ReSAKSS
Regional Strategic Analysis and Knowledge Support System
Facilitated by IFPRI

Annual Trends and Outlook Report | 2016

A THRIVING AGRICULTURAL SECTOR IN A CHANGING CLIMATE

Meeting Malabo Declaration Goals through Climate-Smart Agriculture

Edited by
Alessandro De Pinto
John M. Ulimwengu

Editors

Alessandro De Pinto and John M. Ulimwengu

About ReSAKSS | *www.resakss.org*

Established in 2006 under the Comprehensive Africa Agriculture Development Programme (CAADP), the Regional Strategic Analysis and Knowledge Support System (ReSAKSS) supports efforts to promote evidence- and outcome-based policy planning and implementation. In particular, ReSAKSS provides data and related analytical and knowledge products to facilitate CAADP benchmarking, review, and mutual learning processes. The International Food Policy Research Institute (IFPRI) facilitates the overall work of ReSAKSS in partnership with the African Union Commission, the NEPAD Planning and Coordinating Agency (NPCA), leading regional economic communities (RECs), and Africa-based CGIAR centers. The Africa-based CGIAR centers and the RECs include: the International Institute of Tropical Agriculture (IITA) and the Economic Community of West African States (ECOWAS) for ReSAKSS–WA; the International Livestock Research Institute (ILRI) and the Common Market for Eastern and Southern Africa (COMESA) for ReSAKSS–ECA; and the International Water Management Institute (IWMI) and the Southern African Development Community (SADC) for ReSAKSS–SA.

ReSAKSS is funded by the United States Agency for International Development (USAID), the Bill & Melinda Gates Foundation, the International Fund for Agricultural Development (IFAD), and the Ministry of Foreign Affairs of Netherlands (MFAN). Earlier, ReSAKSS also received funding from the UK Department for International Development (DFID) and the Swedish International Development Cooperation Agency (Sida).

DOI: http://dx.doi.org/10.2499/9780896292949

ISBN: 978-0-89629-294-9

Recommended Citation

De Pinto, A., and J. M. Ulimwengu (Eds). 2017. *A Thriving Agricultural Sector in a Changing Climate: Meeting Malabo Declaration Goals through Climate-Smart Agriculture*. ReSAKSS Annual Trends and Outlook Report 2016. Washington, DC: International Food Policy Research Institute.

Contributors

Carlo Azzarri, Research Fellow, Environment and Production Technology Division, International Food Policy Research Institute (IFPRI) | Patrick Bell, Adjunct Professor, Ohio State University | Samuel Benin, Deputy Division Director, West and Central Africa Office, IFPRI | Elizabeth Bryan, Senior Research Analyst, Environment and Production Technology Division, IFPRI | Francisco Ceballos, Senior Research Analyst, Markets, Trade, and Institutions Division, IFPRI | Nicola Cenacchi, Senior Research Analyst, Environment and Production Technology Division, IFPRI | Jowel Choufani, Senior Research Assistant, Environment and Production Technology Division, IFPRI | Alessandro De Pinto, Senior Research Fellow, Environment and Production Technology Division, IFPRI | Shahnila Dunston, Senior Research Analyst, Environment and Production Technology Division, IFPRI | Wiebke Förch, Programme Advisor, SADC Adaptation to Climate Change in Rural Areas in Southern Africa Programme, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH | Beliyou Haile, Research Fellow, Environment and Production Technology Division, IFPRI | Benjamin Henderson, Economist, Trade and Agriculture Directorate, Organisation for Economic Co-operation and Development | Mario Herrero, Chief Research Scientist, Commonwealth Scientific and Industrial Research Organization | Aziza Kibonge, Adjunct Professor, Department of Economics, Ohio University | Jawoo Koo, Senior Research Fellow, Spatial Data and Analytics Team Leader, Environment and Production Technology Division, IFPRI | Christine Lamanna, Climate Change Decision Scientist, Climate Change Unit, World Agroforestry Centre | Tsitsi Makombe, Senior Program Manager, West and Central Africa Office, IFPRI | Greenwell Matchaya, ReSAKSS Coordinator, International Water Management Institute | Daniel Mason-D'Croz, Scientist, Environment and Production Technology Division, IFPRI | Ruth Meinzen-Dick, Senior Research Fellow, Environment and Production Technology Division, IFPRI | Robert Mgendi, Adaptation Policy Expert, United Nations Environment Programme | Richard Munang, Africa Climate Change and Development Policy Expert, United Nations Environment Programme | Ephraim Nkonya, Senior Research Fellow, Environment and Production Technology Division, IFPRI | Claudia Ringler, Deputy Division Director, Environment and Production Technology Division, IFPRI | Miguel Robles, Advisor to Executive Director, World Bank | Mark W. Rosegrant, Division Director, Environment and Production Technology Division, IFPRI | Todd Rosenstock, Climate Change and Environmental Scientist, World Agroforestry Centre | Timothy B. Sulser, Scientist, Environment and Production Technology Division, IFPRI | Wondwosen Tefera, Research Officer, Eastern and Southern Africa Office, IFPRI | Sophie Theis, Research Analyst, Environment and Production Technology Division, IFPRI | Philip K. Thornton, Flagship Leader and Principal Scientist, CGIAR Research Program on Climate Change, Agriculture and Food Security, International Livestock Research Institute | John M. Ulimwengu, Senior Research Fellow, West and Central Africa Office, IFPRI | Keith Wiebe, Senior Research Fellow, Environment and Production Technology Division, IFPRI | Ho Young Kwon, Research Fellow, Environment and Production Technology Division, IFPRI |

Cover design: Joan Stephens/JKS Design and Shirong Gao/IFPRI

A THRIVING AGRICULTURAL SECTOR IN A CHANGING CLIMATE

Meeting Malabo Declaration Goals through Climate-Smart Agriculture

ReSAKSS

Annual Trends and Outlook Report | 2016

Contents

Contents *Continued*

Contents *Continued*

Contents *Continued*

ANNEXES| CORE CAADP M&E AND SUPPLEMENTARY INDICATORS *continued*

List of Tables

Tables *Continued*

List of Figures

Figures *Continued*

Figures *Continued*

List of Boxes

Abbreviations

ASEZ	agricultural special economic zones
ATOR	*Annual Trends and Outlook Report*
AU	African Union
AUC	African Union Commission
AWD	alternate wetting and drying
BAU	business-as-usual
BL	Bukanga Lonzo
BR	Biennial Review
Ca	calcium
CA	conservation agriculture
CAADP	Comprehensive Africa Agriculture Development Programme
CC	climate change
CEN-SAD	Community of Sahel-Saharan States
CO_2	carbon dioxide
COMESA	Common Market for Eastern and Southern Africa
COV	coefficient of variation
CSA	climate-smart agriculture
DRC	Democratic Republic of the Congo
DSSAT	Decision Support System for Agrotechnology Transfer
EAC	East African Community
EbA	ecosystem-based adaptation
EBAFOSA	Ecosystem Based Adaptation for Food Security Assembly
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
FAO	Food and Agriculture Organization of the United Nations
GAFSP	Global Agriculture and Food Security Support Program
GDP	gross domestic product
GHG	greenhouse gas
HadGEM2-ES	Hadley Centre Global Environment Model version 2—Earth System
ICT	information and communications technology
IFPRI	International Food Policy Research Institute
IGAD	Intergovernmental Authority for Development
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
ISFM	integrated soil fertility management
K	potassium
KCI	potassium chloride
LGP	length of growing period
M&E	monitoring and evaluation
MAP	monoammonium phosphate
Mg	magnesium
N	nitrogen
Na	sodium
NAIP	national agriculture investment plan
NEPAD	New Partnership for Africa's Development
NPCA	NEPAD Planning and Coordination Agency
P	phosphorus
PA	precision agriculture

Abbreviations *Continued*

PES	payment for ecosystem services
PPP	purchasing power parity
R&D	research and development
RCP	representative concentration pathway
REC	regional economic community
ReSAKSS	Regional Strategic Analysis and Knowledge Support System
SPAM	Spatial Production Allocation Model
SADC	Southern African Development Community
SDG	Sustainable Development Goals
SOC	soil organic carbon
SPI	standardized precipitation index
SSA	Africa south of the Sahara
UDP	urea deep placement
UMA	Arab Maghreb Union
USAID	United States Agency for International Development
USDA	United States Department of Agriculture

Acknowledgments

The *2016 Annual Trends and Outlook Report* (ATOR) has benefited from the research and efforts of the many authors and contributors whose work is presented in this report. We express our deepest gratitude to all the authors and co-authors. ReSAKSS node teams comprising Paul Guthiga, Joseph Karugia, Stella Massawe, Greenwell Matchaya, Charles Nhemachena, Sibusiso Nhlengethwa, Manson Nwafor, Maurice Taondyandé, and Mbaye Yade collected and updated data on CAADP indicators that are tracked in Chapter 11 and the Annex of this report.

This report was produced under the overall leadership of Ousmane Badiane. Tsitsi Makombe managed and coordinated the production process.

We are grateful to the valuable and thorough reviews and feedback provided by several reviewers. They include Senthold Asseng (University of Florida), Andy Jarvis (International Centre for Tropical Agriculture), Philip Thornton (International Livestock Research Institute), Todd Benson (IFPRI), Joseph Karugia (ReSAKSS), David Schimmelpfennig (US Department of Agriculture), Todd Rosenstock (World Agroforestry Centre), Patti Kristjanson (World Agroforestry Centre), Jessica Fanzo (Johns Hopkins University), John Ulimwengu (IFPRI), Richard Munang (United Nations Environment Programme), Ephraim Nkonya (IFPRI), Henry Neufeldt (World Agroforestry Centre), Aslihan Arslan (International Fund for Agricultural Development), Sonali McDermid (New York University), Eva "Lini" Wollenberg (University of Vermont), Pablo Pacheco (Center for International Forestry Research), and Joseph Glauber (IFPRI).

Special thanks go to Samuel Benin, who managed the peer-review process and the processing of data on CAADP indicators, as well as to Julia Collins and Wondwosen Tefera, who supported the peer-review process and data processing, respectively.

We appreciate the outstanding editorial support from Tsitsi Makombe, administrative support from Terra Carter and Pamela Dogbe, and research support from Julia Collins. Excellent editorial support from IFPRI's editorial team, under the leadership of Pamela Stedman-Edwards, is gratefully acknowledged. We thank Joan Stephens for the design and layout of the report.

Finally, we would also like to acknowledge the United States Agency for International Development (USAID) for providing financial support for the 2016 ATOR.

Foreword

Climate issues have taken on increasing importance in recent years, both in Africa and globally. African farmers are already experiencing the negative effects of climate change, including shifts in weather patterns and greater frequency of extreme events. Increased climate variability was evident in the unusually strong El Niño event of 2015–2016, which resulted in a severe and widespread drought that put millions of people across eastern and southern Africa in need of emergency food aid in 2016.

The ramifications of climate change will only increase in the future. While impacts will vary across crops and regions, overall effects on food production are expected to be negative if the response is inadequate. In Africa, where yields are already much lower than global averages and large numbers of poor people remain vulnerable to shocks, a failure to address climate change will endanger recent gains in raising living standards and increasing food security.

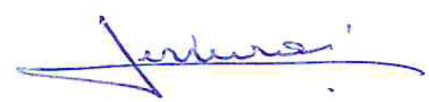
In particular, climate change will affect Africa's efforts to meet the commitments of the 2014 Malabo Declaration, including those to increase agricultural productivity and intraregional trade, halve poverty, and end hunger. The Declaration recognized the importance of responding to and anticipating new sources of climate risk with its commitment to enhancing resilience of livelihoods and production systems to climate variability and other related risks. Under this commitment, African leaders resolved to increase households' resilience to climate- and weather-related risks, enhance investments for initiatives to build the resilience of people and ecosystems, and mainstream resilience and risk management in policies, strategies and investment plans. In addition, the African Union is committed to supporting its member states in implementing the Paris Agreement on climate change, focusing on their nationally determined contributions.

Efforts to meet the Malabo commitments must include the adoption of climate-smart agriculture practices. Climate-smart agriculture (CSA) refers to agricultural practices and approaches that serve three objectives: (1) sustainable agricultural productivity increases; (2) increased resilience of food systems and farming livelihoods; and (3) reduction or removal of agricultural greenhouse gas emissions, when possible. This concept reflects both the vulnerability of agriculture to the effects of climate change and the position of agriculture as a contributor to greenhouse gas emissions.

