Saharan Africa could be reduced by 10 per cent (World Bank, 2013; Cline, 2007). At regional level, relative to average yields between 1998 and 2002, yields for millet and sorghum are projected to be worst affected by climate change in 2030 in Central Africa; cowpeas in East Africa; maize and wheat in Southern Africa; and groundnuts and yam in West Africa (Figure 4, Lobell et al., 2008).). A recent study (Ortiz-Borbea et al., 2021) modeled a 21% decrease total factor productivity over the past 40 years with climate change compared to no change, with larger decreases of 26 to 34% in warmer climates of America and Africa. They estimate that half of the improvements in agriculture in the Sahel was negated by climate change.



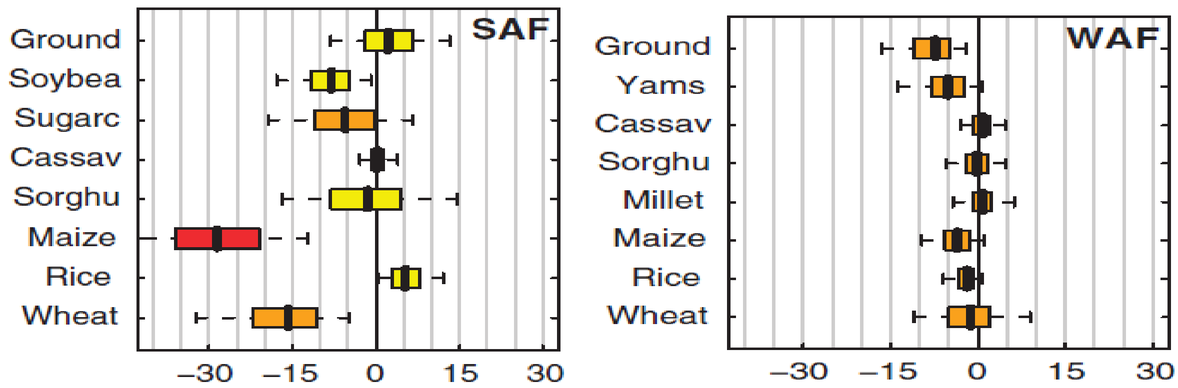


Figure 4: Probabilistic projections of crop yield impacts in 2030 from climate change (expressed as a percentage of 1998 to 2002 mean yields), (CAF, EAF, SAF, WAF refer to Central, East, Southern and West Africa, respectively)

Source: Lobell et al., 2008

Climate change could affect agriculture also by widening yield gaps (AGRA, 2014), which currently exceed 4 t ha^{-1} and 1.5 ha^{-1} for cereals and legumes, respectively. Crop yields are also affected by other factors occasioned in part by climate change, like soil erosion, limited soil organic matter (SOM) and nutrients because of the extractive farming practices which aggravate drought stress (Lal, 2009). The impacts of climate change on livestock are varied but will manifest through low fodder availability and quality, drying of watering points (limited availability of drinking water), heat stress and increases in livestock diseases (IPCC, 2022). These are direct effects of climate change. Indirect effects include damage to infrastructure which limits market access and reduced supply which invariably leads to higher prices of food and fiber.

Another major challenge posed by climate change is its uncertainty. The future climate is unknown. Farmers are uncertain if they will receive high or low rainfall in any given season and whether the rains will be evenly spread, whether they will receive good prices for farm produce, or whether their crops will be affected by disease (Kahan, 2008). Weather-related uncertainty has reduced farmers' incentives to use yield-enhancing inputs (or to use them at recommended levels), as this can be unprofitable in years of low rainfall (Kahan, 2008). This is not surprising as low rainfall in the Sudano-Sahelian zone was linked to limited crop response to increased nutrient use (Bationo et al., 2012). The uncertainty can be reduced by better weather forecast. For example, a study in Ethiopia found that fertilizer use increased by 22.07 kg/ha in response to optimistic weather forecasts (Fufa and Hassan, 2006). In general, farmers are hesitant to use fertilizer in instances where the forecasted rainfall (weather) is poor (Asfaw et al., 2016; Holden and Westberg, 2010). Farmers also tend to use more inputs and improved technologies in high rainfall areas. In Ethiopia, farmers use more inorganic fertilizer in areas with higher mean rainfall and lower maximum temperatures, while those in areas with delayed onset of rainfall and higher maximum temperatures are more likely to use sustainable land management (SLM) practices (Asfaw et al., 2016). Similarly, fertilizer use in the drier agro-ecological zones of Kenya, Ethiopia, and Burkina Faso was found to be much lower than in agro-ecological zones with greater potential, indicating a higher risk of utilizing fertilizer and lower profitability in the drier zones. This may be associated with higher risk involved in, and lower profitability of using fertilizer in the drier areas (Olwande et al., 2009; Tefera et al., 2020; Theriault et al., 2018). These findings emphasize the relevance of rainfall in influencing farmers' decisions to use fertilizers (Naseem and Kelly, 1999).

Mineral fertilizer may result in increased yields under average climatic conditions but may result in poorer yields when rainfall is highly variable or delayed (FAO, 2015; FAO, 2017). Cooper et al (2008), showed that with less rainfall, soils with nitrogen applied had higher yields than those fields that did not apply nitrogen. Falconnier et al. (2020) also found differential impacts of climate change on maize production based on the amount of nitrogen added and concluded that "*low organic and mineral fertilizer use on soils that are often very poor in nutrients, especially nitrogen, is the cause of low yields, contrary to the very popular belief that these low yields are generally caused by insufficient rainfall*". With regards to temperature, Falconnier et al. (2020) found that a temperature increase of 4°C would result in a 14 percent decline in maize yield with no nitrogen fertilizer (which corresponds to most present agricultural practices in SSA). With abundant nitrogen fertilization (160 kg/ha), at par with applications for maize in the countries of the North, this temperature increase would cause an even greater reduction in yields. These findings suggest that farmers' decision to use chemical fertilizers as well as other soil-health-improving methods may be influenced by uncertainty associated with weather patterns.

In conclusion, the impact of global climate change in SSA is readily appreciated given the region's economic and natural conditions that makes it especially vulnerable (Calzadilla et al, 2013). Climate change will reduce agricultural productivity in many areas, potentially driving farmland expansion into natural areas and causing loss of habitat and ecosystem services (Bastien-Olvera & Moore, 2022). Furthermore, subsistence households, who constitute the majority of agricultural producers in SSA, often invest their small savings in food stocks instead of technologies that could improve their quality of life and vulnerability to poverty. As a result, climate change exacerbates a vicious cycle of shocks, risks and poverty (Carter, 2022).

All of these trends have encouraged the majority of African countries to sign up to the United Nations Framework Convention on Climate Change (UNFCCC) and its associated protocols, including the 2015 Paris Agreement on Climate Change, the United Nations Convention on Biodiversity and the United Nations Convention for Combating Desertification (UNCCD). These international agreements seek to strengthen the interdependence of productive agriculture on healthy ecosystems and the natural resource base, thereby contributing to the global goal of reducing greenhouse gas emissions to levels required to limit the global temperature rise to less than 2 degrees Celsius above pre-industrial levels by 2050, and to pursue efforts to limit temperature rise to less than 1.5 degrees Celsius. There needs to be a balance in emphasis between climate change mitigation and adaptation for Africa given the continent's disproportionate exposure to climate change risk in comparison to its contribution to global GHG emissions. The commitment by global multilateral and Paris Club lenders to align financing flows to Africa to accelerate climate action is a welcome move.

5.3 Priority response actions to climate change

Adapting to climate change and variability is necessary to build resilience, and this could be either autonomous or planned. Planned adaptation will require evidence on relative risks of climate change by location and farming systems to prioritize resources, and on likely pathways for the climate impact to inform potential solutions (Lobell et al., 2011). Options to adapt to climate change in agriculture include improved land management and sustainable agricultural practices, improved seed varieties that are tolerant to drought and heat stress, adapting planting dates to prevailing weather patterns, planting short duration varieties and using heat tolerant animal breeds, agricultural and livelihood diversification where farmers engage in a mix of farm and non-farm enterprises, and prioritizing investments in climate hotspots (Cairns et al., 2013; Fisher et al., 2015; Lobell et al., 2011; Lobell et al., 2008).

There is some evidence of the adaptive measures already happening in various places in Africa. As cropping seasons in eastern and western Africa shorten, the yields of longer-duration crop varieties, which are higher-yielding, may decline dramatically because of terminal phase droughts which may shift the positions of longer-term crop varieties (Mutegi 2018). Farmers may adapt by producing short-term maturing crops such as vegetables, which are easily maintained with organic inputs because of smaller plot sizes . Thompson et al. (2015) posits that to cope with climate change, techniques of developing resilient soils that will improve water holding capacity and those that rely on the knowledge, rather than expensive external inputs that are subject to price swings like chemical fertilizers, are required. Importantly, promoting integrated soil fertility management (ISFM), in its broader definition as conceptualized by Vanlauwe et al. (2010), is critical for building organic matter and general long-term and sustainable management of soil nutrients (Katengenza et al., 2019; Mugwe and Otieno, 2021). Soil organic matter content also helps water retention and better crop performance and contributes to better soil health by maintaining a higher population of microorganisms (FAO, 2022, p. 110 and p. 256).

Improved soil management practices have been highlighted as one of the most important adaptation alternatives in SSA for stabilizing yields in the face of low rainfall and higher variability (Rusinamhodzi et al., 2011; Fraser et al., 2008; Mutegi et al., 2018). As a result of beneficial system interactions, a combination of soil water management and nutrient enhancement technology improves crop yields and optimizes water usage efficiency better than any of them used independently (Bationo et al., 2006). Intercropping and agroforestry carried out as part of an integrated system ensure a diverse food supply that may be used during poor seasons brought on by harsh weather (Mugwe and Otieno, 2021; Katengenza et al., 2019).

According to the Alliance for a Green Revolution in Africa (AGRA), smallholder farmers may effectively mitigate the effects of changing climate on agricultural productivity and household income by combining mineral and organic inputs (AGRA, 2021); organic inputs tend to retain moisture in the soil for longer periods of time and therefore enable crops to survive for longer periods of time without rain. But what is required is ways to raise the supply of organic inputs available for farmers in situ, given that markets for organic inputs is hampered by short supply and high transport costs. However, expanding the markets for organic inputs may also be a priority to overcome the constraints posed by limited supply. It would be advantageous for these organic inputs to require little additional labor for reasons stated earlier.

Given the risks posed by climate change and the adaptive measures outlined above, policy makers must prioritize the development of a more resilient and sustainable food system, including efficient production and diversity of inputs that are adapted to the changing local agro-climatic conditions as an urgent national priority. The following are examples of such measures:

i) Development and promotion of agricultural technologies and management practices that make efficient use of water and improve the natural environment. These technologies and practices include drought-tolerant crop varieties; fairly hardy and adaptable livestock breeds; silvopastoral systems; smallholder irrigation and rainwater harvesting, and improved animal feeding systems.

ii) Forging the agenda for climate resilience in African agriculture through research and development (R&D). There is need for enhanced collaboration between national and international agricultural research systems in adaptive research and development and deployment of technologies, innovations, and management practices that are suited to Africa's diverse agro-ecological and economic contexts. There is need to prioritize building the capacity and organizational effectiveness of national agricultural research systems (NARS) and extension systems to enhance their performance in research and extension. This will necessitate actions by both donors and governments. Donors should prioritize support for NARS and public extension services in their funding to international agricultural research system. African governments should increase public funding to research and development and extension as well as build the capacity of NARS and public extension systems in organizational effectiveness for greater accountability. Governments should also strengthen public-private partnerships in research and development and extension, including synergies between national agricultural universities and NARS. Private investors should prioritize innovations for the circular economy and those that de-risk agricultural production, while promoting climate smart technologies throughout the food system. Weather advisories and insurance products to reduce farmers' risks, digital technologies for agricultural services, water recycling systems and solar technologies for irrigation, investments in irrigation infrastructure and value addition are some examples.

iii) Establishment of an African-led climate change adaptation fund. It is important to note that the focus on the global stage is more about mitigation, yet adaptation is more crucial for Africa, and, according to the IPCC's Sixth Assessment Report, Africa received only 3.8% of the global funding for climate research between 1990 and 2019. These facts support the need for a significant shift in climate financing for Africa; to increase financing and channel more of that financing to support climate change adaptation initiatives.

6 Global health crises, regional conflicts, and economic disruptions

The impacts of the COVID-19 pandemic, violent conflicts, and unstable global oil and food prices exacerbate the vulnerability of the continent's food systems and are major contributors to Africa's rampant food insecurity and malnutrition.

6.1 COVID-19 Pandemic

COVID-19 is the largest global pandemic our generation has faced (Gordon, 2020). The pandemic has caused disruptions with significant short-, medium-, and long-term implications for agricultural production (FAO, 2020a; AGRA, 2021). Tens of millions of people have slid into poverty and food insecurity as a result of the pandemic, which has also exacerbated inequality (FAO, 2022).

The immediate impacts of the COVID-19 pandemic have prompted future concerns about supply shocks as a result of international trade disruptions, highlighting nation states' limited resources, such as inorganic fertilizer and fuel supplies to support future food production (FAO, 2020a). Medium term effects include scarcity of inputs such as seed caused by disruptions of planting cycles and associated quality monitoring processes. The pandemic has also had a significant impact on agricultural land-use decision-making by limiting smallholders' access to agricultural technologies such as fertilizers (Nolte et al., 2022; Mishra et al., 2021), which has caused planting seasons to be disrupted (Pais et al., 2020). Some of the short- and medium-term effects may persist longer, which will be confounded by failure of small- and medium-enterprises that support crop production systems (FAO, 2020a).

The pandemic has resulted in a huge economic shock leading to disruption in the agricultural sector and supply chains (OECD, 2020). The health and economic restrictions interrupted the supply chains of agricultural inputs (e.g., fertilizer) and commodities, increasing the storage time for produce due to falling demands, decreasing income, purchasing power and labour availability, and disrupted international and domestic trade (Tripathi et al., 2022; OECD, 2020). Profitability suffered as a result of the disturbance, impacting producers' income, purchasing power, and access to traded food (Ogada et al., 2021; Pais et al., 2020; Ayanlade & Radeny, 2020).

Farmers' coping actions and methods during the pandemic varied depending on the farming systems diversification, the production style, the level of financial access and market activity (Tripathi et al., 2021). National lockdowns due to COVID-19 typically coincided with planting dates in different countries and this caused time-critical tasks to be delayed and impacted the quantity and quality of crops (Tripathi et al., 2021). Farmers may not have been able to purchase sufficient amounts of critical inputs, reducing cropped acreage and crop output in consecutive seasons (Willy et al., 2020; Nchanji et al., 2021). In addition, food export bans lowered domestic prices and may have reduced the incentive to cultivate food crops in the subsequent season (Brenton & Chemutai, 2020).

Planting fewer crops, using less fertilizer, and farming less land were all decisions made by farmers in various places (Mahmud & Riley, 2021; Obayelu et al., 2021; Tripathi et al., 2021). Farmers, farm laborers, agricultural service providers, extension agents, input suppliers, and other actors in the food chain were also limited in their efforts due to the disruptions in transportation (FAO, 2020a). In addition to lockdowns and movement limitations, fiscal difficulties resulted in major budget reallocation and cuts to government spending in agriculture, resulting in limited extension services (Willy et al., 2020). Essential research and development (R&D) efforts may have been hindered (FAO, 2020a). As a result of such disruptions, farmers needed to take drastic actions to safeguard their financial situation in the near term, including selling their assets, including land (Farnese, 2022).

6.2 Regional conflicts

Drivers of insecurity such as civil unrest, armed intercommunity conflicts and organized violence are major contributors to food insecurity and malnutrition in areas such as eastern Democratic Republic of the Congo (DRC), Ethiopia, northern Nigeria, northern Mozambique, central Sahel, Somalia, South Sudan that are marred by different kinds of conflicts (WFP & FAO, 2022). The various forms of violent conflicts in these areas contribute to food insecurity and malnutrition in several ways. First, they often lead to mass displacement and migration of people and affect agricultural production (Holleman et al., 2017). Secondly, violent conflicts cause disruptions in food supply chains. Thirdly, they disrupt the delivery of needed humanitarian assistance in the conflict areas, which further compounds the food insecurity and malnutrition problem. In 2022, the United Nations has profiled seven areas in Africa with medium or high risk of famine, notably due to violent conflicts. These areas include Ethiopia, South Sudan, Somalia, Nigeria, the DRC, Madagascar, and the West African Sahel (WFP & FAO, 2022). It is important to note that starvation has been deliberately used as a war strategy in some of the situations, e.g., in Ethiopia (Tigray region) and South Sudan.

6.3 Economic disruptions

Rapid globalization especially over the past four decades across Africa has increased countries' vulnerability to both regional and global economic shocks. The interconnectedness of these drivers is further revealed by the war in Ukraine, which compounds existing challenges faced by millions of acutely food-insecure people across Africa and globally, because of the importance of the Baltic Sea region in the world supply of grains and cooking oil (The Economist, 2022). Africa's over-reliance on global supply chains for its key agricultural inputs and food commodities, especially chemical fertilizers, grains, and cooking oil, implies that the continent's food systems are acutely vulnerable to global economic disruptions.

The post COVID-19 world food prices have increased drastically, with variable effects in SSA. For instance, higher global and local food prices have the potential to increase opportunities for commercialization of agriculture (Jayne et al., 2021), which would increase demand for fertilizers (Salau et al., 2018). Smallholder (and medium-scale) farmers who are integrated into food markets – including those that have a great deal of market orientation for high value crops – may have greater and increased opportunities to improve farm incomes, which often requires additional investments in purchased inputs (Salau et al., 2018).

However, fertilizer prices have risen rapidly since September 2020 (World Bank, 2021) due to a combination of global and local demand and supply factors. On the demand side, a surge in global demand for mineral fertilizers in 2021 was driven by a rebound in soft commodity prices as farmers responded positively to higher crop prices (Baffes and Koh, 2022). On the supply-side, several factors have led to limited supplies, including strong demand, high energy prices, and high raw material/input prices, in part due to the war in Ukraine.

Despite the economic disruptions due to COVID-19, the worldwide production of agricultural staples was expected to stay largely unaffected. Predictions, which account for COVID-19, indicated that world production of the agricultural staples - rice, wheat, and maize - were less disrupted in 2020/21 than in prior years (Martin & Glauber, 2020). Surprisingly, when compared to other continents, African food systems showed less susceptibility to economic disruptions due to COVID-19 effects, partly because large portions of East and West Africa, as well as South Africa, saw heavy rainfall in late 2019 after years of drought , which helped produce robust harvests (Pais et al., 2020). For instance, maize production in South Africa was anticipated to increase by more than 30% in 2020 compared to the previous years (Reuters, 2020). Additionally, prior to COVID-19's escalation, the main planting seasons in East and West Africa had already started in considerable part, and agricultural inputs had been delivered (Pais et al., 2020). However, the disruptions in the global agriculture and energy markets associated with the ongoing Ukraine war have hampered recovery from the COVID-19 economic downturn.

6.4 Priority response actions for global pandemics, conflicts and economic disruptions

The disruptions associated with the global pandemic, conflicts and economic factors as well as climate shocks will persist in the foreseeable future. This underscores the importance of developing and strengthening short supply chains for stable flow of key inputs and food commodities to and within the continent. Governments are increasingly looking for alternative sources of raw materials and food nearby (Ujunwa et al, 2021), including encouraging investments in food production and processing to be more localized. Governments will also be inclined to renew their commitment to bilateral and multilateral economic cooperation agreements, such as the African Continental Free Trade Area (ACFTA), to secure sources of agricultural inputs and food commodities and markets.

There is need to strengthen public research and development and extension to support viable farm nutrient cycling through the maintenance of soil organic matter, manure use, and beneficial crop rotations, recognizing that farmers are vulnerable to disruptions in input supply chains, for example through border closures and other tariff and non-tariff barriers (Farnese, 2022). For instance, COVID-19 had a lower impact in Tanzania on farmers in diverse and mixed farming systems that primarily rely on highly diverse but low-input mixed cropping, livestock and agroforestry smallholder systems (both food and cash crops) that are less reliant on overseas markets. In contrast, large-scale commercial farmers who rely on cash and single commodity systems of apple and potatoes, suffered enormous losses (Tripathi et al., 2021). The COVID-19 restrictions, with lower fertilizer availability and application, led to improved farm management with consequential reduced environmental impacts, increased food quality and a food system that rebounds within safe planetary boundaries (Lal et al., 2020). By utilizing all available organic fertilizers, such as farm manures, and applying quality-controlled organic leftovers from industry on agricultural land, this better soil management might contribute to a large-scale circular economy (Lal et al., 2020). However, it is noteworthy that the limited availability of organic inputs and their high processing and transport costs will remain a key limitation in deploying them in a large scale Understanding COVID-19's implications and accompanying limits is critical to ensuring a long-term post-pandemic recovery as well as coming up with strategies and plans to weather future pandemics for farmers and farm systems in the SSA region (Gordon 2020). Soil health is essential to the overall resilience of the agricultural sector during a global pandemic (Farnese, 2022). Therefore, the role of global pandemics and disruptions in altering the ability and/or incentive of smallholder farmers to use fertilizers and adopt techniques that increase soil health must be evaluated. This is useful in order to support efforts toward long-term land management and smallholder farmers' resilience in the face of pandemics and other disruptions, like the current war in Ukraine.

Governments can lead in the support of food systems in several ways:

i) Prioritize investments in physical infrastructure for local markets as well as trade corridors that are connected to major sources of raw materials, processing and consumption markets. There is also a need to create incentives that promote professionalization of commodity value chains within countries and sub-regions.

ii) Support investments in the development and strengthening of existing and emerging formal agricultural commodity trading platforms and markets such as digital and virtual markets, auctions, warehouse receipt system (WRS) and commodity exchanges, and futures.

iii) Governments should work closely with the private sector to build effective emergency response mechanisms to anticipate and manage disruptions to the food system. There is need for agricultural sector stimulus programs to support input access and value chain development, promotion and deployment of resilient technologies and digital agricultural solutions, including improving early warning systems, and providing social support to vulnerable communities including before, during and after disruptions (Willy et al., 2020; Steensland, 2020)

iv) Implementation of government policies where food production systems are included among essential services during pandemics and other disruptions to maintain farmers' access to markets (FAO, 2020). Many African countries should critically evaluate trade challenges and opportunities and how they can cushion farmers against global disruptions (Rogito and Rogito, 2022).

7 Advancement in the global rollout of technological innovation but little support for research and development and extension in SSA

African agriculture faces multiple and complex biophysical, socio-economic and policy constraints that limit the effectiveness of conventional agronomic practices and extension and service delivery systems. Targets for increasing agricultural productivity to meet the continent's food and nutrition security will be elusive without adopting technological innovations that enhance the productivity, efficiency, and resilience of production systems. Innovation for building effective value-chains and knowledge management and dissemination systems is also necessary for supporting sustainable agricultural systems.

7.1 Rapid advancement in the global rollout of technological innovations

The technological landscape has drastically changed since the green revolution in the 1960s and the development of new technological innovations is continuing rapidly. Examples of technological innovations that offer opportunities for accelerating the sustainable transformation of agriculture in Africa include ICT and digital technologies for precision agriculture, soil mapping, extension and financial service provision, delivery of agro-inputs and output market linkages, enhanced efficiency fertilizers, and biotechnology and seed innovation.