Although CSA represents a vital strategy in the fight against the potential damage of climate change, much work remains to be done to examine in detail the impacts and conditions for success of different CSA tools. The *2016 Annual Trends and Outlook Report* (ATOR) presents research on CSA in order to understand and evaluate a range of potential techniques and approaches. The ATOR examines the likely effects of climate change on agricultural productivity, hunger, and trade; provides evidence on the impacts of CSA practices; and explores policy frameworks linking CSA with other development concepts. The report finds that climate change threatens to slow Africa's progress in raising crop yields and reducing hunger, but these effects can be offset through adoption of CSA tools as well as through investments in agricultural research and development, natural resource management, and market access. Despite tradeoffs in some cases between the three objectives of CSA, CSA practices can significantly increase crop yields and enhance resilience to weather variability while also lowering greenhouse gas emissions.

This report, as well as the 2017 ReSAKSS Annual Conference, should help to advance knowledge on CSA and aid in the successful adoption of CSA practices, increasing Africa's ability to consolidate development gains and achieve the Malabo commitments. The African Union plans to use findings of the 2016 ATOR in supporting its member states with domesticating the Malabo commitments in their revised or new national agriculture investment plans.

Ousmane Badiane
Director for Africa
International Food Policy Research Institute



H.E. Josefa L. C. Sacko
Commissioner for Rural Economy and Agriculture
African Union Commission

Executive Summary

Evidence continues to mount that climate change will play an increasingly important role in Africa, especially in agriculture. Indeed, rising temperatures and increased frequency of extreme dry and wet years are expected to slow progress toward increasing the productivity of crop and livestock systems and improving food security, particularly in Africa south of the Sahara (SSA). Recent food production projections show that climate change will have a negative impact on production, although the effects will vary by crop; negative effects are likely to be felt in roots and tubers production but more strongly for cereals, which are expected to see reductions in production of 2.9 percent by 2030 and 5.1 percent by 2050 (Sulser et al. 2015). Central and southern Africa show the largest projected negative effects on cereal production, with declines of more than 11 percent compared with the baseline. Although oilseed production in SSA may see a slight benefit from the effects of climate change, in northern Africa it will be negatively impacted, declining by 14 percent.

Given its heavy reliance on rainfed agriculture and projected climatic and weather changes, SSA faces multidimensional challenges in ensuring food and nutrition security as well as preserving its ecosystems. In this regard, climate-smart agriculture (CSA) can play an important role in addressing the interlinked challenges of food security and climate change. CSA practices aim to achieve three closely related objectives: sustainably increase agricultural productivity, adapt to climate change, and mitigate greenhouse gas (GHG) emissions. The CSA objectives directly contribute to achieving the 2014 Malabo Declaration goals, which include commitments to (1) end hunger in Africa by 2025, (2) halve poverty by 2025 through inclusive agricultural growth and transformation, and (3) enhance the resilience of livelihoods and production systems to climate variability and other related risks. These linkages underscore the importance of including CSA in country and regional plans to achieve overarching development objectives in Africa, in particular food security and poverty reduction.

The *2016 Annual Trends and Outlook Report* (ATOR) examines the contribution of CSA to meeting Malabo Declaration goals by taking stock of current knowledge on the effects of climate change, reviewing existing evidence of the effectiveness of various CSA strategies, and discussing examples of CSA-based practices and tools for developing evidence-based policies and programs. The findings and related policy recommendations are summarized below.

Major Findings and Policy Recommendations

CSA practices have on-farm and off-farm benefits that often far outweigh their investment costs. However, off-farm benefits can represent a significant fraction of the total benefits generated by CSA practices and benefits might accrue with a time lag while the necessary investments must be made up front. It is therefore important to design policies and strategies that favor the uptake of CSA technologies and practices. These include mechanisms such as ecosystem services payments and strengthening of the capacity of extension agents to provide the required advisory services. These strategies will simultaneously serve food security and climate change adaptation and mitigation objectives.

Widespread adoption of CSA practices has a positive effect on production and total agricultural output, with a consequent reduction in prices and decrease in the number of people at risk of hunger and the number of children, younger than five years, at risk of malnutrition. Adoption of CSA practices is also expected to increase soil organic carbon content, or at least reduce soil organic carbon losses, indicating that these practices can increase productivity in a more sustainable manner than current practices. Taken together, all of this evidence suggests an increase in resilience to climate change. However, the effects on prices might not lead to reduced pressure for cropland expansion. Given increased productivity, producers might increase cultivated land even with the projected decrease in prices, potentially endangering environmentally sensitive and carbon-rich areas. The effects on GHG emissions are mixed and mostly depend on how much emphasis is placed on reducing emissions. Finally, although beneficial, the adoption of a set of CSA practices only marginally addresses poverty, food security, and most of all, emissions reduction, indicating that broader interventions are necessary.

CSA is more than just a set of agricultural practices. Evidence suggests that CSA should be interpreted broadly and not reduced to a list of acceptable agricultural practices. Food systems as a whole (that is, trade, stocks, nutrition, and social policies) should adjust to climate change, and their interaction with other land uses as well as the role of agroforestry, livestock, and value chains should be considered as an essential component of climate-smart agricultural development.

CSA significantly increases both yields and agricultural trade flows, suggesting a potential role for CSA in improving resilience and spreading agricultural production risks. The evidence also suggests a heterogeneous response of trade flows to CSA in different regional economic communities. Although these findings are informative, it is worth noting that even if famers have complete information about a portfolio of CSA practices and their agronomic potential, adoption may be suboptimal due to, for example, limited budgets, missing or imperfect markets, and institutional barriers. Given that CSA practices have a more complex set of tangible and intangible components than does a single and discrete class of technologies, adoption of all the components is necessary to benefit from all the synergistic effects of CSA on productivity and sustainability. Additional research is therefore needed to examine possible general equilibrium effects of large-scale adoption of CSA practices and to identify location-specific factors that mediate the interaction between climate change, agriculture, and trade.

At the micro level, findings suggest that farmers could greatly benefit from CSA practices that rely on precision agriculture (PA), mainly through efficient and georeferenced application of inorganic fertilizers, use of selected seeds, use of cover crops, and minimal or no tillage. Though farmers may have to invest more at first on fertilizers under PA, the significant increase in crop yield more than offsets the cost of fertilizer. In addition, the total fertilizer cost is expected to decrease over time because the climate-smart practices implemented would enhance soil conditions and preserve the environment. The results also indicate that the revenue under PA/CSA is significantly higher than without these practices. It goes without saying that "blind farming"—farming without PA/CSA—is highly inefficient and exacerbates the challenges of addressing climate change. African governments should promote PA/CSA as a way of optimizing the use of limited resources while accounting for the effects of climate change. For example, it should be mandatory to include the results of soil analysis in farming loan and crop insurance applications. Similarly, under the National Agricultural Investment Plans, ministries of agriculture should require detailed soil analysis prior to every new land development for farming purposes.

There is still a gap of information on the costs, benefits, synergies, and trade-offs of many CSA interventions. Indeed, more comprehensive information could help target interventions more effectively and precisely. However, evidence is also accumulating on the kinds of approaches that can support the scaling up of CSA interventions. Multistakeholder platforms and policy-making networks are key, especially if paired with capacity enhancement, learning, and innovative approaches to support farmers' decision making. Modern information and communications technology offers efficient and cost-effective ways to disseminate and collect information at a massive scale, as well as an infrastructure for developing and utilizing new and diverse partnerships. A certain level of local engagement will still usually be needed, paying attention to farmers' needs and their own situations to better understand the benefits of CSA practices.

Risk management is an important component of CSA, and formal insurance instruments complete the farmers' tool kit to cope with weather shocks. Deteriorating farming conditions caused by rising temperature trends and shifting precipitation patterns can increase yield volatility and induce risk-reducing responses that, on the aggregate, might prove suboptimal for household diets, incomes, and national food security goals. Agricultural risk management is becoming an increasingly important area of intervention to achieving food security. Even though traditional crop indemnity insurance is not widespread in the continent, other options have been brought forward in the past decades. Weather index insurance is a promising alternative with several advantages. It avoids moral hazard issues, it is not subject to adverse selection, and the implementation and administration of index insurance is cheaper than that of traditional indemnity insurance. Among other risk management options, African policy makers should consider innovative weather index insurance tools as part of a comprehensive CSA package to help farmers manage weather risks. Such efforts can go a long way in helping the continent meet the Malabo Declaration commitment to enhance the resilience of farming livelihoods by 2025.

Gender and nutritional status affect people's ability to respond to climate change and their response choices. Changes in gender equity, nutritional status, and environmental sustainability are also outcomes of decisions on climate change and adaptation. Development programming is moving toward more integrated, systems-based approaches that address multiple interlinked development challenges simultaneously. However, this shift requires coordination across different disciplines and domains of expertise. Frameworks that link multiple areas can reveal the strategic aspects of a problem that need interdisciplinary approaches. A framework that links gender, climate change, and nutrition, for example, identifies (1) the importance of gender-differentiated capacities to respond to climate change, the needs and preferences for response options, and the outcomes of different practices and approaches; (2) consideration of the food system and nutritional status as factors influencing individuals' capacities to respond to climate change; (3) how environmental impacts and women's empowerment affect nutrition and health outcomes; and (4) the importance of multiple pathways through which climate change responses influence nutrition, health, gender equity, and other development outcomes. These types of frameworks enable program implementers and policy makers to think about the systems and institutions across different scales that affect each other, and how to properly measure and monitor such interactions. They can also provide guidance for identifying opportunities and obstacles related to the program and outcomes of interest and for tracing the impact pathways from interventions to outcomes.

Ecosystems-based adaptation (EbA) is a known strategy for building climate resilience and enhancing the ecosystems that underpin the productivity of key socioeconomic sectors in Africa. In light of mounting climate impacts and the escalating degradation of ecosystems, the urgent need to upscale the practice of EbA cannot be overstated. Generalizing this integrated approach will require inclusive partnerships among complementary actors to bridge the requisite policy and nonpolicy gaps and to foster practical means to achieve this integration. UN Environment is already fostering these inclusive, mutual, multistakeholder partnerships at the policy and operational levels by facilitating the country-driven Ecosystems Based Adaptation for Food Security Assembly (EBAFOSA) policy implementation framework.

CHAPTER 1

Introduction

Climate change is a significant and growing threat to food security already affecting vulnerable populations in many developing countries and expected to affect more people, more areas, and more farmers in the future. Climate disruptions to agricultural production have increased over the past 40 years and are projected to become more frequent over the next 25 years (Hatfield et al. 2014, Hatfield and Pruege 2015). Farmers in many agricultural regions already appear to have experienced declines in crop and livestock production because of climate change–induced stress (Lobell and Field 2007; Lobell, Schlenker, and Costa-Roberts 2011). Although climate change is expected to produce both winners and losers, on balance, losses in productivity in many regions are expected to outweigh gains in other regions (Jarvis et al. 2011).

The scale of the potential impacts of climate change is alarming. For example, the National Research Council (2011) has projected that each degree Celsius of global warming will lead to an overall loss in crop yields of about 5 percent. As climate change continues, it is increasingly likely that current cropping systems will cease to be viable in many locations. Jones and Thornton (2008), for example, argued that by 2050, as many 35 million farmers may switch from mixed crop-livestock to livestock-only systems.

Developing countries are expected to receive the brunt of climate change (Morton 2007). The Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) projects that under more optimistic scenarios, climate change could reduce food crop yields in parts of Africa by between 10 and 20 percent, a large drop for already at-risk populations and regions (IPCC 2014). The outlook for key food crops across the African continent under climate change is mostly negative and indicates that low productivity, together with increasing global demand, will likely drive up food prices (Jalloh et al. 2013; Waithaka et al. 2013; Hachigonta et al. 2013). Climate change is expected to negatively affect the yields of most of Africa's major crops, with cereals showing the most consistent decline in each of the continent's regions (Sulser et al. 2015). Nelson and colleagues (2010) predicted that staple food prices could rise by 42 to 131 percent for maize, 11 to 78 percent for rice, and 17 to 67 percent for wheat between 2010 and 2050 as a result of the combined effects of climate change, increasing population, and economic growth. Moreover, localized weather shocks and emerging pest and disease outbreaks are already compromising stability in crop production, highlighting the urgency for immediate and adaptable management responses (FAO and PAR 2011).

The 2014 Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods represents Africa's shared commitment to transforming the agricultural sector for sustainable development on the continent between 2015 and 2025. The declaration sets out seven specific commitments for advancing the Comprehensive Africa Agriculture Development Programme (CAADP) agenda. The sixth commitment is focused on enhancing the resilience of livelihoods and production systems to climate variability and other related risks. In order to make good on these promises, rapid action is required. Such action will draw from new tools and techniques to build resilience to climate- and weather-related risks, commonly referred to as climate-smart agriculture (CSA). CSA comprises agricultural systems that contribute to the outcomes of (1) sustainable and equitable increases in agricultural productivity and incomes; (2) greater resilience of food systems and farming livelihoods; and (3) where possible, reduction or removal (or both) of greenhouse gas emissions associated with agriculture (including the relationship between agriculture and ecosystems). The agricultural production systems created through CSA methodologies and practices are expected not only to be more productive and efficient but also to increase resilience to the short-, medium-, and long-term shocks and risks associated with climate change and climate variability. The operational aspects of CSA still need substantial investigation. Agricultural practices in particular may be climate smart in some circumstances, but local contexts determine the enabling environment, trade-offs, and synergies (Below et al. 2012). As a consequence, conditions for adoption are highly context and location specific, highlighting the need for information and data to make the approach operational (McCarthy, Lipper, and Branca 2011).

As the official monitoring and evaluation report for CAADP at the continent level, the *Annual Trends and Outlook Report* (ATOR) plays an important role in promoting review, dialogue, and mutual accountability in support of evidence-based policy making and implementation. And in light of the growing intensity and frequency of climate change effects, the 2016 ATOR takes an in-depth look at the role of CSA in helping to meet Malabo Declaration goals and, in particular, the goal of enhancing the resilience of livelihoods and production systems to climate variability. Through a series of contributions in key areas spanning the regional to the household level, the report offers significant insights into the state of our knowledge and understanding of the role that CSA can play for agricultural development under changing climate regimes.

Chapter 2 describes the context in which policy and investment decisions will have to take place, finding that in the years leading up to 2050, African countries will continue to grow, and many will reach middle-income status. As the agricultural sector grows, it will need to become technologically more sophisticated to withstand the vagaries of climate and market conditions. Key to future growth will be regionally tailored, evidence-based efforts to address increased regional market integration and the regional shifts in agroecological conditions.

The next two chapters analyze CSA in Africa south of the Sahara (SSA) for more traditional crop production systems and for mixed crop-livestock systems, respectively. Chapter 3 shows the benefits of CSA adoption but also its limits when the approach is interpreted in a restrictive way and applied only to crop production. Chapter 4, while providing an assessment of possible investments in CSA in SSA, proposes a framework to prioritize among CSA interventions. Both chapters reach the conclusion that although multiple wins are possible, "silver bullets" do not appear to exist in climate-smart systems.

Chapter 5 focuses on the role of CSA in the context of trade flows in three regional economic communities (RECs): the Economic Community of West African States (ECOWAS), the Common Market for Eastern and Southern Africa (COMESA), and the Southern African Development Community (SADC). Likely agroclimatic changes will not only impact agriculture but also countries' ability to fully benefit from regional and international trade, especially when rainfed-based agricultural commodities dominate trade flow. The authors find that CSA practices have the potential to mitigate climate-induced risks in agricultural production and food security through increased and less volatile agricultural trade flows.

Chapter 6 provides important insights into the promises and limits of production risk management through financial mechanisms. In particular, the authors investigate the role that weather index insurance can play in generating better adaptation pathways to weather shocks for smallholder farmers than existing ones. Evidence from several pilot insurance programs shows that although the potential for innovative insurance mechanisms is real, additional work to understand their effectiveness and substantial scale-up efforts will be needed to achieve a sustainable expansion of efficient agricultural insurance markets in Africa.

The next two chapters bring to our attention localized experiences related to the adoption of CSA. Chapter 7 goes to the heart of the location specificity of CSA by investigating the potential benefits of using precision agriculture in the Democratic Republic of the Congo, finding that this approach can boost sustainable productivity through increased efficiencies in the use of inputs. Even though the use of precision agriculture may still be many years away, we can extrapolate an important lesson that applies to many other African countries: increased use of fertilizers, coupled with increased efficiency in their use, can lead to an optimal response to the effects of climate change. Chapter 8 uses information from several SSA countries to revisit the long-standing problem of practices that demonstrably show both on-farm and off-farm benefits that outweigh investment costs, yet scarcely get adopted. This is clearly a problem that affects CSA as well.

The last two chapters broaden our understating of CSA by connecting it to ecosystems, gender, and nutrition. Chapter 9 tackles the nexus of CSA, gender, and nutrition, providing an integrated conceptual framework with entry points for action as well as information requirements to guide interventions in the context of climate change. The authors clearly argue that to go beyond incremental approaches to adaptation, these types of integrated approaches are essential in order to address the development challenges that the future climate creates.

Chapter 10 considers ecosystem-based adaptation and CSA as new paradigms that offer an integrated solution to maximizing the productivity of agriculture and food systems under changing climate regimes. The author posits that ecosystem-based adaptation and CSA offer an opportunity to break from traditional approaches and the silos that have limited the capacity for improving the food security condition of many.

This collection of studies shows the breadth and richness of the knowledge that is accumulating around the CSA approach. Although clearly there is still much to be investigated, the information available can already be used to assist African countries in the design and implementation of national agricultural investment plans that account for climate change.

As in previous ATORs, Chapter 11 tracks progress on CAADP indicators outlined in the CAADP Results Framework for 2015–2025 in the areas of economic growth, food and nutrition security, employment, poverty, agricultural production and productivity, intra-African trade and market performance, and public agriculture-sector expenditure. It also reviews countries' progress in the CAADP implementation process and in strengthening systemic capacity to deliver results. The ATOR concludes with Chapter 12, which highlights key policy recommendations for the CAADP/Malabo agenda. Finally, the report's appendixes provide aggregate-level data on the CAADP indicators, organized by geographic regions, regional economic communities, economic characteristics, and CAADP groups, showing when a CAADP compact was signed or the level of CAADP implementation reached.

CHAPTER 2

The Effects of Climate Change on Agriculture and Food Security in Africa

Keith Wiebe, Timothy B. Sulser, Daniel Mason-D'Croz, and Mark W. Rosegrant[1]

[1] This chapter draws on work conducted as part of the Global Futures and Strategic Foresight project, a CGIAR initiative led by the International Food Policy Research Institute, with support from the CGIAR Research Program on Policies, Institutions, and Markets; the CGIAR Research Program on Climate Change, Agriculture and Food Security; the Bill & Melinda Gates Foundation; the United States Agency for International Development; and others.

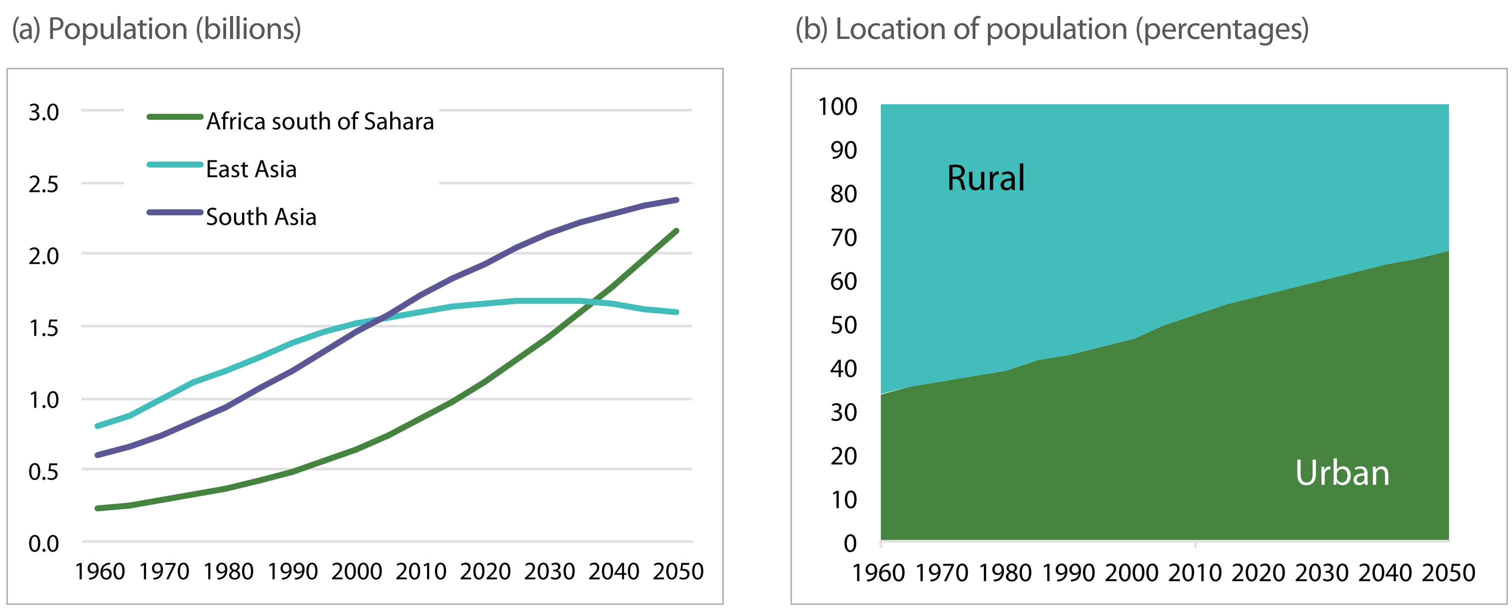
Climate change will play an increasingly important role in Africa, as elsewhere, during the course of the 21st century. Rising temperatures and increased frequency of extremely dry and wet years are expected to slow progress toward increased productivity of crop and livestock systems and improved food security, particularly in Africa south of the Sahara (FAO 2016). But other drivers of change in agriculture and food security are also changing in significant ways. In order to place the impacts of climate change in context, we look first at changes that affect demand for food and other agricultural commodities, and then at changes affecting supply.

Key Trends and Challenges for Agriculture and Food Security in Africa

Demand Side: Population, Income, Urbanization, and Globalization

On the demand side, a key factor that immediately distinguishes Africa from other regions of the world is population (Figure 2.1, panel [a]). The populations of East Asia and South Asia are projected to peak and then begin declining by the 2030s and 2050s, respectively, whereas the United Nations

FIGURE 2.1—CHANGES IN DEMOGRAPHICS WILL INFLUENCE THE LEVEL AND NATURE OF DEMAND FOR FOOD



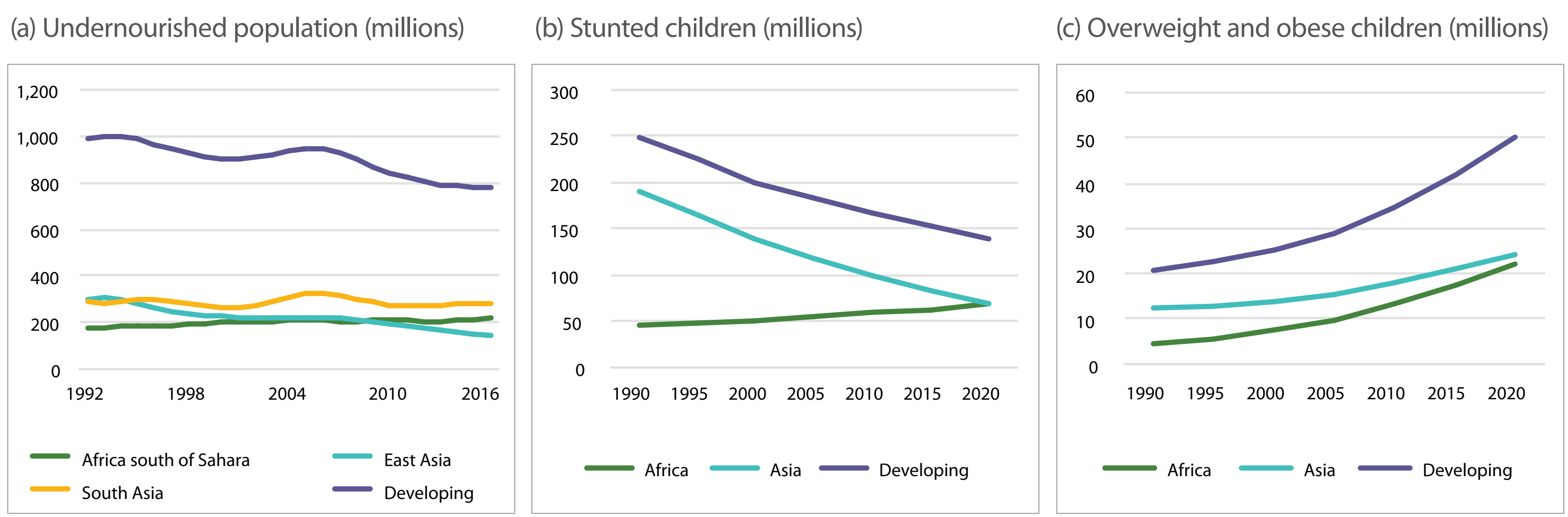
Source: United Nations, Department of Economic and Social Affairs, Population Division (2014, 2017).

projects that population in Africa will continue to grow rapidly throughout the 21st century. Africa's population is projected to exceed that of East Asia by the 2030s (at around 1.6 billion) and that of South Asia by midcentury (at around 2.3 billion). This growth will have direct effects on the demand for agricultural commodities, particularly staple food crops.