The trend of resource use efficiencies in crop production systems in the USA clearly illustrates the critical role of technology in supporting efficient production systems (Dimitri and Effland, 2020). Over the past seven decades, technological innovations have enabled consistent increases in farm productivity and resource use efficiencies without increased inputs. Concurrent advances in breeding, including the development of hybrid seed, fertilizer and pesticides, combined to increase yields and resource use efficiencies dramatically. The three indices (Figure 5) indicate that farm output increases were primarily due to greater productivity of inputs; that is, more output was produced with the same level of inputs (USDA-ERS, 2018). Technologies underlying the tremendous increase in productivity and technical efficiency in the 20th century centered on the introduction of self-propelled machinery, manufactured chemical inputs and conventional animal and plant genetic improvements. In the 21st century, the technological drivers of productivity growth were based on three areas of innovation: genetics, including biotechnology and seed innovation; information technology and digital systems, including precision agriculture and robotics. We can categorize the trends in technology and innovations in African agriculture into ICT and digital technologies, specialty fertilizers and biotechnology and seed innovation.

7.1.1 ICT and digital technologies

Use of ICT to deliver input subsidies

The use of ICT and digital technologies in improving access to inputs is gaining traction in sub-Saharan Africa, enabled by high rates of mobile phone access. Smart subsidies supported by digital technologies provide a mechanism to address structural constraints of traditional subsidies, such as poor targeting and inefficiency in the late delivery of fertilizers to farmers (Mink, 2021). Several countries have adopted electronic voucher (e-voucher) schemes designed to deliver inputs efficiently, accountable and transparently. There are two main ways that e-voucher schemes have been developed in sub-Saharan Africa. These include (i) text messages delivered on mobile phones with a limited agro-dealer network (i.e., used in countries such as Niger, Mali, Burkina Faso etc.); and (ii) e-cards or e-wallets with complementary agro-dealer networks (i.e., used in countries such as Kenya, Nigeria, Uganda, Zambia, Zimbabwe). The e-voucher schemes reduce input delivery costs by cutting unnecessary intermediaries and reducing fraud. Moreover, e-vouchers can be used as collateral for farmers to access credit and link to output buyers – particularly cooperatives.

Despite their potential value, the adoption of smart subsidies in all sub-Saharan African countries has been limited. Also, some countries that established smart subsidies are either scaling down or reverting to traditional input delivery systems (Duchoslav and Rusike, 2021). The limited success of smart fertilizer systems is mainly due to the overall subsidy costs, the realization that scarce public funds could achieve greater benefits when reallocated to other public investments and "political economy forces" (Mink, 2021).

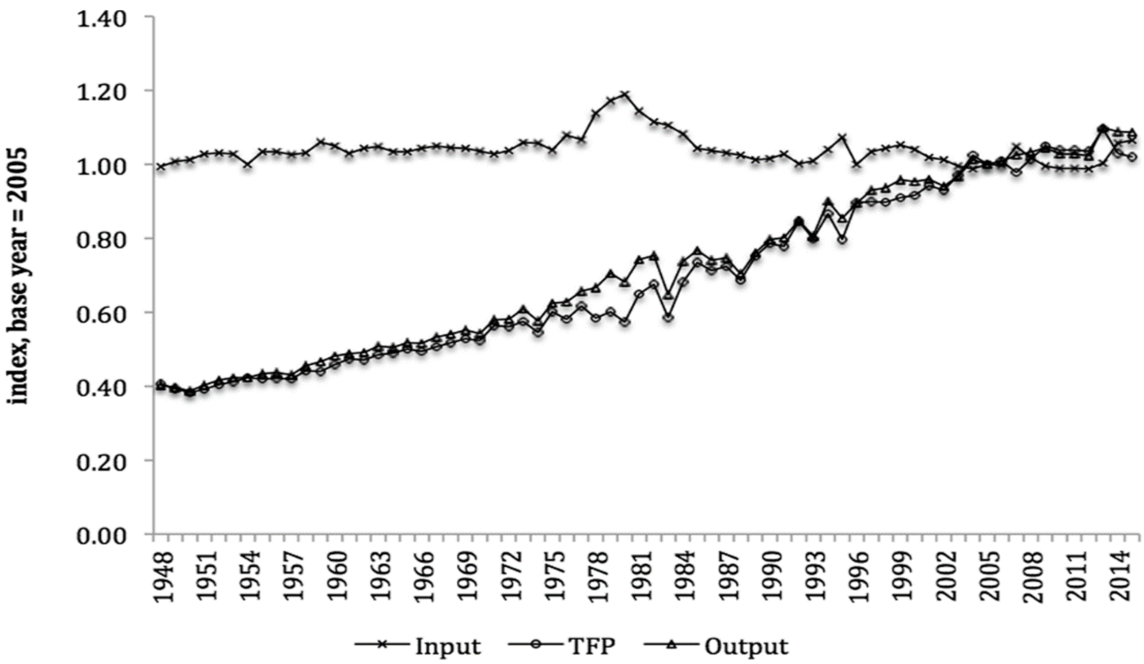


Figure 5: Changes in farm output, input use and total factor productivity in crop production systems in the USA, 1948–2015.

Productivity captures the increase in production not accounted for by the growth in quantity of inputs used and is expressed as total factor productivity (the ratio of total outputs to total inputs).

Source: Economic Research Service, USDA-ERS, 2018.

ICT and Digital/e-Commerce platforms for market linkage solutions, advisory and extension and financial access

Digital solutions that support market linkages, advisory and extension and financial access, can accelerate agricultural transformation by reducing transaction costs and increasing supply chain efficiency (Goedde *et al*., 2019). Digital platforms have been developed for a range of commercial services, with notable examples including (a) Africa Analytics Service, which provides a digital business platform that connects farmers and input suppliers; (b) "smart borrowing", which adapts other platforms such as Uber and Amazon; and (c) the partnership between AFAP and AFRICOM, which engages in data analytics of fertilizer markets to support business intelligence for the private sector and guiding policy decisions for the government (Rusike, 2021). A wide range of e-commerce platforms have been established in the broader agricultural sector for connecting farmers to output markets (Mercy Corps, 2018). Existing e-platforms can be leveraged to provide a range of services. For example, use of digital platforms to disseminate extension messages market information and advisory services on weather and disease and pest outbreak and control; facilitate input and output market linkages; and provide financial services such as weather insurance products, credit and savings.

Digital solutions for precision agriculture

The African Union (AU) identified precision agriculture as a potential game-changer for the African continent (AU, 2018). Precision agriculture supports decision-making for whole farm management with more knowledge. Although precision agriculture is often associated with machinery and technology, precision agriculture guides a more site-specific approach to nutrient management, with a range of technologies that vary in complexity. The top technologies in precision agriculture include mobile device-based decision support tools, digital platforms for data collection and data storage, technologies for variable rate applications, remote imaging and unmanned aerial vehicles (UAVs). Combining drone technology with the global positioning system (GPS) and geographic information system (GIS) tools dramatically enhances the analytical capabilities of technology by allowing high-resolution mapping and monitoring of various crop parameters. Data generated by integrating these tools provide more intensive and efficient cultivation methods, which can help farmers adjust fertilizer applications. Big data generated by these tools empower farmers to make more informed decisions based on economic and environmental factors – for example, by optimizing fertilizer treatment and applying only the right amount at the right time – which significantly reduces production costs and enhances environmental benefits. Public-Private partnerships are necessary to support the investments in technologies and capacity building necessary to achieve impact with digital technologies.

Despite the recognition of drones and their powerful application in agriculture, the regulation governing UAV manufacture and use in Africa is still underdeveloped, and there are concerns that the existing regulatory environment is either too restrictive or disabling to the import and use of drones (AU, 2018). The capacity for data management, analysis, and interpretation is also limited in SSA.

Digital soil mapping and decision support systems

Lack of soil information and knowledge is one of the major obstacles to reducing land degradation, improving agricultural productivity, and facilitating the adoption of sustainable soil management among smallholder farmers (Liniger et al., 2011). Digital soil mapping is a new technological advancement that seeks to fulfill the increasing worldwide demand for spatial soil data through more rapid and accurate production and delivery of soil information, increased coverage, and improved spatial resolution of mapped areas. New tools and methods are constantly being developed to support digital soil mapping (Omuto et al. 2013; Hengl et al. 2017). Africa has led the global effort in digital soil mapping at scale, using spectral soil analysis methods and geostatistical methods to combine information from soil point data with high-resolution gridded environmental explanatory variables. The initial map of a wide range of soil properties for the entire African continent at spatial resolutions up to 250 m has been generated. Beyond generating soil information, decision support platforms are necessary to enable stakeholders making decisions, including farmers, to access practical solutions that enhance performance and sustainable resource management. Efforts in place to translate soil information for use in various domains, including agronomic and policy advisory must be accelerated and consolidated.

Tsan et al (2019) report that services through ICT and digital technologies reach about 33 million agri-food value chain actors in SSA and majority of these are smallholder farmers. Widespread application and ICT and digital technology solutions in Africa's food systems can improve availability and flow of information among actors, thereby improving coordination of activities and response to potential shocks.

7.1.2 Specialty fertilizers

Specialized fertilizers can significantly increase crop productivity while minimizing nutrient losses and negative environmental impacts. Three main classes of specialty fertilizers have been identified: i) nutrients, ii) biostimulants and iii) biological fertilizers/stimulants. Each of these classes can be subdivided into several subclasses, with different modes of action (Opperman, 2017). All of the subclasses have either one or two main objectives, i) the improvement of nutrient use efficiency, and ii) increasing the plants ability to cope with environmental stress conditions (biotic and abiotic).

Nutrient specialty fertilizers are versatile and can be applied via seed treatment, pre-plant, or foliar fertilizer. They are be divided into three subclasses: water soluble, high purity macro- and secondary nutrient salts; micronutrients (foliar, seed treatments, fertilizer coatings); and inhibitors and slow/controlled release fertilizers.

Biostimulants are any substance or microorganism applied to seeds, plants, or the soil to enhance nutrition efficiency, abiotic stress tolerance, and/or crop quality traits, regardless of their nutrient content. The biostimulant market has grown exponentially over the past few years, with an estimated global market value of over 2 billion USD in 2018, and it is paramount that identifying products that work in this growing market becomes important.

Biological fertilizers/stimulants are of bacterial or fungal origins. Both bacterial and fungal products act upon plant growth in a symbiotic way, with a varied mode of action. They improve plant growth by improving nutrient availability and uptake (biofertilization), producing compounds that stimulate growth and disease resistance, control pathogenic organisms and pests, and improve soil structure. Most products available in the market are either applied directly to the soil or as seed treatments.

Inhibitors and slow/controlled release nitrogen fertilizers are of priority interest due to their potential to increase and sustain higher crop yields efficiently and environmentally sustainably (World Economic Forum, 2019). For maximum benefits, the application of slow/controlled-release fertilizers must be integrated with data analytics, artificial intelligence (AI), and various sensor systems to determine the exact quantities of fertilizer and water required by plants as part of a holistic precision agriculture framework. The technologies offer new innovations that must be targeted to crop production systems where they can be viably adopted and used by smallholder farmers, starting with high-value crop niches. Mechanisms to support scaling include: (i) building local research and extension capacity for technology adaptation, dissemination and technical service provision; (ii) providing incentives for adoption of the technologies with high outlay costs; (iii) reward instruments for improved management that results in higher water and nutrient efficiencies and support climate change adaption and mitigation.

7.1.3 Biotechnology and seed innovation

Biotechnology in plant breeding involves developing Genetically Engineered (GE) plants through gene transfer. Recent evidence has shown that GE crops increase maize yields by 17% after controlling for weather variability (Lusk et al., 2017). GE crops have been adopted widely in the USA, where more than 90% of maize, cotton, and soybeans are grown from GE seeds. GE seed has also been widely adopted in Canada, Brazil and Argentina, and in India and China for cotton (James, 2015). The European Commission (EC) is reviewing EU regulations on genetically modified organisms (GMOs), which may lead to possible relaxation of restrictions on gene-editing technology (Blenkinsop, 2021; Sihlobo, 2022). Since 2018, the EU subjected genetically engineered (GE) crops to the same rules as GMOs, including checks and content labeling for products, on the grounds of possible environmental risks (Blenkinsop, 2021). However, scientists distinguish between gene-editing technology and genetic modification, with the former targeting specific genes within an organism to promote certain characteristics or curb others, and the latter involving transferring a gene from one organism to another (Blenkinsop, 2021). The gene-editing accelerates processes that occur naturally, and emerging evidence is showing potential for new genomic techniques to contribute to sustainable food production (European Commission, 2021).

Sub-Saharan Africa remains the only region in the global South with significant restrictions on GE crops. With a body of evidence to suggest that gene editing techniques may be the key to developing more resilient, sustainable crops, allowing for lower insecticide use, more environmentally friendly tillage practices, and improved crop yields, sub-Saharan African countries should accelerate efforts to guide the safe adoption of GE crops in line with the global trend. Specific examples include:

- Genetically modified crops that mature faster, with the ability to produce higher yields during shorter harvest times, ensuring higher resource use efficiency
- The control of bollworm and other pests by Bt cotton
- The control of fall army worm with Bt maize

7.2 Chronically low public investments in agricultural research and extension (R&D&E) SSA

7.2.1 Agricultural Research & Development

The total world expenditure in agricultural research and development (R&D) was $56 billion US dollars in 2011 (the year in which the fullest set of time-series data was available). Globally, the private sector contributed $13bn (23%), the public sector contributed $21bn (38%) in developing countries and another $21bn in developed countries. Despite its importance and impact, the investment of donor funding to CGIAR was a mere 0.1% of the world total, or $0.7bn (Fuglie 2018, from ASTI 2022). Regionally, public R&D spending for 2011 was lowest in SSA ($1.9bn). China spent about 4 times as much ($7.8bn) followed closely by Western Europe ($7.1b). The United States plus Canada spent 3 times as much ($5.5bn); South Asia ($3.8bn) and South America ($3.8bn) twice as much (Fuglie 2018, from ASTI 2022).

According to Beintema & Stads (2017), different countries in East, West, and Central Africa have reported widely disparate patterns in agricultural R&D capabilities and investments. The study further states that, during the period 2000–2014, sixteen of the 28 SSA countries for which a full set of time-series data was available experienced annual growth in public agricultural research spending of more than 1.0 percent, the target set by the New Partnership for Africa's Development (NEPAD); seven countries (Namibia, The Gambia, Mauritania, Botswana, Cote d'Ivoire, Kenya and Mauritius) experienced near-zero growth (at rates of between –1.0 and +1.0 percent per year); and five countries (Guinea, Madagascar, Mali, Togo and Gabon) experienced yearly growth of more than –1.0 percent per year. The report shows, however, that only a few countries are making the necessary investments (see Table 1). According to Pardey et al. (2006), only eight countries in the study—Botswana, Burundi, Kenya, Mauritania, Mauritius, Namibia, South Africa, and Uganda—spent more than one percent of their agricultural GDP on research and development in 2008. This growth could be attributed to the fact that several high-profile projects have stressed the relevance of (agricultural) science and technology in decreasing poverty and guaranteeing food security in recent years, according to Beintema & Stads (2006). Well-developed, funded and staffed agricultural research programs are crucial if farmers are to be more productive and prosperous in the future (Pardey et al., 2006).

Table 1 shows some important metrics on agriculture and development in SSA, Latin America and Caribbean (LAC), and South and Southeast Asia (SEA). Total R&D spending increased steadily from 1981 to 2016 in SSA and LAC but SSA spent less than half what LAC spent throughout the time period. Investment increased dramatically in SEA from 1996 to 2016, spending three times as much as SSA in 2016, showing the increasing commitment by governments to National Agricultural Research System plus universities (NARS) in this region. Spending as percentage of the agricultural GDP decreased in SSA, increased steadily in LAC and was constant but lower in SEA. The number of agricultural researchers increased in all regions, but SSA had the lowest number. Research intensity, measured as the number of full-time researchers in relation to the number of farmers they serve, can be a useful indicator of investment in agricultural research. It is largest by far in LAC but now lowest in SEA, with SSA in between. The research intensity obviously ignores the quality and relevance of the R&D scientists and the efficiency of their institutions and bunches the most efficient NARS with the least efficient ones.

The statistics in Table 1 confirm that spending in agricultural R&D is lowest in SSA but has increased steadily and is certainly not stagnant. Research intensity---the most important indicator---shows that it is also not stagnant in SSA.

In SSA, the government is still the main player in public agricultural R&D, in terms of execution as well as funding (Lynam et al., 2012). Many countries, however, are extremely dependent on external funding (Beintema & Stads, 2011). Overall, during 2009 – 2014, 60 percent of the funding to NARS across SSA (excluding Nigeria and South Africa), was provided by national governments, while funding from donors and development banks constituted 27 percent. Dependency on donor funding is particularly high among francophone West African countries (Beintema & Stads, 2017).

Table 1: Indicators of investments in R&D in Sub-Saharan Africa, Latin America and the Caribbean, and developing countries of South Asia, Southeast Asia, including Papua New Guinea, but excluding China

AGRICULTURE R&D	**1981**	**1990**	**2000**	**2010**	**2016**
Total spending ($bn):					
Sub-Saharan Africa	1.07	1.16	1.49	2.10	2.41*
Latin America. & Caribbean	2.13	2.59	3.13	4.56	4.95***
South and Southeast Asia	-	1.18**	4.21	5.76	6.94
Spending as % Ag GDP:					
Sub-Saharan Africa	1.3	1.1	1.0	0.8	0.7
Latin America. & Caribbean	0.8	0.8	0.8	1.3	1.3***
South and Southeast Asia	-	-	0.5	0.4	0.4
Ag researchers:					
Sub-Saharan Africa	3,912	5,584	7,519	11,686	10,586
Latin America& Caribbean	8,226	10, 914	13,983	18,776	19,959***
South and Southeast Asia	-	-	24,391	27,253	28,888
Research Intensity (FTEs/100,000 farmers):					
Sub-Saharan Africa	11.9	16.9	18.1	19.5	23.6

AGRICULTURE R&D	1981	1990	2000	2010	2016
Latin America & Caribbean	51.1	68.4	61.1	67.1	72.3***
South and Southeast Asia	-	-	11.5	15.2	15.3

FTE: full time equivalents of agricultural research scientists.
*2014, **1996, ***2013
Source: Authors' compilation using data from ASTI, accessed on 28-07-2022

Additionally, about 20 percent of the agricultural research budgets in SSA are left unspent, often due to either funds being disbursed too slowly or complications in project implementation (Pernechele et al., 2021). These often come with severe repercussions on the day-to-day operations of agricultural research agencies.

A common and major constraint encountered by NARS is the little operational funds beyond salaries. Our experience indicates that a ratio of salary to operations of 60:40 is a good target for agricultural R&D in Africa. Indeed, such ratio happens in many African NARS budgets (Stads et al. 2021) but these operational funds are often late or discontinued by higher authorities, hampering implementation of research projects. It is quite common that NARS researchers get only their salaries and benefits with no funds to travel to their research sites or fix essential laboratory equipment. Furthermore, there often is no budget to travel to national and international conferences. This issue is not commonly described in publications about NARS´s funding but operational funds, including international travel and interactions with others involved in agricultural R&D&EE are key to strengthening these NARS.

Nevertheless, over the last five decades, agricultural R&D has made a significant contribution to agricultural development, food security, and poverty reduction in developing countries (Pardey et al., 2006). Agricultural research investment has been shown to have a positive impact on agricultural productivity growth and to provide high returns on investment in SSA (Fuglie & Rada 2016). But the success of NARS is highly predicated on their ability to obtain adequate funding.

Private R&D is still scarce in SSA, with the exception of South Africa, although it is expanding quickly in a number of nations and is mainly focused in the seed sector (Table 2). New agricultural technology has largely come from improvements in plant varieties, machinery, herbicides, fertilizers, and poultry imported by commercial agriculture. Additionally, universities and government research centers are the primary providers of scientists for private R&D organizations (Pray et al., 2015).

Table 2: Private-sector R&D in five African countries, 2008

Measures	Kenya	Senegal	South Africa	Tanzania	Zambia
Private Agricultural R&D (millions 2005 U.S. dollars)	1.6–3.2	3.6–4.7	41–50	0.9–1.8	1.3–2.5
Private Agricultural R&D as a share of AgGDP	0.025–0.05	0.18–0.24	0.49–0.60	0.015–0.03	0.05–0.09
AgGDP (billions 2005 U.S. dollars)	6.3	2.0	8.3	6.2	2.8

Source: Pray et al., 2015

7.2.2 Extension

Many publications indicate that extension financing should be no less than 1% of the agricultural GDP (AgGDP). The data we had available indicate that R&D and extension spending in SSA was 0.38 percent of AgGDP (Fuglie et al., 2020). We calculated total AgGDP for SSA to be $233bn in 2010 (since $2.10bn spent on R&D was 0.8% of the total). Expenditures on extension, therefore, would be $0.72bn.

A key barrier confronted by agricultural extension agents is the low extension agent to-farmer ratios (Antwi-Agyei, 2021). The recommended ratio is 1 extension agent per 400 farmers (Mutegi et al., 2018). Ratios for some countries in SSA are shown in Table 3. Rwanda's low ratio means that Rwandese farmers have better access to extension services, closely followed by Ethiopia, Zimbabwe and Burkina Faso when compared to their counterparts in other African countries. Nigeria has the highest ratio 1:7500, which means that one extension officer is responsible for 7500 farmers. These high ratios are a problem in many SSA countries and imply that a majority of the farmers do not receive adequate extension services.

It is noteworthy that Ethiopia has about 70 percent of the extension workers in SSA and the ratio of extension workers to farmers exceeds 1:400. Since there are no data from Zimbabwe, South Africa and Uganda, it is probably safe to state that Ethiopia has two-thirds of the extension workers of SSA. Again, as with research intensity, the effectiveness of these extension workers is not included as a metric.

According to Piesse & Thirtle (2010), the balance between R&D and extension has long been an issue, as many workers in extension had little to extend owing to weak R&D. The fact that agricultural R&D and extension are often based at different institutions constitutes a communication barrier between researchers and extensionists.

Table 3: Number of government extension workers and ratio of extension agents to farmers in countries in SSA (2019-2020).

COUNTRY	**Number of Government Extension Workers**	**Ratio of Government Extension Workers to Farmers**
Rwanda	466	1:136
Ethiopia	71,400	1:237
Zimbabwe	--	1:400
Burkina Faso	3,993	1:424
Zambia	2,525	1:560
Ghana	4,286	1:594
Mali	2,014	1:598
Tanzania	6,704	1:820
South Africa	-	1:1056
Kenya	5,000	1:1078
Liberia	130	1:1565
Uganda	-	1:1800
Burundi	996	1:1855
Malawi	1,604	1:2007
Nigeria	6,000	1:7500
TOTAL	**101,318**	
MEAN	**6,976**	**1:1360**

Source: The Africa Seed Access Index (TASAI, 2020)

More important, in our view, is the chronically limited operational resources, such as inadequate facilitation for transport (fuel and vehicles) and hence little farm visits, as extension budgets are spent mainly on salaries and benefits (Tieme Ndo, 2020). Like many NARS researchers, extension specialists often lack the tools to do their jobs. Informal communications with Malawi´s extension service providers indicate that an agent´s budget should be increased to include the following: motorcycle, laptop computer and phone (totaling $8600 every 5 years) and annual costs for agent training, internet connectivity, motorcycle fuel and maintenance, and demonstration land costs (totaling $3000 per year).