At the same time, Africa and other developing regions are projected to experience a continuing increase in per capita incomes (see, for example, Sulser et al. 2015) and a demographic shift from rural to urban areas, with two-thirds of the world's people living in urban areas by 2050 (Figure 2.1, panel [b]). Changing employment patterns, along with growth in incomes and increased globalization, have important implications for the nature of demand. Demand for traditional staples (excluding rice) is likely to slow in per capita terms as demand for purchased and processed foods increases.

These changing patterns of consumption affect food security and nutrition in diverse ways. Cheaper calories have reduced the number of undernourished people and of stunted children in much of the developing world but have not kept pace with population growth in Africa (Figure 2.2, panels [a] and [b]). At the same time, the number of overweight and obese children has increased in all regions, including Africa (Figure 2.2, panel [c]). Rising incomes improve access to higher-value foods such as fruits, vegetables, and animal-source foods for many, but these foods remain beyond reach for the poorest.

FIGURE 2.2—UNDERNOURISHMENT REMAINS A CHALLENGE IN AFRICA, EVEN WHILE OVERCONSUMPTION INCREASES



Source: FAO (2017); de Onis, Blossner, and Borghi (2010, 2012).

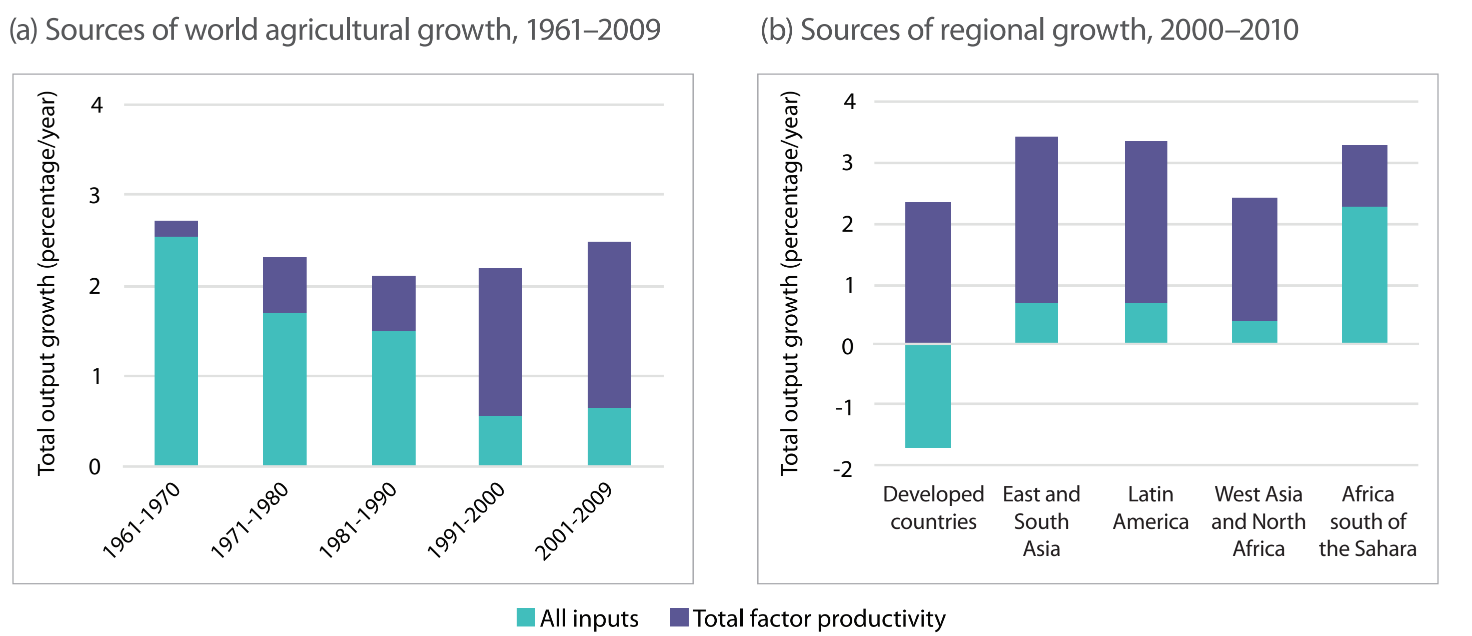
Supply Side: Land, Water, Infrastructure, and Technology

Whereas the level and composition of demand changes with population, income, and other factors, changes in natural resources and technology present new challenges and opportunities in meeting that demand. Over the past half century, growth in world agriculture has been driven increasingly by increases in total factor productivity, or the efficiency with which inputs such as land, water, and fertilizer are used (Figure 2.3, panel [a]). This is true in all regions except Africa south of the Sahara, where growth continues to be driven primarily by increases in agricultural inputs (Figure 2.3, panel [b]).

Because irrigation and commercial fertilizer use remain low in Africa south of the Sahara, soil nutrients are being depleted in many areas and crop yields also remain low. Cereal yields in Africa average about 1.5 tons[2] per hectare—only half of those in South Asia and 20–25 percent of those in East Asia and North America (Figure 2.4)—and maize yields represent only 20–50 percent of potential yields in the region (van Ittersum et al. 2016). These figures illustrate the challenge faced by the region but also the potential to be realized from improvements in productivity through increased investment in agricultural research, resource use efficiency, and infrastructure. We will return to these potential returns later.

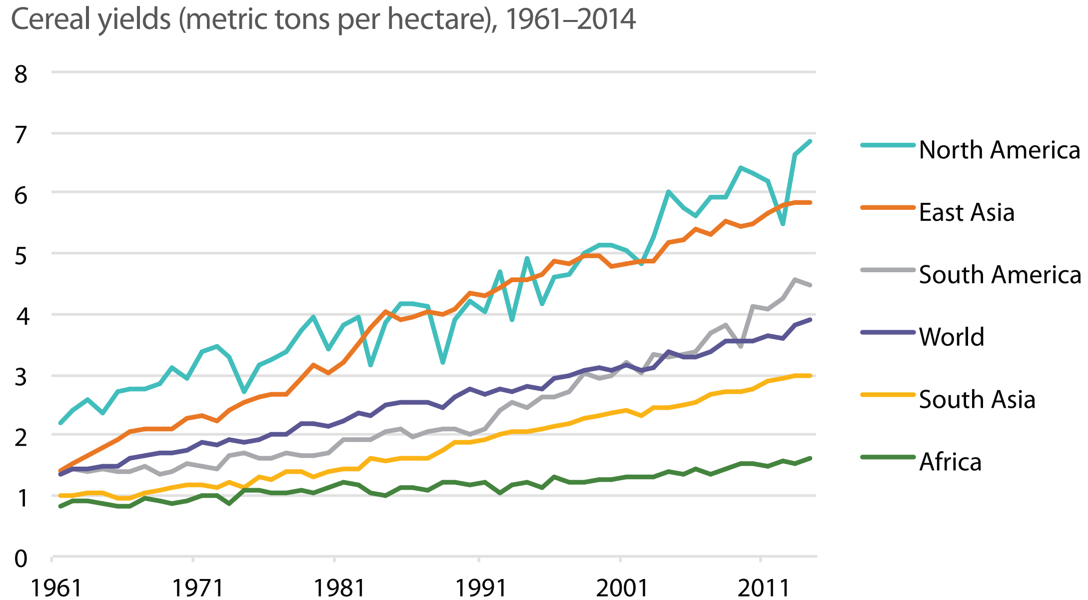
2 Throughout the chapter, *tons* refers to metric tons.

FIGURE 2.3—AFRICA LAGS BEHIND OTHER REGIONS IN AGRICULTURAL PRODUCTIVITY GROWTH



Source: Fuglie and Wang (2012), Fuglie and Rada (2013).

FIGURE 2.4—CROP YIELDS IN AFRICA REMAIN A FRACTION OF THOSE IN OTHER PARTS OF THE WORLD



Source: FAO (2017).

The Special Challenge of Climate Change

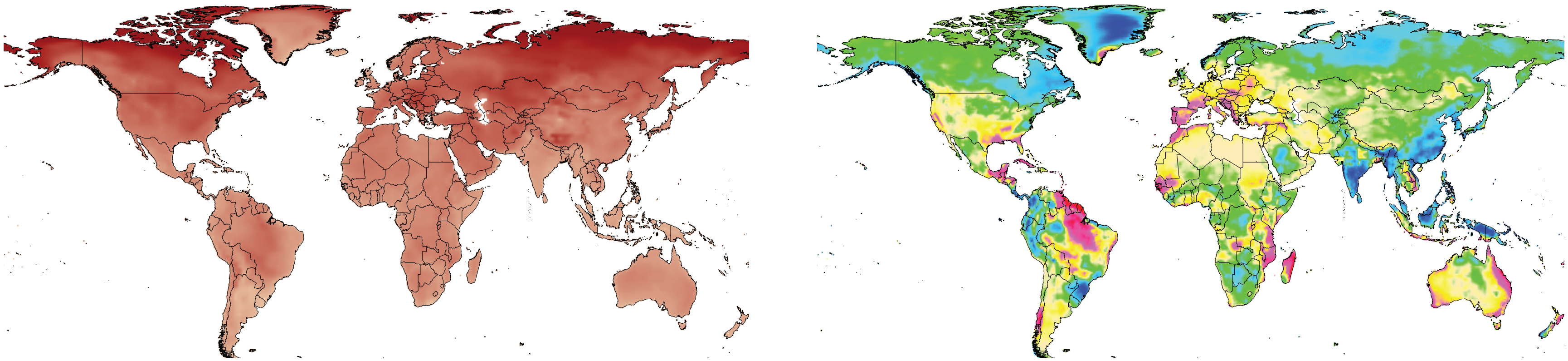
Compounding the effects of rising population and low productivity, climate change will present new challenges to Africa's farmers and consumers. Projections of impacts depend on general circulation models of Earth's climate and assumptions about the rate of change in greenhouse gas emissions in the coming decades. Details vary depending on the climate model and scenario considered, with general agreement on rising temperatures (Figure 2.5, panel [a]) but less consensus on how precipitation patterns will change (Figure2.5, panel [b]).

The combination of rising temperatures and changing precipitation patterns is projected to result in a wide range of impacts, including increases in weather volatility and extreme events, rising sea levels, changes in glacial meltwater flows (initially increasing and ultimately declining), changes in the incidence of agricultural pests and diseases, and direct effects on crop productivity. Many of these impacts are beyond our current ability to model at the global scale, but we are able to simulate the impact of expected changes in temperature and precipitation on crop yields at the local, regional, and global levels. To do so, we use projections from global climate models as inputs in crop simulation models such as the Decision Support

FIGURE 2.5—TEMPERATURES ARE PROJECTED TO RISE AND PRECIPITATION PATTERNS TO CHANGE

(a) Increase in temperature, 2050 relative to 2000

(b) Change in annual precipitation, 2050 relative to 2000



Source: Rosegrant and colleagues (2017), using the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model, assuming representative concentration pathway (RCP) 8.5.

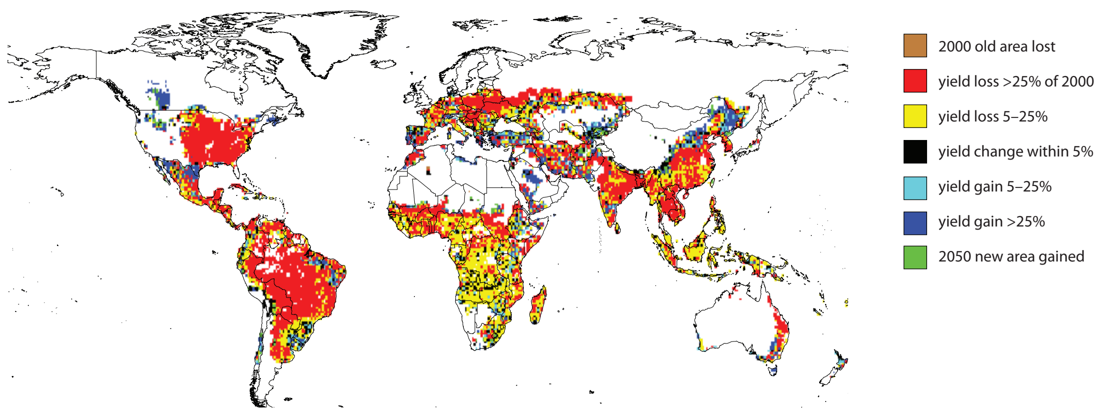
Note: The color gradient in panel (a) shows increases in maximum temperature in 2050 relative to 2000, from < 0˚C (white) to > 6˚C (dark red). The color gradient in (b) shows changes in annual precipitation in 2050 relative to 2000, from < -400 mm (dark red) to > 400 mm (dark blue).

System for Agrotechnology Transfer (DSSAT) to simulate impacts on yields under different climate scenarios. The results presented here are based on a scenario using the United Kingdom's Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones et al. 2011) and assuming relatively rapid increases in greenhouse gas emissions combined with middle-of-the-road assumptions about growth in population and incomes.[3] These results thus represent the impacts of relatively large changes in temperature and precipitation, but they omit the other dimensions of climate change noted above.