The challenge of weak extension in SSA due to thin (very high extension officers to farmer ratio) and under-resourced public extension can be partly addressed through the disruptive digital innovations discussed earlier. Where they are applied, digital platforms have unlocked the ability to deliver real time advice to farmers through intuitive multimedia formats and often in local languages. For a small fraction of the cost of traditional extension services, many smallholder farmers now have unprecedented access to critical information such as weather forecasting, pest and disease surveillance, latest animal and crop husbandry techniques and market intelligence. While farmer advisory services only account for an estimated 35% of unique digital solutions across Africa, they account for 68% of all subscriptions (Tsan, 2019).

7.3 Priority response actions for rapid advancement in technological innovations

i) Capacity development: The African Union Agenda 2063 aims to position Africa to become a major knowledge and innovation force in the global economy. The Agenda's action plan provides a more integrated and inclusive Africa that uses its natural resources, human capital, and institutions to drive technological, social and business innovation for development. It proposes to leapfrog the conventional approaches in ways that ensure rapid and sustainable growth. Highly skilled human resources are essential to developing and deploying new technologies to meet the Agenda's goals. This is most important in agriculture and other primary sectors which provide food, employ a larger proportion of the population and provide the largest export and foreign exchange earnings for the continent. There is a need to build the capacity of Technical Vocational Education Training (TVET), Higher Education Science and Technology (HEST), and Research and Development (R&D) institutions to support the development of cutting-edge technologies. In addition to investment in basic education., it is imperative to increase investment in tertiary education to strengthen the production of the required human resources at all levels (from vocational education graduates to PhDs) and through technological innovation. Higher education partnerships are also critical enabling mechanisms for African tertiary education institutions to share resources and experiences to fulfill the mandate for technological development.

ii) Institutional development**:** The strengthening of national and regional research and extension institutional capacity and management is required to enable their effective function to support the development and delivery of technological innovations. The digital agricultural revolution shows great potential to enhance productivity, lower transaction costs, and reduce information asymmetries across Africa's food systems. However, among the major constraints to scaling digital solutions are lack of capacity in the national research system in data science, advanced analytics, geospatial analytics, among others, and lack of expertise among extension agents and agro-dealers in diagnosing and delivering site-specific agronomic information. Therefore, the full potential of benefits of new science and applications can only be achieved from increased public investment in national agriculture research, development and extension to strengthen their capacity to develop and adapt technologies and innovations to local contexts. With advances in the ability to reach farmers in remote areas through digital platforms, the binding constraint on farm productivity has increasingly become the availability of evidence-based guidance that is truly useful to farmers that could result in willingness to pay for services. Public extension services could collaborate with content moderators on digital platforms to ensure greater oversight over the content targeted at smallholder farmers as well as safeguard farmer privacy. Particular emphasis should be placed on the engagement of youth in the deployment of such tools and approaches. Most SSA countries will also need to reduce the extension to farmer ratio and ensure that many farmers are reached with rapidly changing technology.

iii) Enabling policy and regulatory environment: The creation of enabling policy and regulatory environments at the national and regional levels is required to remove the bottlenecks that impede the development and adoption of new technologies. There is a need for policies and regulations that balance public security concerns while encouraging and incentivizing innovation and entrepreneurship.

Governments and development partners will play a key role in minimizing the growing "digital divide", so as not to leave behind underprivileged members of society, especially the poor, rural, elderly, women and handicapped people who lack access to information and communication technologies. There is a need for deliberate creation and maintenance of an enabling environment that will accelerate the pace of investment in communications infrastructure especially in rural areas.

iv) Public-Private Partnerships**:** Development and deployment of advanced agricultural technologies have a substantial financial, infrastructural and skill demand. Public-Private partnerships have a critical role in mobilizing the limited resources and the technological development and implementation capacity. Partnerships that bring together business, government and civil society provide a mechanism for harnessing resources and capacity for driving growth with agriculture technological innovation. Of note, global fertilizer companies are investing in non-traditional technologies in a transition towards sustainable fertilizer business models that provide integrated plant nutrition solutions. Multi-sectoral collaboration can accelerate the impact of such investments in fertilizer technology to enhance fertilizer use efficiency and meet the targets for environmental sustainability.

8 Conclusions and priorities for the AFSH Action Plan

Strategies for improving soil health and fertilizer use must consider the current megatrends that are shaping the trajectory of Africa's agrifood system for them to be contextually relevant. In light of the six megatrends identified in this report the following actions are proposed for inclusion in the AFSH Action Plan:

8. **Prioritize raising farm yields and productivity on existing farmland rather than relying on expansion of cropped area as the main source of agricultural growth in Africa.** This will require investment in several areas:

    e) National governments prioritizing integrated soil fertility management (ISFM).

    f) Increasing the efficiency of fertilizer use on smallholder farms. Currently many smallholder farmers do not obtain enough additional crop yield to make it worthwhile for them to use fertilizers. This problem will worsen at least temporarily as fertilizer costs have skyrocketed in 2022. But the main point is that smallholder farmers will demand more fertilizer if they can utilize it profitably. Therefore, the following are the actions that will be needed to enable farmers to increase crop yield response to fertilizer use.

    - Revive support for commitments already made by African governments: While almost all African governments have formally committed themselves to allocating 10% of national public expenditures to agriculture under the Comprehensive African Agricultural Development Program (CAADP) launched in Maputo, Mozambique, in 2003, only seven countries (out of over 50) have achieved this outcome. Ethiopia is one of the few African countries to substantially increase its spending on public agricultural research, which has more than tripled in real terms since 2000. Ethiopia also employs half of Sub-Saharan Africa's agricultural extension workers

(Fuglie et al., 2020). Not surprisingly, Ethiopia has enjoyed the highest rate of agricultural growth of any country in SSA since 2000 at 6.0% per year (FAOSTAT, 2021; World Development Indicators, 2021).

- Increase or sustain long-term core donor support for the CGIAR and Feed the Future Innovation Lab (IL) systems. Greater weight should be put on ensuring that funds to the CGIAR directly contribute to strengthening the capacity of national partner agricultural institutions in developing countries. Involving national partner institutions as grant co-awardees and co-directorships would be some concrete first step in this direction. Doing so will require that CGIAR and IL prime awardees are rewarded and held accountable for building the capacity of national partners in addition to the achievement of shorter-term outcomes such as introducing a given number of new articles, varieties, or improved management practices generated under the award.

- Scale up and target investments in agricultural R&D initiatives that promote smallholder climate adaptation, sustainable intensification, or have dual benefits for crop yields and the environment. This could include increasing investments to scale up the sequencing and trait mining of genetic material to improve crop and animal varieties to help farmers improve their productivity and livelihoods. CGIAR holds around 10 percent of the world's germplasm – including seeds and other genetic material – in banks across the globe. This rich supply of germplasm is key to developing new crop varieties adapted to climate change, including the development of more productive, nutritious disease resistant local crops that communities rely on for their food security. In addition, greater investment in research on improved fertilizer management practices and viable alternatives to commercial fertilizers should also be considered. Additional R&D investments to improve animal agriculture (health, nutrition, efficiency) are also essential to improving the nutrition and livelihoods of smallholders. Healthy animals also possess a lower carbon footprint and can support sustainability.

- Encourage developing country governments to make greater investments in their own agricultural R&D&E systems and strengthen the capacities and accountabilities of international, regional, and national agricultural R&D&E systems in developing countries. The responses will differ according to country readiness; Kenya and Ethiopia, for example, can build on strengthening their existing national institutions to achieve required responses, while many fragile states may lack such institutions entirely and thus have little ability to respond, at least in the near future. The latter category of countries may therefore rely more on regional approaches to mobilize R&D&E services for national constituencies. Several options can be considered:

- Encourage international development partners to leverage developing country government investments in national agricultural R&D&E systems by offering matching funds for developing country governments to support their own national R&D and policy institutes.

- In addition, donors can jointly establish with national governments accountability systems to encourage good performance for the use of greater funding of national R&D&E systems in developing countries. While increased funding for national R&D&E is an important requirement for developing climate-resilient local agricultural systems, simply calling for greater spending on agricultural research is unlikely to unlikely by itself to build national capacity for agricultural innovation (Lynam et al., 2016; Fuglie et al., 2020). Performance contracts and accountability frameworks led by national governments can generate greater accountability for the funds allocated for national climate adaptation efforts.

g) Promote diversification of agricultural production and value chains in areas where new crops have great potential to adapt to local agro-ecological conditions and thus improve resilience and sustainability.

h) Strengthen the performance of national and regional early warning systems and the coordination between them – work with international, continental and regional partners to strengthen climate information services and early warning systems.

9. **Improve policy and enabling environments** that incentivize the private sector (which includes millions of smallholder farmers and traders) to make climate-smart investments in the various stages of agri-food systems.

10. **Inter-ministerial coordination**, recognizing the multifaceted decisions required across many national ministries and departments to make sustained progress.

11. **Bolster programs that anticipate and respond to emerging new diseases and pests** affecting crops and animals, with a special focus on vulnerable regions increasingly affected by extreme weather.

12. Governments need to establish **enabling policy and regulatory environment** that makes it possible for technologies, innovations and management practices to be developed and adopted in the African agri-food food systems. There is a need for policies and regulations that balance public security concerns while encouraging and incentivizing innovation and entrepreneurship. Deliberate efforts are needed for creation and maintenance of an enabling environment that will accelerate the pace of investment in communications infrastructure and minimize the "digital divide", so as not to leave behind underprivileged members of society, especially the poor, elderly, women, handicapped and rural people who often lack or have limited access to information and communication technologies.

13. **Highly skilled human resource** is essential to developing and deploying new technologies and innovations to Africa's agriculture and other primary sectors which provide food, employ a larger proportion of the population and provide the largest export and foreign exchange earnings for the continent. There is a need to build the capacity of Technical Vocational Education Training (TVET), Higher Education Science and Technology (HEST), and R&D&E institutions to support the development of cutting-edge technologies and innovations. It is imperative to increase investment in tertiary education to strengthen the production of the required human resources at all levels (from vocational education graduates to PhDs) and through technological innovation. Higher education partnerships are also critical enabling mechanisms for African tertiary education institutions to share resources and experiences to fulfill the mandate for technological development.

14. **Establishment of an African-led climate change adaptation fund**. It is important to note that the focus on the global stage is more about mitigation, yet adaptation is more crucial for Africa, and, according to the IPCC's Sixth Assessment Report, Africa received only 3.8% of the global funding for climate research between 1990 and 2019. These facts support the need for a significant shift in climate financing for Africa; to increase financing and channel more of that financing to support climate change adaptation initiatives.

The goal of the AUC 's Africa Fertilizer and Soil Health Summit is to build consensus on an Africa Fertilizer and Soil Health Action Plan, which will constitute high-impact solutions and investments over a 10-year horizon that will increase fertilizer use, improve soil health, raise crop yields and contribute to sustainable agricultural transformation in the context of the megatrends discussed in this report. Therefore, the conclusions of this study are well aligned with the AFSH Summit goal and anticipated outcomes. African governments, development partners and private sector entrepreneurs will be in a stronger position to successfully achieve these outcomes if the key trends and priorities identified in this report are integrated into the post-Summit actions of African governments and the relevant regional and continental organizations.

References

Abay, K. A., Chamberlin, J., & Berhane, G. (2021). Are land rental markets responding to rising population pressures and land scarcity in sub-Saharan Africa? *Land Use Policy*, 101, 105139.

African Union (2018). Drones on the Horizon: Transforming Africa's Agriculture. African Union Development Agency-New Partnership for Africa's Development (AUDA-NEPAD). Midrand, South Africa.

Agyei-Holmes, A. (2016). Tilling the soil in Tanzania: What do emerging economies have to offer?. *The European Journal of Development Research*, *28*(3), 379-396.

Agyei-Holmes, A., Buehren, N., Goldstein, M., Osei, R. D., Osei-Akoto, I., & Udry, C. (2020). The Effects of Land Title Registration on Tenure Security, Investment and the Allocation of Productive Resources. *Global Poverty Research Lab Working Paper*, (20-107).

AGRA. (2014). Africa agriculture status report: climate change and smallholder agriculture in sub-Saharan Africa. Nairobi, Kenya. Alliance for a Green Revolution in Africa (AGRA).

AGRA. (2021). Africa Agriculture Status Report. A Decade of Action: Building Sustainable and Resilient Food Systems in Africa (Issue 9). Nairobi, Kenya: Alliance for a Green Revolution in Africa (AGRA).

Agricultural Science and Technology Indicators (ASTI). 2022. Agricultural Science and Technology Indicators (ASTI) Database. Washington, DC: International Food Policy Research Institute (IFPRI). http://hdl.handle.net/1902.1/20514

Altieri, M. A., & Nicholls, C. I. (2020). Agroecology and the reconstruction of a post-COVID-19 agriculture. *The Journal of Peasant Studies*, *47*(5), 881-898.

Antwi-Agyei, P., & Stringer, L. C. (2021). Improving the effectiveness of agricultural extension services in supporting farmers to adapt to climate change: Insights from northeastern Ghana. *Climate Risk Management, 32*, 100304.

Asfaw, S., McCarthy, N., Lipper, L., Arslan, A. & Cattaneo, A. (2016). What determines farmers' adaptive capacity? Empirical evidence from Malawi. *Food Security, 8*(3), 643-664.

AUDA (African Union Development Agency). (2021). *Africa Common Position on Food Systems: Regional Submission to the UN Food Systems Summit*. Johannesburg: African Union Development Agency.

Ayanlade, A. & Radeny, M. (2020). COVID-19 and food security in Sub-Saharan Africa: implications of lockdown during agricultural planting seasons. NPJ Science of Food, 4, 13.

Baffes, J. and Koh, W.C. (2022). Fertilizer prices expected to remain higher for longer. World Bank Blogs. May 11, 2022.

Bastien-Olvera, B. A., & Moore, F. C. (2021). Climate Impacts on Natural Capital: Consequences for the Social Cost of Carbon. *Annual Review of Resource Economics*, Forthcoming, Available at SSRN: http://dx.doi.org/10.2139/ssrn.3945184

Bationo, A., Hartemink, A. E., Lungo, O., Naimi, M., Okoth, P., Smaling, E. M. A., & Thiombiano, L. (2006). African soils: their productivity and profitability of fertilizer use: background paper for the African Fertilizer Summit 9-13th June 2006, Abuja, Nigeria. IFDC.

Bationo, A., Kimetu, J., Kihara, J., Traore, Z., Bagayoko, M., Bado, V., ... & Koala, S. (2012). Cropping systems in the Sudano-Sahelian zone: Implications on soil fertility management over varied seasons. In Lessons learned from Long-term soil fertility management experiments in Africa (pp. 137-158). Springer, Dordrecht.

Beintema, N., & Stads, G.-J. (2017). A Comprehensive Overview of Investments and Human Resource Capacity in African Agricultural Research. Washington, DC: International Food Policy Research Institute.

Beintema, N.M. & Stads, G.-J. (2011). African Agricultural R&D in the New Millennium: Progress for Some, Challenges for Many. IFPRI Food Policy Research Report, International Food Policy Research Institute, Washington D.C., USA. http://www.ifpri.org/sites/default/files/publications/pr24.pdf

Blenkinsop, P. (2021). EU calls for rethink of GMO rules for gene-edited crops. Reuters. Brussels. April 29, 2021.

Brenton, P. & Chemutai, V. (2020). Trade and COVID-19 Guidance Note. Trade responses to the COVID-19 crisis in Africa. World Bank, 06 April 2020.

Brevik, E. C. (2013). The potential impact of climate change on soil properties and processes and corresponding influence on food security. *Agriculture*, *3*(3), 398-417.

Broms, G. 2020. Materialisation of Emergent Farmers in a Malawian context: A Privileged Class' Positioning in Agricultural Transformation. Swedish University of Agricultural Sciences, Department of Urban and Rural Development, Uppsala.

Cairns, J.E., Hellin, J., Sonder, K., Araus, J.L., MacRobert, J.F., Thierfelder, C., Prasanna, B.M., 2013. Adapting maize production to climate change in sub-Saharan Africa. Food Security 5, 345-360.

Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S., & Ringler, C. (2013). Economywide impacts of climate change on agriculture in Sub-Saharan Africa. *Ecological Economics*, 93, 150-165.

Carter, M. 2022. Can digitally-enabled financial instruments secure an inclusive agricultural transformation? Agricultural Economics, in press, DOI: 10.1111/agec.12743

Chamberlin, J., Jayne, T.S., Sitko, N.J. (2020). Rural in-migration and agricultural development: Evidence from Zambia. *Agricultural Economics*, 2020, 1–14. https://doi.org/10.1111/agec.12567

Chan, K. Y. (2011). Climate change on soil structure and soil health: Impacts and adaptation. In *Soil Health and Climate Change* (pp. 49-67). Springer, Berlin, Heidelberg.

Chimhowu, A. (2019). The 'new' African customary land tenure. Characteristic, features and policy implications of a new paradigm. *Land Use Policy*, 81, 897-903.

Choularton, R., Frankenberger, T., Kurtz J. & Nelson, S. (2015). Measuring Shocks and Stressors as Part of Resilience Measurement. Resilience Measurement Technical Working Group. Technical Series No. 5. Rome: Food Security Information Network. Available at: http://www.fsincop.net/fileadmin/user_upload/fsin/docs/resources/FSIN_TechnicalSeries_5.pdf

Christiaensen, L., and Y. Todo. 2014. Poverty reduction during the rural-urban transformation – The role of the missing middle. *World Development* 63: 43-58.

Cline, W. (2007). Global Warming and Agriculture: Impact Estimates by Country. Peterson Institute, Washington DC.

Cooper, PJM, J Dimes, KPC Rao, B Shapiro, B Shiferaw and S Twomlow.. 2008. Coping better with current climatic variability in the rainfed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change. Agriculture, Ecosystems, and Environment 126: 24-35

De Bruin, S., Dengerink, J., and Van Vliet, J. (2021). Urbanization as driver of food system transformation and opportunities for rural livelihoods. *Food Security*, 1-18

Dimitri, C., & Effland, A. (2020). From farming to food systems: The evolution of US agricultural production and policy into the 21st century. Renewable Agriculture and Food Systems, 35(4), 391-406. doi:10.1017/S1742170518000522.

Djurfeldt, A. A. (2015). Urbanization and linkages to smallholder farming in sub-Saharan Africa: Implications for food security. *Global Food Security*, 4, 1-7.

Duchoslav J., and Rusike, J. (2021). Why Are Fertilizer Prices in Malawi High? And what can be done? Policy Note 42, International Food Policy Research Institute (IFPRI), and African Fertilizer and Agribusiness Partnership (AFAP).

European Commission (2021). Study on the status of new genomic techniques under the Union law and in light of the Court of Justice ruling in Case C-528/16. Commission Staff Working Document. Brussels.

Falconnier, G. N., Corbeels, M., Boote, K. J., Affholder, F., Adam, M., MacCarthy, D. S., ... & Webber, H. (2020). Modelling climate change impacts on maize yields under low nitrogen input conditions in sub-Saharan Africa. *Global change biology*, *26*(10), 5942-5964.

FAO (2020). Sustainable Crop Production and COVID-19. Policy brief/paper, April 2020, Rome. Available at https://www.fao.org/3/ca8807en/CA8807EN.pdf

FAO. (2020b). Climate change: Unpacking the burden on food safety. Food safety and quality series No. 8. Rome. Available at: https://www.fao.org/3/ca8185en/CA8185EN.pdf

FAO, (2011). Sustainable Land Management in Practice: Guidelines and Best Practices for Sub-Saharan Africa. FAO, Rome. Available at: https://www.fao.org/3/i1861e/i1861e00.pdf

FAO, (2015). Climate Change and Food Systems: Global Assessments and Implications for Food Security and Trade. FAO, Rome. Available at: http://www.fao.org/3/a-i4332e.pdf

FAO and DWFI. (2015). Yield gap analysis of field crops – Methods and case studies, by Sadras, V.O., Cassman, K.G.G., Grassini, P., Hall, A.J., Bastiaanssen, W.G.M., Laborte, A.G., Milne, A.E., Sileshi , G., Steduto, P. FAO Water Reports No. 41, Rome, Italy

FAO, (2017). The future of food and agriculture–Trends and challenges. Annual Report, 296, 1-180.

FAO. 2022. The future of food and agriculture – Drivers and triggers for transformation. The Future of Food and Agriculture, no. 3. Rome. https://doi.org/10.4060/cc0959en.

Farnese, P. L. (2022). Soil governance in a pandemic. *Soil Security, 6*, 100033.

FEWS NET (Famine Early Warning Systems Network). (2022), Unprecedented drought brings threat of starvation to millions in Ethiopia, Kenya, and Somalia. Issue Date: 9 June 2022.

Fisher, M., Abate, T., Lunduka, R.W., Asnake, W., Alemayehu, Y., Madulu, R.B., 2015. Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. Climatic Change 133, 283-299.

Fox, L., & Signé, L. (2022). From Subsistence to Disruptive Innovation: Africa, The Fourth Industrial Revolution, and the Future of Jobs. Africa Growth Initiative at Brookings, Washington, D.C.

Fraser, E. D., Termansen, M., Sun, N., Guan, D., Simelton, E., Dodds, P., ... & Yu, Y. (2008). Quantifying socioeconomic characteristics of drought-sensitive regions: evidence from Chinese provincial agricultural data. Comptes Rendus Geoscience, 340(9-10), 679-688.

Fufa, B. & Hassan, R. M. (2006). Determinants of fertilizer use on maize in Eastern Ethiopia: A weighted endogenous sampling analysis of the extent and intensity of adoption.pdf. *Agrekon, 45*(1), 38-49.

Fuglie, K., & Rada, N. (2016). Economies of size in national agricultural research systems. *Investing in Future Harvests*, 59.

Fuglie, K., Gautam, M., Goyal, A. & Maloney, W. F. (2020). Harvesting Prosperity Technology and Productivity Growth in Agriculture, Washington, DC: World Bank.

Girard, J., Delacote, P., & Leblois, A. (2021). Agricultural households' adaptation to weather shocks in Sub-Saharan Africa: implications for land-use change and deforestation. *Environment and Development Economics, 26*(5-6), 538-560.

Girvetz, E., Ramirez-Villegas, J., Claessens, L., Lamanna, C., Navarro-Racines, C., Nowak, A., .& Rosenstock, T. S. (2019). Future climate projections in Africa: where are we headed? In The climate-smart agriculture papers (pp. 15-27). Springer, Cham.

Goedde, L., Ooko-Ombaka, A. and Pais P. (2019). Winning in Africa's agricultural market: Private-sector companies can find practical solutions to enter and grow in Africa's agricultural market. McKinsey & Company.

Gordon, L. J. (2020). The Covid-19 pandemic stress the need to build resilient production ecosystems. *Agriculture and Human Values, 37*(3), 645-646.

Gordon, L. J. (2020). The Covid-19 pandemic stress the need to build resilient production ecosystems. *Agriculture and Human Values, 37*(3), 645-646.

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., Vogt-Schilb, A., 2016. Shock waves: Managing the impacts of climate change on poverty Climate change and development series. World Bank, Washington, DC.

Headey, D. D., & Jayne, T. S. (2014). Adaptation to land constraints: Is Africa different?. *Food Policy*, *48*, 18-33.