Yields of rainfed maize, for example, are projected to decline by as much as 25 percent or more in some regions under this scenario by 2050, relative to 2000 levels (Figure 2.6). It is essential to note that this projection is based on crop modeling that holds everything else constant—that is, it assumes that farmers continue to grow the same varieties in the same locations on the same planting calendar and using the same management practices. But we know that farmers won't continue to do everything the same as before—not only because they will respond to changing climate conditions but also because market conditions and technologies will also be changing in the coming decades.

[3] Specifically, these results assume climate change as represented by representative concentration pathway (RCP) 8.5 and shared socioeconomic pathway (SSP) 2. See Moss and others (2008) and O'Neill and others (2014) for more information.

FIGURE 2.6—MAIZE YIELDS WILL BE HARD HIT BY CLIMATE CHANGE (YIELDS EXPRESSED AS PERCENTAGE OF 2000 LEVELS)



Source: Robertson (2015).

Note: Decision Support System for Agrotechnology Transfer (DSSAT) crop model results for rainfed maize based on the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) model and representative concentration pathway (RCP) 8.5 for 2050, before economic adjustments.

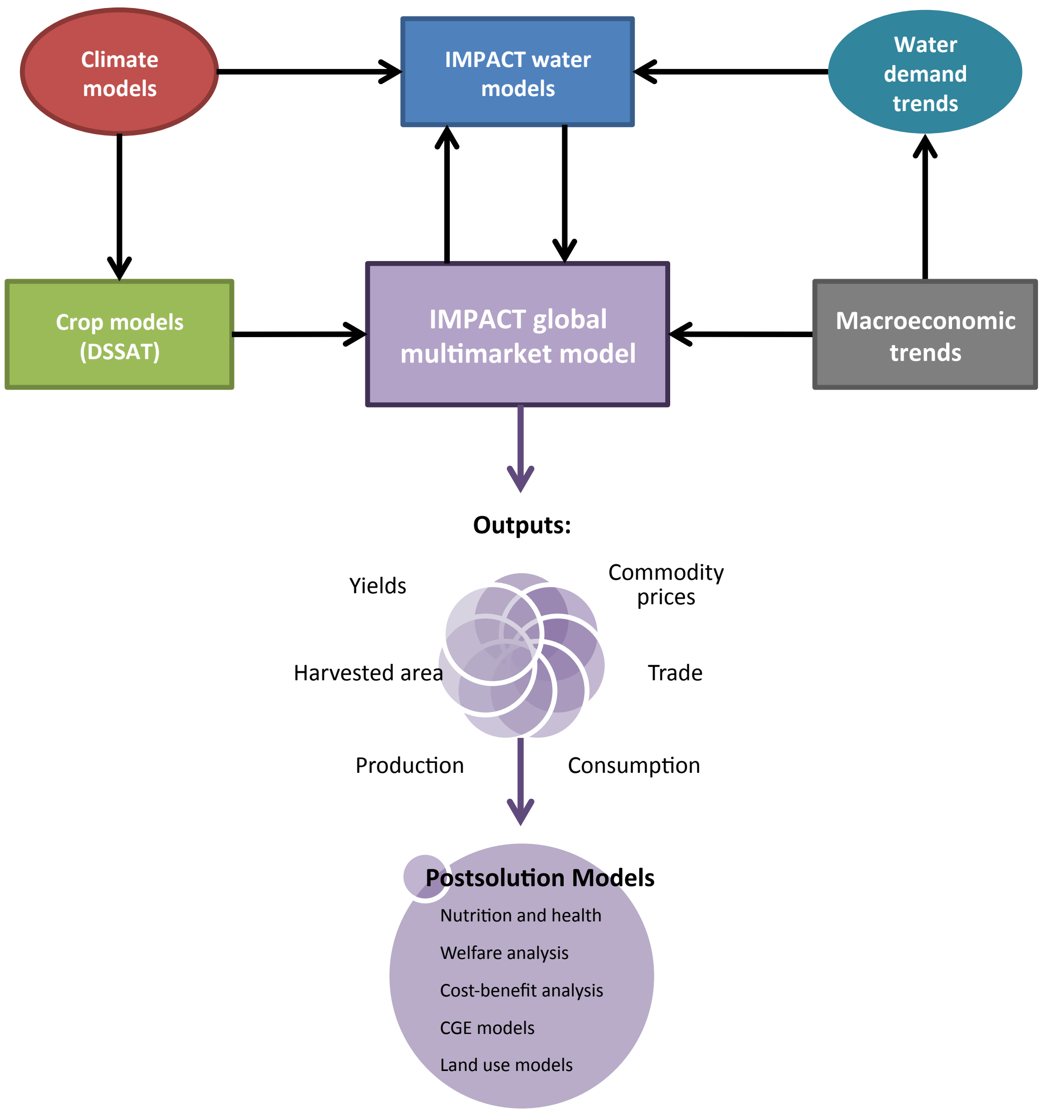
This chapter explores the future impacts of these various changes, incorporating economic adjustments. The following sections present baseline projections for agriculture and food in Africa to 2050 based on changes in the driving factors described here, and then explore how these projected outcomes can be changed by decisions we make today, specifically in relation to investment in agricultural research, natural resource management, and infrastructure.

Baseline Projections for Production, Area, Yield, Consumption, Prices, Trade, Hunger, and the Environment to 2050

The IMPACT System of Models

To explore how changes in population, income, technology, climate, investment, and policy will affect agriculture and food in Africa in the coming decades, we use a system of models developed by the International Food Policy Research Institute (IFPRI), called the International Model for Policy

FIGURE 2.7—THE IMPACT SYSTEM OF MODELS



Source: Robinson and others (2015).

Note: CGE = computable general equilibrium; DSSAT = Decision Support System for Agrotechnology Transfer; IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

Analysis of Agricultural Commodities and Trade (IMPACT) (Figure 2.7). IMPACT is a linked system of climate, water, crop, and economic models designed to explore the impacts of changes in population, income, technology, climate, and other factors on agricultural production, resource use, trade, and food security (Rosegrant et al. 2008). IMPACT has been further developed in recent years through ongoing collaboration among the 15 CGIAR Centers and with other climate, crop, and economic modeling groups through the Agricultural Model Intercomparison and Improvement Project (Robinson et al. 2015).[4]

Baseline Projections for Africa South of the Sahara

Using the IMPACT model with standard assumptions on changes in population, income, and climate as reflected in shared socioeconomic pathway (SSP) 2 and representative concentration pathway (RCP) 8.5, together with moderate growth in agricultural productivity, IFPRI recently released a new set of baseline projections of agricultural production, food consumption, trade, and risk of hunger in its *2017 Global Food Policy Report* (IFPRI 2017). Selected results from those projections

4 More details on the IMPACT model and methodology can be found at www.ifpri.org/program/impact-model.

TABLE 2.1— IMPACT PROJECTIONS OF CEREAL AND MEAT PRODUCTION, CONSUMPTION, AND TRADE TO 2050

Food group / region	Total production (million metric tons)					Per capita food consumption (kg per capita per year)					Net trade (million metric tons)				
	Without climate change			With climate change		Without climate change			With climate change		Without climate change			With climate change	
	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050
Cereals															
World	**2,155**	**2,746**	**3,235**	**2,621**	**2,990**	**143.5**	**146.7**	**148.3**	**143.4**	**140.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**151**	**230**	**303**	**220**	**279**	**139.9**	**143.8**	**145.9**	**138.9**	**136.2**	**-59.7**	**-106.6**	**-185.0**	**-103.2**	**-169.2**
West	49	79	110	75	99	143.5	152.4	155.3	146.9	144.8	-13.7	-29.8	-60.3	-29.1	-56.9
Central	7	12	18	12	17	59.3	65.4	68.9	62.4	63.0	-3.1	-6.3	-11.8	-5.9	-10.5
East	39	65	91	64	91	115.7	125.6	134.1	119.7	123.1	-8.7	-17.1	-31.9	-13.7	-21.8
Southern	13	18	21	19	23	182.8	194.8	201.5	187.5	187.3	-3.5	-7.1	-12.5	-4.6	-7.2
Northern	42	55	62	49	50	204.7	202.5	198.7	199.6	191.0	-30.6	-46.4	-68.5	-49.9	-72.8
Meats															
World	**274**	**381**	**460**	**380**	**455**	**39.4**	**45.6**	**49.5**	**45.4**	**49.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**14**	**27**	**45**	**27**	**45**	**14.7**	**20.1**	**28.4**	**20.0**	**28.1**	**-0.9**	**-3.9**	**-12.4**	**-3.8**	**-11.9**
West	3	6	11	6	11	10.2	16.2	26.6	16.1	26.3	-0.3	-1.9	-7.3	-1.9	-7.1
Central	1	1	2	1	2	9.1	12.2	17.0	12.1	16.8	-0.4	-1.0	-2.1	-1.0	-2.0
East	3	6	10	6	10	10.3	14.4	22.5	14.3	22.2	0.0	-1.1	-4.9	-1.1	-4.7
Southern	2	4	5	4	5	45.2	61.0	73.3	60.8	72.7	-0.2	-0.1	-0.1	-0.1	-0.1
Northern	5	10	17	10	17	22.6	32.0	42.9	31.9	42.7	0.0	0.3	2.0	0.3	2.0
Fruits and vegetables															
World	**1,592**	**2,334**	**3,044**	**2,297**	**2,945**	**196.2**	**240.0**	**284.7**	**236.2**	**275.5**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**153**	**276**	**435**	**255**	**378**	**121.8**	**141.7**	**166.5**	**139.1**	**160.2**	**2.2**	**12.8**	**22.1**	**-3.1**	**-18.4**
West	40	74	118	70	106	117.2	145.3	174.4	142.4	167.9	0.3	-3.5	-14.8	-6.0	-22.1
Central	10	17	27	16	22	66.0	82.4	103.1	80.2	97.7	0.1	-1.3	-4.4	-2.5	-7.5
East	36	70	121	65	107	82.2	105.5	138.5	103.2	132.4	-1.2	-5.4	-12.9	-8.1	-20.3
Southern	9	15	21	14	17	76.2	89.2	98.3	87.4	94.3	2.9	6.4	10.1	5.2	7.2
Northern	57	99	149	90	126	228.9	250.1	270.3	246.7	262.9	0.0	16.5	44.1	8.3	24.4

Source: IMPACT version 3.3 results from IFPRI (2017).

Notes: World figures include other regions not reported separately. Country-level details are available online at https://dataverse.harvard.edu/dataverse/impact. Total production is aggregated across irrigated and rainfed systems at the national level and aligned with years as reported in FAOSTAT, the statistical database of the Food and Agriculture Organization of the United Nations. Per capita food consumption is based on food availability at the national level. Net trade includes negative and positive numbers indicating that a region is a net importer or exporter, respectively, and balances to 0 at the global level. Cereals include barley, maize, millet, rice, sorghum, wheat, and aggregated other cereals. Meats include beef, pork, poultry, and sheep and goats. Fruits and vegetables include bananas, plantains, aggregated temperate fruits, aggregated tropical fruits, and aggregated vegetables. Oilseeds include groundnut, rapeseed, soybean, sunflower, and aggregated other oilseeds. Pulses include beans, chickpeas, cowpeas, lentils, pigeon peas, and aggregated other pulses. Roots and tubers include cassavas, potatoes, sweet potatoes, yams, and aggregated other roots and tubers. Values reported for 2010 are calibrated model results. Projections for 2030 and 2050 assume changes in population and income as reflected in the Intergovernmental Panel on Climate Change's (IPCC's) shared socioeconomic pathway (SSP) 2. Climate change impacts are simulated using the IPCC's representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model. Further documentation is available at www.ifpri.org/program/impact-model. IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