Hengl Tomislav. Johan G. B. Leenaars . Keith D. Shepherd . Markus G. Walsh . Gerard B. M. Heuvelink . Tekalign Mamo . Helina Tilahun . Ezra Berkhout . Matthew Cooper . Eric Fegraus . Ichsani Wheeler . Nketia A. Kwabena. (2017) Soil nutrient maps of Sub-Saharan Africa: assessment of soil nutrient content at 250 m spatial resolution using machine learning. Nutr Cycl Agroecosyst, 109:77–102.

Holden, S. T. & Westberg, N. B. (2010). Exploring technology use under climate risk and shocks through an experimental lens. *African Journal of Agricultural and Resource Economics, 11* (1), 47-62.

Holleman, C., Jackson, J., Sánchez, M.V. and Vos, R. 2017. Sowing the seeds of peace for food security - Disentangling the nexus between conflict, food security and peace. FAO Agricultural Development Economics Technical Study 2. Rome: Food and Agriculture Organization of the United Nations. 95 pp.

IPCC (Intergovernmental Panel on Climate Change). (2022) Sixth Assessment Report - Regional Fact Sheet - Africa, Available at https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Africa.pdf

IPCC, 2022. Climate Change 2022: Impacts, Adaptation and Vulnerability.

James, C. (2015). Global status of commercialized Biotech/GM crops: (2014) ISAAA Brief 49.

Jayne, T. S., Fox, Fuglie, K.L., and Adelaja, A. (2021). Agricultural Productivity Growth, Resilience, and Economic Transformation in sub-Saharan Africa: Implications for USAID. Bureau of Resilience and Food Security (BIFAD), United States Agency for International Development (USAID) and Association of Public and Land-grant Universities (APLU).

Jayne, T. S., Ayala Wineman, Jordan Chamberlin, Milu Muyanga, and Felix Kwame Yeboah (2022). Changing Farm Size Distributions and Agricultural Transformation in Sub-Saharan Africa. *Annual Review of Resource Economics,* 2022 14:1.

Jayne, T. S., Chamberlin, J., & Headey, D. D. (2014). Land pressures, the evolution of farming systems, and development strategies in Africa: a synthesis. *Food Policy*, 48, 1-17.

Jayne, T. S., Chamberlin, J., Holden, S., Ghebru, H., Ricker-Gilbert, J., & Place, F. (2021). Rising land commodification in sub-Saharan Africa: Reconciling the diverse narratives. *Global Food Security*, *30* (September), 100565.

Jayne, T.S., Yeboah F.K., and Henry, C. (2017). The future of work in African agriculture: Trends and drivers of change. Research Department Working Paper No. 25. International Labour Office.

Josephson, A. L., Ricker-Gilbert, J., and Florax, R. J. (2014). How does population density influence agricultural intensification and productivity? Evidence from Ethiopia. *Food Policy*, 48, 142-152.

Kahan, D. (2008). Managing risk in farming (Farm management extension guide). *Rural Infrastructure and Agro-Industries Division Food and Agriculture Organization of the United Nations. Rome, Italy.(153)*, 38-75.

Katengeza, S. P., Holden, S. T. & Fisher, M. (2019). Use of Integrated Soil Fertility Management Technologies in Malawi: Impact of Dry Spells Exposure. *Ecological Economics, 156*, 134-152.

Kiita, M.E. (2013). An investigation into causes and effects of agricultural land use conversions in the urban fringes: A Case Study of Nairobi-Kiambu Interface. MSc Dissertation, University of Nairobi.

Lal, R. (2009). Soils and food sufficiency. A review. *Agronomy for Sustainable Development, 29*(1), 113-133.

Lal, R., Brevik, E. C., Dawson, L., Field, D., Glaser, B., Hartemink, A. E., . . . Sánchez, L. B. R. (2020). Managing Soils for Recovering from the COVID-19 Pandemic. *Soil Systems, 4*(3).

Larson, D. F., Savastano, S., Murray, S., and Palacios-López, A. (2015). Are women less productive farmers? How markets and risk affect fertilizer use, productivity, and measured gender effects in Uganda. World Bank Policy Research Working Paper, (7241).

Liniger, H. P., R. M. Studer, C. Hauert and M. Gurtner (2011). Sustainable Land Management in Practice - Guidelines and Best Practices for Sub-Saharan Africa. Rome, TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO).

Lobell, D. B., & Field, C. B. (2007). Global scale climate–crop yield relationships and the impacts of recent warming. *Environmental research letters*, *2*(1), 014002.

Lobell, D.B., Bänziger, M., Magorokosho, C., Vivek, B., (2011). Nonlinear heat effects on African maize as evidenced by historical yield trials. *Nature Climate Change* 1, 42-45.

Lobell, D.B., Bänziger, M., Magorokosho, C., Vivek, B., 2011. Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature Climate Change 1, 42-45.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., Naylor, R.L., 2008. Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science* 319, 607-610

Lusk, J.L., Tack, J., and Hendricks N.P. (2017). Heterogeneous yield impacts from adoption of genetically engineered corn and the importance of controlling for weather. National Nureau for Economic Research (NBER) Working Paper Series. Working Paper 23519. Massachusetts. http://www.nber.org/papers/w23519

Lynam, J. K., & Twomlow, S. (2012). A 21st Century Balancing Act: Smallholder Farm Heterogeneity and Cost Effective Research. International Fund for Agricultural Development, Rome.

Mabaya, E., & Porciello, J. (2022). Can digital solutions transform agri-food systems in Africa?. Agrekon, 61(1), 67-79.

Maggio, A., Scapolo, F., van Criekinge, T., & Serraj, R. (2019). Global drivers and megatrends in agri-food systems. In Serraj, R. & Pingali, P. (eds.), *Agriculture & Food Systems to 2050: Global Trends, Challenges and Opportunities* (pp. 47-83). Singapore: World Scientific Publishing Co. Pte. Ltd.

Mahmud, M., & Riley, E. (2021). Household response to an extreme shock: Evidence on the immediate impact of the Covid-19 lockdown on economic outcomes and well-being in rural Uganda. *World Development, 140*, 105318.

Martin, W., & Glauber, J. (2020). Trade policy and food security. In Baldwin, R., & Evenett, S. (Eds.), *COVID-19 and trade policy: Why turning inward won't work. VoxEU Book*. London, UK: CEPR Press.

Mathenge, M. K., & Smale, M., 2013. Off-farm Income and Fertilizer Investments by Smallholder Farmers in Kenya. Fourth International Conference, September 22-25, 2013, Hammamet, Tunisia 161470, African Association of Agricultural Economists (AAAE). Accessed at https://ideas.repec.org/p/ags/aaae13/161470. html DOI: 10.22004/ag.econ.161470

Mercy Corps (2018). Benchmarking e-commerce models for Africa's smallholders: Summary of Benchmark Findings. Agrifin Accelerate Program. Mercy Corps and Mastercard Foundation. Nairobi, Kenya.

Michler, J. D. (2020). Agriculture in the process of development: A micro-perspective. *World Development*, 129, 104888.

Mink, S. (2021). Design and Delivery Mechanism of e-Voucher Schemes in Agriculture in sub-Saharan Africa. World Bank, African Development Bank (AfDB), and the Alliance for a Green Revolution in Africa (AGRA).

Mishra, A., Bruno, E. & Zilberman, D. (2021). Compound natural and human disasters: Managing drought and COVID-19 to sustain global agriculture and food sectors. *Science of the Total Environment, 754*, 142210.

Mugwe, J., & Otieno, E. O. (2021). Integrated Soil Fertility Management Approaches for Climate Change Adaptation, Mitigation, and Enhanced Crop Productivity. In Handbook of Climate Change Management (pp. 1-22).

Mutegi, J., Ameru, J., Harawa, R., Kiwia, A. & Njue, A. (2018). “Soil health and climate change: Implications for food security in Sub-Saharan Africa”, *International Journal of Development and Sustainability, 7* (1), 21-33.

Mutegi, J., Ameru, J., Harawa, R., Kiwia, A. & Njue, A. (2018). “Soil health and climate change: Implications for food security in Sub-Saharan Africa”, *International Journal of Development and Sustainability, 7* (1), 21-33.

Naseem, A. and V. Kelly. (1999). Macro Trends and Determinants of Fertilizer Use in Sub-Saharan Africa. International Development Working Paper no. 73, Dept. of Agricultural Economics, Michigan State University.

Nchanji, E. B., Lutomia, C. K., Chirwa, R., Templer, N., Rubyogo, J. C., & Onyango, P. (2021). Immediate impacts of COVID-19 pandemic on bean value chain in selected countries in sub-Saharan Africa. *Agricultural systems, 188*, 103034.

Nguru, W. M., Gachene, C. K., Onyango, C. M., Ng'ang'a, S. K. & Girvetz, E. H. (2021). Factors constraining the adoption of soil organic carbon enhancing technologies among small-scale farmers in Ethiopia. *Heliyon, 7*(12), e08497.

Nolte, K., Sipangule, K., & Wendt, N. (2022). Agricultural households in times of crisis. The COVID-19 pandemic, livelihoods and land-use decisions. Journal of Land Use Science, 17(1), 134-160. doi:10.1080/1747423X.2021.2020922

Nyaku, A., Flory, A., Ledlie, N., Andridge, C., Fletcher, E. K., Huestis, A., Detwiler, B., Hawkes, C., & Trübswasser, U. (2022). *Taking a Food Systems Approach to Policymaking: A Resource for Policymakers*. Washington: Results for Development.

Obayelu, A. E., Ogbe, A. O., & Edewor, S. E. (2021). Household welfare and indirect consequences of the coronavirus disease outbreak in Nigeria. Journal of African Transformation Revue des mutations en Afrique, 89.

OECD, (2020). COVID-19 and the food and agriculture sector: Issues and policy responses OECD Policy Responses to Coronavirus (COVID-19). April 2020. https://read.oecd-ilibrary.org/view/?ref=130_130816-9uut45lj4q&title=Covid-19-and-the-food-and-agriculture-sector-Issues-and-policy-responses

Ogada, M. J., Justus, O., Paul, M., Omondi, S. G., Juma, A. N., Taracha, E., & Ahmed, H. (2021). Impact of COVID-19 pandemic on African indigenous vegetables value chain in Kenya. *Agriculture & Food Security, 10*(1), 1-10.

Ogwu, M. C. (2019). Towards sustainable development in Africa: the challenge of urbanization and climate change adaptation. In *The geography of climate change adaptation in Urban Africa* (pp. 29-55). Palgrave Macmillan, Cham.

Olwande, J., Sikei, G. & Mathenge, M. (2009). Agricultural Technology Adoption: A Panel Analysis of Smallholder Farmers' Fertilizer use in Kenya. CEGA Working Paper Series No. AfD-0908. Centre of Evaluation for Global Action. University of California, Berkeley.

Oluwatoba J. Omotilewa, T. S. Jayne, Milu Muyanga, Adebayo B. Aromolaran, Lenis Saweda O. Liverpool-Tasie and Titus Awokuse. 2021. A revisit of farm size and productivity: Empirical evidence from a wide range of farm sizes in Nigeria. World Development, 146. https://doi.org/10.1016/j.worlddev.2021.105592

Omuto, C., Freddy, N., and Ronald V.R. (2013). FAO-Report State of the Art Report on Global and Regional Soil Information.

Opperman, H. (2017). Speciality fertilizers in agriculture: An overview. Fertilizer Association of South Africa. http://www.fertasa.co.za/wp-content/uploads/2017/04/6-Dr-Hugo-Opperman-Speciality-fertilizers.pdf

Ortiz-Bobea, A., Ault, T.R., Carrillo, C.M. et al. Anthropogenic climate change has slowed global agricultural productivity growth. Nat. Clim. Chang. 11, 306–312 (2021). https://doi.org/10.1038/s41558-021-01000-1

Pais, G., Jayaram, K., Van Wemelen, A., (2020). Safeguarding Africa's Food Systems Through and Beyond the Crisis. McKinsey & Company. Retrieved from. https://www .mckinsey.com/featured-insights/middle-east-and-africa/safeguarding-africas-foodsystems-through-and-beyond-the-crisis.