TABLE 2.1— IMPACT PROJECTIONS OF CEREAL AND MEAT PRODUCTION, CONSUMPTION, AND TRADE TO 2050, *continued*

Food group / region	Total production (million metric tons)					Per capita food consumption (kg per capita per year)					Net trade (million metric tons)				
	Without climate change			With climate change		Without climate change			With climate change		Without climate change			With climate change	
	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050
Oilseeds															
World	**673**	**1,033**	**1,293**	**1,017**	**1,257**	**6.8**	**8.2**	**7.8**	**7.9**	**7.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**56**	**94**	**118**	**91**	**110**	**5.7**	**6.7**	**7.5**	**6.4**	**6.9**	**-1.2**	**-2.7**	**-6.3**	**-2.4**	**-5.4**
West	43	74	94	72	88	8.1	9.3	10.1	8.8	9.2	0.3	-0.5	-2.7	-0.4	-2.5
Central	4	6	8	6	7	9.0	10.0	10.6	9.4	9.5	0.1	0.1	0.1	0.2	0.4
East	4	6	7	6	7	3.7	4.4	5.3	4.2	4.8	0.1	-0.3	-1.3	-0.2	-0.9
Southern	1	1	2	1	1	1.9	2.1	2.1	2.0	2.0	-0.2	-0.3	-0.3	-0.2	-0.2
Northern	4	6	7	5	6	4.6	5.3	5.7	5.1	5.3	-1.5	-1.8	-2.2	-1.7	-2.1
Pulses															
World	**66**	**94**	**121**	**92**	**118**	**6.2**	**7.5**	**8.9**	**7.5**	**8.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**13**	**20**	**30**	**20**	**28**	**10.0**	**12.0**	**14.3**	**11.8**	**14.0**	**-1.7**	**-5.2**	**-11.1**	**-5.4**	**-11.5**
West	5	9	16	9	14	8.5	9.8	11.6	9.6	11.1	0.3	0.1	-0.3	0.0	-0.6
Central	1	2	2	2	2	6.7	7.4	8.7	7.3	8.4	-0.1	-0.2	-0.3	-0.2	-0.2
East	5	7	9	7	10	15.3	18.2	22.0	18.0	21.6	-0.7	-3.3	-7.9	-3.2	-7.5
Southern	0	0	0	0	0	3.8	4.2	4.5	4.1	4.4	-0.1	-0.1	0.0	-0.1	0.0
Northern	1	2	2	1	2	8.2	9.7	11.4	9.8	11.5	-1.1	-1.8	-2.6	-2.1	-3.2
Roots and tubers															
World	**780**	**1,006**	**1,185**	**963**	**1,103**	**65.0**	**70.5**	**73.4**	**67.8**	**69.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Africa	**232**	**362**	**506**	**346**	**469**	**129.0**	**138.0**	**143.7**	**134.4**	**137.0**	**-0.7**	**-10.2**	**-28.3**	**-15.1**	**-37.8**
West	133	207	297	201	281	197.5	199.0	198.8	194.9	191.1	1.5	-4.3	-11.7	-4.2	-10.2
Central	37	59	80	56	72	172.5	170.6	166.7	167.1	159.9	1.0	2.6	-2.2	0.1	-8.2
East	50	78	107	71	91	129.6	138.5	142.0	134.6	134.4	-3.2	-9.4	-15.3	-13.9	-24.6
Southern	3	4	5	4	5	36.8	37.7	38.7	36.6	37.1	0.0	0.7	1.3	0.9	1.3
Northern	9	14	18	15	20	33.7	38.3	42.1	35.7	37.9	-0.1	0.2	-0.3	2.0	4.0

Source: IMPACT version 3.3 results from IFPRI (2017).

Notes: World figures include other regions not reported separately. Country-level details are available online at https://dataverse.harvard.edu/dataverse/impact. Total production is aggregated across irrigated and rainfed systems at the national level and aligned with years as reported in FAOSTAT, the statistical database of the Food and Agriculture Organization of the United Nations. Per capita food consumption is based on food availability at the national level. Net trade includes negative and positive numbers indicating that a region is a net importer or exporter, respectively, and balances to 0 at the global level. Cereals include barley, maize, millet, rice, sorghum, wheat, and aggregated other cereals. Meats include beef, pork, poultry, and sheep and goats. Fruits and vegetables include bananas, plantains, aggregated temperate fruits, aggregated tropical fruits, and aggregated vegetables. Oilseeds include groundnut, rapeseed, soybean, sunflower, and aggregated other oilseeds. Pulses include beans, chickpeas, cowpeas, lentils, pigeon peas, and aggregated other pulses. Roots and tubers include cassavas, potatoes, sweet potatoes, yams, and aggregated other roots and tubers. Values reported for 2010 are calibrated model results. Projections for 2030 and 2050 assume changes in population and income as reflected in the Intergovernmental Panel on Climate Change's (IPCC's) shared socioeconomic pathway (SSP) 2. Climate change impacts are simulated using the IPCC's representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model. Further documentation is available at www.ifpri.org/program/impact-model. IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

are presented in Tables 2.1 and 2.2.[5] Given the complexity and uncertainty inherent in the underlying processes involved, it is important to note that projections vary depending on the specific models and assumptions used. Those presented here represent current baselines with and without climate change, but work is under way to analyze a wider range climate and socioeconomic assumptions (Wiebe et al. 2015).

Cereal production is projected to double in Africa south of the Sahara by midcentury, but production in 2050 will be about 5 percent less than it would have been in the absence of climate change. (These results assume moderate growth in agricultural productivity—an assumption that can be adjusted according to decisions made regarding investment in agricultural research and development.) Net imports of cereals in the region are projected to increase threefold relative to 2010 levels. Perhaps counterintuitively, net cereal imports into the region are projected to be lower in 2050 with climate change than they would have been in the absence of climate change. This is because in this scenario, based on climate results from HadGEM2-ES, temperature increases and changes in precipitation reduce growth in production by the major cereal-producing and -exporting countries in the Americas and Europe (Figure 2.6), thereby raising prices.[6] Higher prices will in turn reduce cereal imports by African and other developing countries. The

5 The full set of results can be found online at https://dataverse.harvard.edu/dataverse/impact.

6 Increased levels of atmospheric carbon dioxide increase plant productivity under certain circumstances and may partially offset some adverse impacts of climate change, but their effects are sensitive to other factors and remain controversial (Nowak 2017; Obermeier and colleagues 2016), and therefore they are not included in the scenarios described here.

TABLE 2.2— IMPACT PROJECTIONS OF FOOD PRODUCTION, CONSUMPTION, AND HUNGER TO 2050

Region	Aggregate food production (index, 2010 = 1.00)					Per capita food consumption (KCAL per capita per day)					Hunger (millions of people at risk)				
	Without climate change			With climate change		Without climate change			With climate change		Without climate change			With climate change	
	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050	2010	2030	2050	2030	2050
World	**1.00**	**1.37**	**1.69**	**1.33**	**1.60**	**2,795**	**3,032**	**3,191**	**2,982**	**3,079**	**838.1**	**528.2**	**405.8**	**592.3**	**476.9**
Africa	**1.00**	**1.63**	**2.32**	**1.55**	**2.12**	**2,505**	**2,709**	**2,947**	**2,642**	**2,810**	**215.5**	**202.2**	**157.4**	**229.7**	**196.0**
West	1.00	1.65	2.36	1.59	2.19	2,637	2,853	3,056	2,778	2,909	30.1	28.0	29.0	32.5	33.5
Central	1.00	1.66	2.33	1.56	2.07	2,101	2,432	2,843	2,366	2,701	52.3	36.5	21.2	43.2	25.4
East	1.00	1.68	2.50	1.59	2.28	2,110	2,345	2,629	2,273	2,488	112.1	115.6	89.2	130.6	116.3
Southern	1.00	1.50	1.87	1.49	1.81	2,881	3,134	3,308	3,059	3,165	3.8	3.0	2.3	3.3	2.8
Northern	1.00	1.56	2.14	1.43	1.85	3,029	3,182	3,360	3,137	3,254	17.2	19.1	15.9	20.2	18.0

Source: IMPACT version 3.3 results from IFPRI (2017).

Notes: World figures include other regions not reported separately. Country-level details are available online at https://dataverse.harvard.edu/dataverse/impact. Aggregate food production is an index, by weight, of cereals, meats, fruits and vegetables, oilseeds, pulses, and roots and tubers (which are reported separately in Table 2.1). Per capita food consumption is a projection of daily dietary energy supply in kilocalories. Estimates of the number of people at risk of hunger are based on a quadratic specification of the relationship between national-level calorie supply and the share of population that is undernourished as defined by the Food and Agriculture Organization of the United Nations. Values reported for 2010 are calibrated model results. Projections for 2030 and 2050 assume changes in population and income as reflected in the Intergovernmental Panel on Climate Change's (IPCC's) shared socioeconomic pathway (SSP) 2. Climate change impacts are simulated using the IPCC's representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model. Further documentation is available at www.ifpri.org/program/impact-model. IMPACT = International Model for Policy Analysis of Agricultural Commodities and Trade.

combined impact of increased population, slower growth in production due to climate change, and imports that are lower than they would have been in the absence of climate change means that per capita consumption of cereals will remain basically unchanged in the region in 2050 relative to 2010.

Meat production in Africa south of the Sahara is projected to grow by around 24 million tons (a threefold increase) by 2050, and net imports are projected to grow from less than 1 million tons to around 13 million tons, resulting in a doubling of per capita meat consumption.

Pulse production in the region is projected to more than double, and net imports are projected to grow from less than 1 million tons to around 9 million tons. Per capita consumption is projected to rise by about a third.

Root and tuber production in the region is projected to double, and net imports are projected to grow from around 1 million tons to 43 million tons by 2050. Per capita consumption will remain basically unchanged, at around 150 kg per capita per year.

Oilseed production will also double, to 105 million tons, with a small increase in net imports, to around 4 million tons, and relatively little change in per capita consumption.

Fruit and vegetable production in the region is projected to increase by 1.6 times by 2050, and per capita consumption by half. The region is projected to become a net importer of fruits and vegetables, with about one-quarter of total demand being met by imports.

Based on the combined effects of changes in population, income, climate, and productivity, the number of people at risk of hunger in Africa south of the Sahara is projected to decline from 209.5 million in 2010 to 188.7 million in 2050 in this scenario (Table 2.2). Projected improvements are greatest in central Africa, with slight increases in the number at risk in eastern and western Africa. Climate change reduces the improvement that would be projected in the absence of climate change, leaving 38 million more people at risk of hunger in Africa south of the Sahara in 2050 than would otherwise be the case, most of them in eastern Africa. And the malnutrition rate for children younger than five years (as measured by wasting) is projected to rise from 21.7 to 24.4 percent by 2050—an increase of more than 4 million children (Waithaka et al. 2013; Jalloh et al. 2013; Hachigonta et al. 2013; Thomas and Rosegrant 2015).

Gains from Improvements in Productivity, Resource Management, and Infrastructure

Adoption of Improved Agricultural Technologies for Sustainable Intensification

Rosegrant and colleagues (2014) analyzed a wide range of agricultural technologies selected for their potential to improve productivity while reducing adverse environmental impacts. Approaches ranging from new stress-tolerant crop varieties to no-till and precision agriculture were simulated worldwide for maize, rice, and wheat crops, under a warmer and wetter future climate scenario.

In Africa south of the Sahara, among the technologies considered, no-till farming and nitrogen-efficient crop varieties show the greatest promise under a warmer and wetter climate in 2050, compared with a scenario without adoption of those technologies (Table 2.3). Overall, rice yields in Africa south of the Sahara receive the largest boost through the use of nitrogen-use-efficient varieties (+21 percent), whereas no-till farming is the most favorable technology for both maize (+15 percent) and wheat (+17 percent).

Increased production and lower prices due to adoption of improved technologies translates into better access to food, and simulations show a potential reduction in the population at risk of hunger of up to 11 percent in Africa south of the Sahara (Figure 2.8).

Islam and others (2016) also examined the potential impact of adoption of drought- and heat-tolerant crop varieties, including maize and groundnuts, in selected countries of Africa south of the Sahara. They found that in many cases the new technologies are projected to more than offset the adverse impacts of climate change on yields for those crops and countries—at least through the duration of the projected period (to 2050). Farmers and countries that adopt the new technologies improve their productivity faster than projected increases in demand, which improves those countries' terms of trade.

Although such technologies show promise in terms of increased productivity and food security, their adoption, particularly by poor smallholder farmers in Africa south of the Sahara, is often limited by well-known barriers in the form of poor access to resources; information; and markets for inputs, outputs, and risk-management tools. Overcoming these barriers will require major investment in research and technology as well as in the institutional and physical infrastructure

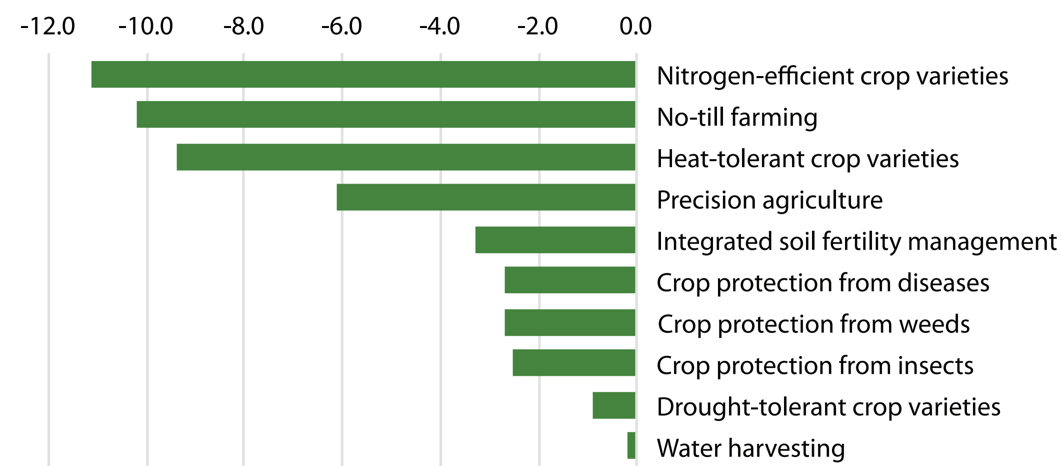
TABLE 2.3—PERCENTAGE CHANGE IN YIELDS FOR MAIZE, RICE, AND WHEAT IN AFRICA SOUTH OF THE SAHARA, COMPARED WITH BASELINE WITHOUT ADOPTION OF IMPROVED TECHNOLOGIES, 2050

Technology	Maize	Rice	Wheat
Nitrogen-efficient crop varieties	7.9	20.9	4.4
No-till farming	15.0	-0.4	17.1
Heat-tolerant crop varieties	3.5	0.2	4.5
Precision agriculture	-0.6	7.9	6.2
Integrated soil fertility management	5.8	5.7	6.1
Crop protection from diseases	4.4	10.5	2.6
Crop protection from weeds	6.5	10.3	2.1
Crop protection from insects	4.9	11.7	1.9
Drought-tolerant crop varieties	3.5	0.4	2.6
Water harvesting	0.6	0.0	0.9

Source: Rosegrant and colleagues (2014).