Pardey, P. G., Beintema, N. M. S. Dehmer, S. & Wood, S. (2006). Agricultural research: A growing global divide? Food Policy Report. Washington, D.C.: International Food Policy Research Institute.

Pernechele, V. Fontes, F. Baborska, R. Nkuingoua, J. Pan, X. & Tuyishime C. (2021). Public Expenditure on Food and Agriculture in Sub-Saharan Africa: Trends, Challenges and Priorities. Rome: Food and Agriculture Organization of the United Nations.

Phatty-Jobe, A., Seth, A., & Norton, K. (2020). Digital agriculture maps 2020 state of the sector in low and middle-income countries. GSMA AgriTech and IDH Farmfit. https://www.gsma.com/r/wp-content/uploads/2020/10/GSMA-Agritech-Digital-Agriculture-Maps-2020-1.pdf (accessed June 14, 2021).

Picard, P.M. and Selod H. (2020). Customary Land Conversion and the Formation of the African City. Policy Research Working Paper 9192, World Bank. Washington DC.

Piesse, J., & Thirtle, C. (2010). Agricultural R&D, technology and productivity. Philosophical Transactions of the Royal Society B: *Biological Sciences, 365*(1554), 3035-3047.

Porciello, J., Coggins, S., Mabaya, E., & Otunba-Payne, G. (2022). Digital agriculture services in low-and middle-income countries: A systematic scoping review. Global Food Security, 34, 100640.

Potts, D. (2012). Whatever Happened to Africa's Rapid Urbanization? In *World Economics* 13(2) 17-29.

Potts, D. (2017). Urban Data and Definitions in Sub-Saharan Africa: Mismatches between the Pace of Urbanisation and Employment and Livelihood Change. Urban Studies, 55, 965-986. https://doi.org/10.1177/0042098017712689

Pray CE, Byerlee D, Nagarajan L. 2015. Private-sector investment in Africa. In Agricultural Research in Africa: Investing in Future Harvests, ed. NBeintema, J Lynam, Chapter 7. Washington, DC: IFPRI.

Reuters, (2020, March 25). South Africa's maize harvest expected to be 33% higher than last season. Available at: https://www.reuters.com/article/safrica-grains/south-africas-maize-harvest-expected-to-be-33-higher-than-last-season-idUSL8N2BJ3EZ

Rogito, J. M. & Rogito, N. (2022). Addressing the effects of COVID-19 on agriculture and food security situation in Africa. *Journal of Innovations and Sustainability,* 6(1), 05.

Ruben, R., Cavatassi, R., Lipper, L. et al. Towards food systems transformation—five paradigm shifts for healthy, inclusive and sustainable food systems. Food Security 13, 1423–1430 (2021). https://doi.org/10.1007/s12571-021-01221-4

Rusike, J. (2021). Trends in fertilizer supply chains in selected African Countries: Implications for reaching the last mile and increasing impacts at the farm level. Africa Fertilizer Partnership (AFAP) and AFRIQOM. Presentation at the Arab Fertilizer Association 27th Annual Forum. 6th-8th April 2021, Sharm El Sheikh.

Rusinamhodzi, L., Corbeels, M., Van Wijk, M. T., Rufino, M. C., Nyamangara, J., & Giller, K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for sustainable development, 31*(4), 657-673.

Salau, S., Omotesho, O., and Muhammad-Lawal, A. (2018). Agricultural Commercialization, Fertilizer Use and Non-Farm Employment: What Options for Smallholder Farmers in Nigeria? Paper presented at the 30th Conference of Agricultural Economists, July 28th – August 2nd, 2018, Vancouver.

Schoneveld, G (2014) The geographic and sectoral patterns of large-scale farmland investments in sub-Saharan Africa. *Food Policy*, *48*, 34-50. https://doi.org/10.1016/j.foodpol.2014.03.007

Sihlobo, W. (2021). A New Chance for Genetically Engineered Crops. Project Syndicate. May 26, 2021.

Sissoko, K., van Keulen, H., Verhagen, J., Tekken, V., & Battaglini, A. (2011). Agriculture, livelihoods and climate change in the West African Sahel. *Regional Environmental Change*, *11*(1), 119-125.

Sridhar, A., Balakrishnan, A., Jacob, M. M., Sillanpää, M., & Dayanandan, N. (2022). Global impact of COVID-19 on agriculture: role of sustainable agriculture and digital farming. *Environmental Science and Pollution Research*, 1-17.

Stads, G., Nin-Pratt, A., & Beintema, N. (2021). Building a Case for Increased Investment in Agricultural Research in Africa. Report prepared for the African Union Fourth Ordinary Session of the Specialized Technical Committee on Agriculture, Rural Development, Water, and Environment to be held during 13–15 December, 2021.

Steensland, A. (2020). 2020 Global Agricultural Productivity Report: Productivity in a Time of Pandemics (Thompson, T., Ed.), Virginia Tech College of Agriculture and Life Sciences.

Tefera, T., Elias, E., & Beek, C. V. (2020). Determinants of smallholder farmers' decisions on fertilizer use for cereal crops in the Ethiopian highlands. *Experimental Agriculture, 56*(2020), *677–687*.

The Economist, 2022. The coming food catastrophe: War is tipping a fragile world towards mass hunger. Fixing that is everyone's business, May 19th 2022 *(Updated May 20th 2022) Available at https://www.economist.com/leaders/2022/05/19/the-coming-food-catastrophe*

Theriault, V., Smale, M., & Haider, H. (2018). Economic incentives to use fertilizer on maize under differing agro-ecological conditions in Burkina Faso. *Food Security,10*(5), 1263-1277.

Thompson, K., Chidawanyika, F., Kruszewska, I. & Tirado, R. (2015). Building resilience in East African agriculture in response to climate change. Greenpeace Research Laboratories Technical Report 05-2015: 30 pp.

Tieme Ndo, (2020). Why Do Farmers Need the Service of an Extension Officer? https://tiemendo.com/why-do-farmers-need-the-service-of-an-extension-officer/

Tripathi, H. G., Smith, H. E., Sait, S. M., Sallu, S. M., Whitfield, S., Jankielsohn, A., ... & Nyhodo, B. (2021). Impacts of COVID-19 on diverse farm systems in Tanzania and South Africa. *Sustainability, 13*(17), 9863.

Tsan, M., Totapally, S., Hailu, M. and Addom, B.K. (2019). The Digitalisation of African Agriculture Report 2018–2019. CTA.

Tsan, M., Totapally, S., Hailu, M. and Addom, B.K., 2019. The Digitalisation of African Agriculture Report 2018–2019. CTA.

Tschirley, D. L., Snyder, J., Dolislager, M., Reardon, T., Haggblade, S., Goeb, J., Traub, L., Ejobi, F., & Meyer, F. (2015). Africa's unfolding diet transformation: implications for agrifood system employment. *Journal of Agribusiness in Developing and Emerging Economies*, *5*(2), 102-136. https://doi.org/10.1108/JADEE-01-2015-0003

Tschirley, D., Reardon, T., Dolislager, M., & Snyder, J. (2015a). The rise of a middle class in East and Southern Africa: Implications for food system transformation. *Journal of International Development*, *27*(5), 628-646. https://doi.org/10.1002/jid.3107

Ujunwa, A. I., Ujunwa, A., & Okoyeuzu, C. R. (2021). Rethinking african globalization agenda: Lessons from COVID-19. *Research in Globalization*, 3, 100055.

UN DESA (United Nations Department of Economic and Social Affairs). (2019). *World Urbanization Prospects: The 2018 Revision*. New York: United Nations.

United Nations. (2022). Secretary-General's remarks to the Global Food Security Call to Action Ministerial. 18 May 2022. https://www.un.org/sg/en/content/sg/speeches/2022-05-18/secretary-generals-remarks-the-global-food-security-call-action-ministerial%C2%A0

US Department of Agriculture, Economic Research Service (USDA-ERS) (2018) Agricultural productivity in the U.S. Available at https://www.ers.usda.gov/data-products/agricultural-productivity-in-the-us/.

van Ittersum, M. K., Van Bussel, L. G., Wolf, J., Grassini, P., Van Wart, J., Guilpart, N., ... & Cassman, K. G. (2016). Can sub-Saharan Africa feed itself?. *Proceedings of the National Academy of Sciences*, *113*(52), 14964-14969.

Vanlauwe B, A Bationo, J Chianu, KE Giller, R Merckx, U Mokwunye, O Ohiokpehai, P Pypers, R Tabo, K Shepherd, E Smaling, PL Woomer, and N Sanginga 2010 Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. Outlook on Agriculture, 39, 17-24.

WFP (World Food Programme). (2022). *Global Report on Food Crises - 2022*. 4 May 2022. Rome: World Food Programme. https://www.wfp.org/publications/global-report-food-crises-2022.

WFP and FAO. 2022. *Hunger Hotspots. FAO-WFP early warnings on acute food insecurity: June to September 2022 Outlook*. Rome: Food and Agriculture Organization of the United Nations. https://www.wfp.org/publications/hunger-hotspots-fao-wfp-early-warnings-acute-food-insecurity-june-september-2022

Willy, D. K., Yacouba, D., Hippolyte, A., Francis, N., Michael, W. & Tesfamicheal, W. (2020). COVID-19 Pandemic in Africa: Impacts on agriculture and emerging policy responses for adaptation and resilience building. Technologies for African Agricultural Transformation (TAAT), 1-15.

Wineman, A., and Jayne, T. S. (2016). Intra-rural migration and pathways to greater well-being: Evidence from Tanzania (Research Paper No. 60). East Lansing, MI: Michigan State University Innovation Lab for Food Security Policy. https://doi.org/10.22004/ag.econ.261669

World Bank, (2021). Special Focus: Urbanization and commodity demand. Commodity Market Outlook, October 2021. Washington DC.

World Bank, (2021). Special Focus: Urbanization and commodity demand. *Commodity Market Outlook*, October 2021. Washington D.C.

World Bank, 2020. Scaling up Action for Transformative Change: Food Systems 2030. Washington, DC, the World Bank. https://thedocs.worldbank.org/en/doc/183211604418620533-0090022020/original/BrochureFS20306Oct2020.pdf

World Bank. 2013. *Turn Down the Heat: Climate Extremes, Regional Impacts, and the Case for Resilience*. A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics. Washington, DC: World Bank.

World Economic Forum (2019). Top 10 Emerging Technologies 2019: Smarter Fertilizers Can Reduce Environmental Contamination: New formulations deliver nourishment on demand (pp 10). World Economic Forum Insight Report. Geneva, Switzerland.

Yaro, J.A.; Wahab, I.; Afful-Mensah, G. and Awenam, M.B. (2021) The Drivers of Medium-Scale Farms and the Emerging Synergies and Contradictions Among Socially Differentiated Farmers in Northern Ghana, APRA Working Paper 71, Brighton: Future Agricultures Consortium, DOI: 10.19088/APRA.2021.030

Yeboah, F. K., & Jayne, T. S. (2018). Africa's evolving employment trends. *The Journal of Development Studies*, 54(5), 803-832.

Zhao, C., Liu, B., Piao, S., Wang, X., Lobell, D. B., Huang, Y., Huang, M., Yao, Y., Bassu, S., Cias, P., Durand, J. L., Elliott, J., Ewert, F., Janssens, I. A., Li, T., Lin, E., Liu, Q., Martre, P., Müller, C., Peng, S., . Peñuelas, J., Ruane, A. C., .Wallach, D., Wang, T., Wu, D., Liu, Z., Zhu, Y., Zhu, Z., & Asseng, S. (2017). Temperature increase reduces global yields of major crops in four independent estimates. *Proceedings of the National Academy of Sciences*, *114*(35), 9326-9331.