Note: International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) simulations under Model for Interdisciplinary Research on Climate (MIROC) scenario A1B (a wetter and warmer climate).

FIGURE 2.8—PERCENTAGE CHANGE IN POPULATION AT RISK OF HUNGER IN AFRICA SOUTH OF THE SAHARA, COMPARED WITH BASELINE WITHOUT ADOPTION OF IMPROVED TECHNOLOGIES, 2050



Source: Rosegrant and colleagues (2014).

Note: International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) simulations under Model for Interdisciplinary Research on Climate (MIROC) scenario A1B (a wetter and warmer climate).

needed to improve access to new opportunities. Recent findings on the impacts of such investments are described in the next section.

Investment in Productivity-Enhancing Research and Development, Water Management, and Infrastructure

A recent analysis by Rosegrant and colleagues (2017) in collaboration with the 15 CGIAR Centers examined three sets of alternative investment scenarios for the developing world, each of which increases investment in one of the areas described in the previous section. A fourth comprehensive scenario combines elements from the first three:

1. Enhanced productivity through increased investments in agricultural research and development (R&D). Five scenarios explore the impacts of different levels of increased investment in research by CGIAR and national agricultural research systems, with different regional emphases, to help overcome the disparities in productivity growth evident in Figure 2.4, particularly in Africa south of the Sahara and South Asia.
2. Improved water resource management. Three scenarios explore the impacts of increased investment to expand irrigated area, increase water use efficiency, and increase the water-holding capacity of soil.
3. Improved marketing efficiency through increased investment in infrastructure. One scenario explores the impact of increased investment in transportation and marketing infrastructure to reduce price margins between producers and consumers.
4. A comprehensive scenario combining selected elements of 1–3.

Scenarios were run to 2050, but we focus here on results for 2030, which is the time frame for the Sustainable Development Goals. Globally, we project that crop yields would increase by 30 percent, on average, by 2030 over 2010 levels in a baseline scenario without climate change or additional investments, but climate change is projected to reduce this increase to 25 percent (Table 2.4). The comprehensive portfolio of investments in agricultural research, improved resource management, and improved infrastructure (#4 in the list above) would more than offset the adverse impacts of climate change through 2030 and would increase average crop yields by 35 percent over 2010 levels.[7] (Note that adverse impacts of climate change, though already occurring, are relatively modest through 2030 and even through midcentury, but are projected to accelerate thereafter.)

Similar patterns are projected for developing countries and for Africa, with average yield increases of 32–43 percent by 2030 in the absence of climate change, reductions of 4–9 percentage points due to climate change, and overall increases of 40–56 percent with a comprehensive investment portfolio. With such investment, yields in Africa are projected to grow more rapidly than those in other developing regions, with average increases of 47–56 percent, compared with 40 percent for developing countries as a whole and 35 percent globally.

Based on these increased yields (together with smaller increases in cropland area), food availability in terms of dietary energy is projected to increase by 2030 globally and in all regions of Africa (Table 2.5). The overall

7 Increasing investment in agricultural R&D, resource use efficiency, and marketing efficiency separately rather than as part of a comprehensive package would cost less but would also offer lower benefits. In some cases it would also generate trade-offs between different goals, for example in the case of improved marketing efficiency, which would increase agricultural production and lower food prices but also expand forestland conversion and greenhouse gas emissions. More on these scenarios can be found in Rosegrant and colleagues (2017).

TABLE 2.4—AVERAGE CROP YIELDS IN 2030 (INDEXED, 2010 = 1.0), BY REGION AND SCENARIO

Region	2010	2030, no CC	2030, CC	2030, COMP
World	1.00	1.30	1.25	1.35
Developing countries	1.00	1.32	1.28	1.40
Africa	1.00	1.35	1.28	1.51
Northern Africa	1.00	1.35	1.24	1.48
Africa south of the Sahara	1.00	1.35	1.28	1.52
Western Africa	1.00	1.36	1.30	1.53
Eastern Africa	1.00	1.38	1.31	1.56
Central Africa	1.00	1.32	1.23	1.47
Southern Africa	1.00	1.43	1.40	1.54

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above.

pattern is similar to that of crop yields, with projected increases slowed by climate change but adverse climate impacts offset by the effects of increased investment. In the latter case, kilocalorie availability per capita per day is projected to increase by more than 10 percent, to 2,834, for Africa as a whole, with subregional averages ranging from around 2,500 kilocalories per capita per day in eastern and central Africa to more than 3,000 kilocalories per capita per day in northern, southern, and western Africa.

Because of rapid population growth, the prevalence of hunger declines only slightly by 2030 in the case of no climate change, and actually increases in the climate change baseline (Table 2.6). Increased investment is projected to reduce the number of people at risk of hunger in Africa, in terms of average caloric deficiency, to 161 million by 2030, representing a decline of

TABLE 2.5—AVERAGE FOOD SUPPLY (KILOCALORIES PER CAPITA PER DAY) IN 2010 AND 2030, BY REGION AND SCENARIO

Region	2010	2030, no CC	2030, CC	2030, COMP
World	1.00	1.30	1.25	1.35
Developing countries	1.00	1.32	1.28	1.40
Africa	1.00	1.35	1.28	1.51
Northern Africa	1.00	1.35	1.24	1.48
Africa south of the Sahara	1.00	1.35	1.28	1.52
Western Africa	1.00	1.36	1.30	1.53
Eastern Africa	1.00	1.38	1.31	1.56
Central Africa	1.00	1.32	1.23	1.47
Southern Africa	1.00	1.43	1.40	1.54

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above. The horizontal axis at 1,800 kilocalories per capita per day represents the daily minimum requirement; 2,400 is the recommended daily consumption for an active 20- to 35-year-old female and 3,000 is the recommended daily consumption for an active 20- to 35-year-old male.

TABLE 2.6—PREVALENCE OF HUNGER IN 2010 AND 2030 (MILLIONS OF PEOPLE)

Region	2010	2030, no CC	2030, CC	2030, COMP
World	838	528	598	416
Developing countries	823	513	582	403
Africa	215	202	231	161
Northern Africa	17	19	20	16
Africa south of the Sahara	209	196	224	155
Western Africa	30	28	33	22
Eastern Africa	112	116	131	98
Central Africa	52	36	43	23
Southern Africa	4	3	3	3

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above.

30 percent relative to 2010 levels, with the largest numeric improvement (33 million) in eastern Africa and the largest percentage improvement (nearly 50 percent) in central Africa.

The share of the population at risk of chronic hunger is projected to remain at more than 10 percent in Africa by 2030 in the absence of climate change (Table 2.7). The share is lower in western and southern Africa and higher in eastern Africa. Climate change reverses these gains in Africa, as in other regions, but its effects can be offset by a comprehensive set of investments in agricultural research, resource management, and infrastructure. It is important to note that the assessments of population at risk of chronic hunger are based on the average availability of food energy and do not take into account other dimensions of food insecurity such as micronutrient deficiencies, episodes of conflict, or other shocks that create localized vulnerability.

TABLE 2.7—PREVALENCE OF HUNGER IN 2010 AND 2030 (AS A SHARE OF THE TOTAL POPULATION, PERCENTAGE)

Region	2010	2030, no CC	2030, CC	2030, COMP
World	12.2	6.4	7.2	5.0
Developing countries	14.3	7.4	8.3	5.7
Africa	20.9	13.2	15.0	10.5
Northern Africa	7.7	6.5	6.9	5.5
Africa south of the Sahara	24.3	14.8	16.9	11.7
Western Africa	9.9	5.8	6.9	4.6
Eastern Africa	34.9	23.2	26.4	19.7
Central Africa	41.3	18.2	21.6	11.5
Southern Africa	6.6	4.4	4.9	3.7

Source: Mason-D'Croz and others (2016).

Note: No CC assumes no climate change (a constant 2005 climate); CC reflects a future with climate change using representative concentration pathway (RCP) 8.5 and the Hadley Centre Global Environment Model version 2—Earth System (HadGEM2-ES) general circulation model (Jones and others 2011); COMP refers to a scenario with climate change and a comprehensive investment portfolio as described above.

Discussion, Institutional and Political Challenges, and Conclusion

In the face of a growing threat to food security, policy makers are under increasing pressure to devise policies that promote adaptation to climate change while also reducing greenhouse gas emissions. These policies need to address the local impacts of global change and must be feasible in the short term and sustainable in the long term, designed to weather challenges from forces that are both global and local, exogenous and endogenous to a country (De Pinto, Wiebe, and Rosegrant 2016). Recent analyses offer insights on alternative scenarios and inform the consideration of policy options that can contribute to a country's climate-change readiness. A global-to-local approach also helps in identifying climate opportunities—that is, places where climate change will improve conditions for agriculture—as well as which crops to invest in, given changes in comparative advantage and commodity prices.

In the years ahead, up to 2050, African countries are projected to continue the substantial growth observed in recent decades. Many will enter middle-income status. Agriculture will grow absolutely and decline as a share of national economies as services and manufacturing increase more rapidly than primary agriculture. In order to engage constructively in the process of structural transformation and growth, African agriculture will need to become technologically more sophisticated and derive more benefit from a strong foundation in agricultural science. A vibrant scientific establishment will facilitate sectoral adaptation to changing conditions of the climate and markets, and create jobs for young people seeking to share in the national transition to middle-income status. This is all the more important because climate change impacts will accelerate after midcentury, and—uniquely among world regions—population will continue to grow in Africa south of the Sahara throughout the 21st century.

Many of the issues that African farmers will confront are regional in nature, due to both increased integration of markets and regional dimensions of shifts in agroecology. Thus, the scientific effort to facilitate agriculture's contribution to growth must be regional in design. Given the weak foundation of agricultural science in the region at present, the effort to rebuild will require focused and targeted training and investment. Improvements are also needed in modeling tools to address the impacts of increases in weather volatility and extreme events, rising sea levels, and changes in the incidence of agricultural pests and diseases, as well as to better account for uncertainty and the costs involved in addressing these challenges. The foresight analysis presented above and subsequent refinements of the work can serve as a platform for rigorous consideration of investment alternatives. Foresight analysis can also provide early warning of locally specific agricultural challenges, thereby facilitating planning to assist affected populations, as well as highlight new opportunities.

CHAPTER 3

The Effects of Widespread Adoption of Climate-Smart Agriculture in Africa South of the Sahara under Changing Climate Regimes

Alessandro De Pinto, Ho Young Kwon, Nicola Cenacchi, and Shahnila Dunston[8]

8 The authors acknowledge the generous support of the United States Agency for International Development. This work was implemented as part of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors.

Current scenarios for "business-as-usual" (BAU) farming under climate change project increasing food shortages by 2050. The worst hit will be underdeveloped economic regions of the world where food security is already problematic and populations are vulnerable to shocks (Rosegrant et al. 2014). Without substantial measures to adapt to increasing temperatures and more frequent extreme weather events, losses in crop and livestock productivity are expected to undermine the rate of gain from technological and management improvements (Lobell and Gourdji 2012). Furthermore, climate change not only is threatening the productivity of the world's agricultural systems but is also expected to have consequences on a wide range of ecosystem services (Knight and Harrison 2012).

Developing countries are expected to bear the brunt of climate change (Morton 2007). The Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) projects that under more optimistic scenarios, climate change could reduce food crop yields in parts of Africa by between 10 and 20 percent, a large drop for already at-risk populations and regions. The outlook for key food crops across the African continent under climate change is mostly negative. Low productivity, together with increasing global demand, will likely drive up the prices of staple foods, which may rise by 42 to 131 percent for maize, 11 to 78 percent for rice, and 17 to 67 percent for wheat between 2010 and 2050 (Hachigonta et al. 2013; Jalloh et al. 2013; Nelson et al. 2010; Waithaka et al. 2013). Moreover, localized weather shocks and emerging pest and disease outbreaks are already compromising stability in crop production, highlighting the urgency for immediate and adaptable management responses (FAO 2016).

Agriculture not only is affected by climate change but also significantly contributes to the problem. Yearly greenhouse gas (GHG) emissions from the agricultural sector range from 5.0 to 5.8 gigatons[9] of carbon dioxide (CO_2) equivalent, or about 11 percent of total anthropogenic GHG emissions, not including land use change (Smith et al. 2014). Poor soil management and land conversion from tropical forests to poorly productive agricultural systems also have a large climate footprint. Combined with forestry and other land uses, anthropogenic land activities contribute about a quarter of annual GHG emissions, three-fourths of which are estimated to originate in the developing world (Smith et al. 2014). Importantly, smallholder farming systems worldwide contribute 3.4 percent of total global emissions (Vermeulen and Wollenberg 2017).

Considering existing expectations for agricultural production in developing countries, including the production of smallholder producers—for example, Sustainable Development Goal (SDG) 2.3 calls for doubling the agricultural productivity and incomes of small-scale food producers by 2030—it is undisputed that farmers need options to increase production under a changing climate and, ideally, to reduce emissions.

Climate-smart agriculture (CSA) is an approach that addresses these problems jointly. After years of dichotomy in the climate change research community between climate change adaptation and mitigation, the two concepts were combined in the term *CSA*. CSA was introduced in 2009 (FAO 2009a, 2009b) and became prominent a year later at the first Global Conference on Agriculture, Food Security and Climate Change (FAO 2010). It is an umbrella term that includes many approaches built upon geographically specific solutions, and it is recognized as a potential means to help achieve the SDGs. It is composed of agricultural systems that contribute to three objectives: (1) sustainable and equitable increases in agricultural

9 *Tons* refers to metric tons throughout the chapter; 1 gigaton = 10^9 tons.

productivity and incomes; (2) greater resilience of food systems and farming livelihoods; and (3) reduction, removal, or both of greenhouse gas emissions associated with agriculture (including the relationship between agriculture and ecosystems), where possible.

Agricultural production systems that follow the general principles of CSA are expected to be not only more productive and efficient, but also more resilient to short-, medium-, and long-term shocks and risks associated with climate change and climate variability. There is a general consensus that CSA, albeit with limits (Wheeler and von Braun 2013), helps to advance the discussion on future agricultural production under a significantly different climate environment.

Indeed, CSA is an important departure from the single-objective analysis that has supported most food policies so far. CSA is expected to address climate-related risks by simultaneously considering three main objectives and by fully accounting for the trade-offs and synergies among them (Rosenstock et al. 2016). CSA's broader and more flexible approach is supposed to distinguish it from more prescriptive practices such as conservation agriculture or agroforestry. Furthermore, its multi-objective approach has the potential to spur productive conversations and negotiations among ministries that often do not share or coordinate objectives.

Many operational aspects of CSA are still under investigation. Agricultural practices may be climate smart in particular circumstances, but local contexts determine the enabling environment and the trade-offs and synergies across the multiple objectives (Below et al. 2012). As a consequence, conditions for adoption are highly context and location specific, and farmers need access to considerable information to make the approach operational (Mccarthy, Lipper, and Branca 2011). The literature has also focused on technical aspects related to economic feasibility (Sain et al. 2017), the emission reduction and adaptation benefits (de Nijs et al. 2015), and the local-level impacts (Zougmoré et al. 2016) of CSA.

However, to our knowledge, no study has produced a comprehensive analysis of the effects that widespread adoption of CSA practices and technologies may have on the production of key crops, on GHG emissions, and on key food security metrics, regionally or globally. This chapter investigates the potential broad benefits of a widespread adoption of CSA practices, focusing its analysis on Africa south of the Sahara (SSA).

Results of this analysis indicate that there might be significant challenges for CSA to deliver across the three objectives, particularly the abatement of GHG emissions. So-called win-win outcomes, cases in which both productivity and reduction of emissions are achieved, do exist but are not as common as often believed. In order to achieve significant GHG emission abatement, mechanisms that incentivize a reduction in emission intensity must be in place. Importantly, the current results indicate that CSA should not be interpreted simply as a list of acceptable practices from which farmers can choose. If the CSA approach is to have a significant impact on food security, sustainable development, and GHG emission reduction, it should consider activities across production systems as well as the interaction of agricultural land use with carbon-rich land uses such as forests.

Background

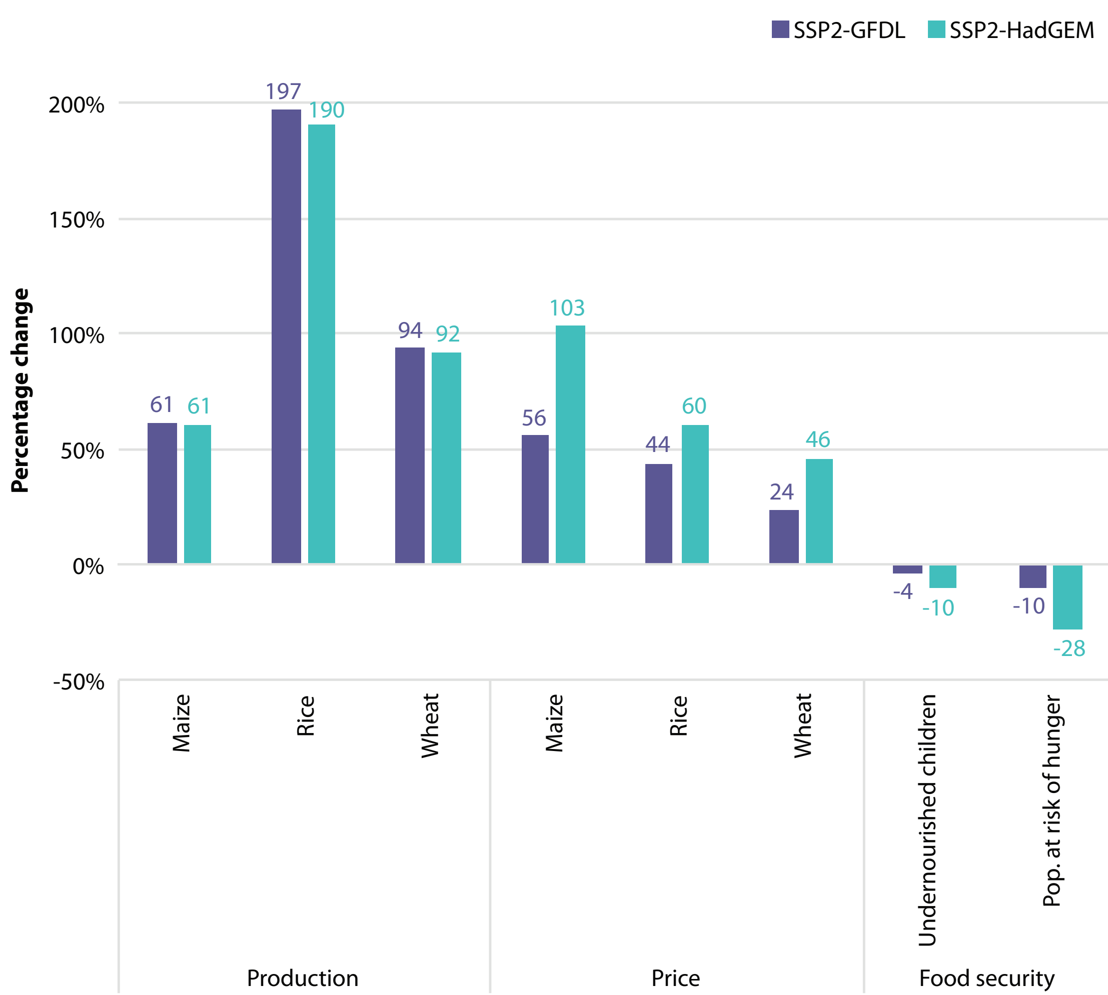
Uncertainties in climate change scenarios make it difficult to determine the precise impacts of climate change on future agricultural productivity. However, although the expectations are mixed, studies have consistently found that under the most severe scenarios of climate change, significant losses should be expected worldwide (Darwin et al. 1995, 1996; Easterling et al. 2007; Fischer et al. 1993; Fischer and van Velthuizen 1996; Nelson et al. 2010; Rosenthal and Kurukulasuriya 2003; Rosenzweig and Parry 1994). Regional differences in crop production are expected to grow stronger through time, potentially widening the gap between the haves and have-nots and increasing hunger among the poorer nations (Parry et al. 2004; Nelson et al. 2010). Interregional trade flows, as a result, may expand from their current location in mid- to high-latitude regions into low-latitude regions, although trade alone might not be a sufficient strategy for adaptation to climate change (Elbehri, Elliott, and Wheele 2015).

SSA is expected to be strongly affected by climate change. Niang and colleagues (2014) found that climate change is very likely to have negative effects on yields of major cereal crops in the African region, albeit with strong subregional variation. Schlenker and Lobell (2010) indicated that in a "worst-case" scenario, a warming of about 2°C above preindustrial levels by midcentury, losses of 27–32 percent for maize, sorghum, millet, and groundnut should be expected. Thornton and others (2010) estimated mean yield losses of 24 percent for maize and 71 percent for beans under a warming scenario exceeding 4°C. Rosenzweig and colleagues (2014) found yield decreases of more than 50 percent for maize in the Sahel region and in the range of 10–20 percent in other regions south of the Sahara. On the other hand, crops like cassava, are likely to be more resistant to higher temperatures and the increasing seasonality of precipitation, compared with cereal crops (Niang et al. 2014); furthermore, alternative practices and cropping systems are expected to reduce the risk of crop failure (Waha et al. 2013).

Thomas and Rosegrant (2015) found that production of some crops in SSA may rise faster under climate change than under a scenario without climate change. This seemingly counterintuitive result is due to the market effects resulting from the global negative impact of climate change on yields. Reduced global yields have the effect of boosting world crop prices, making increasing production attractive to some African farmers. Yet even with increased production in some crops, Thomas and Rosegrant (2015) found, the price increase will ultimately cause food insecurity to rise. According to their calculations, SSA could have a malnutrition rate of 21.7 percent among children younger than five years in 2050 without climate change, but this rate may rise to 24.4 percent with climate change, an increase of more than 4 million children.

Projections of future production for maize, wheat, and rice in SSA for the period 2010–2050 obtained using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) (Robinson et al. 2015) indicate that their output is expected to increase by 61 percent, 92–94 percent, and 190–197 percent, respectively, depending on the particular general circulation model used. During the same 40-year period, prices are projected to increase by 56–103 percent for maize, 24–46 percent for wheat, and 44–60 percent for rice. Growth in world prices, combined with regional growth in production and income, and changing diets, will have an effect on hunger and nutrition. In SSA, the number of undernourished children younger than five years is anticipated to decrease by 4–7 percent and the population at risk of hunger by 10–22 percent by 2050. These results, summarized in Figure 3.1, constitute the BAU scenario against which we will evaluate the performance of CSA practices and technologies. The BAU scenario was generated using two particular climate scenarios:

FIGURE 3.1—CHANGES IN PRODUCTION, PRICES, UNDERNOURISHED CHILDREN YOUNGER THAN FIVE YEARS, AND POPULATION AT RISK OF HUNGER , 2010–2050, UNDER TWO CLIMATE SCENARIOS WITH BUSINESS-AS-USUAL FARMING PRACTICES



Source: Authors.

Note: SSP2-GFDL = Geophysical Fluid Dynamics Laboratory model under shared socioeconomic pathway 2; SSP2-HadGEM = Hadley Centre Global Environment Model under shared socioeconomic pathway 2. Production and food security results are specific for SSA, cereal prices are global.

GFDL-ESM2M (Geophysical Fluid Dynamics Laboratory Earth System Model version 2M) (Dunne et al. 2012) and HadGEM2-ES (Hadley Centre Global Environment Model version 2—Earth System) (Jones et al. 2011), both under a representative concentration pathway (RCP) of 8.5 and coupled with trends of population and income growth obtained through the shared socioeconomic pathways (SSPs) 2 scenario (O'Neill et al. 2014) developed for the IPCC AR5.

Methods and Data

To perform an ex ante assessment of the effects of adoption of CSA practices and technologies in SSA, we linked the inputs and outputs of three models: the Spatial Production Allocation Model (SPAM) (You, Wood, and Wood-Sichra 2006), the Decision Support System for Agrotechnology Transfer (DSSAT) (Jones et al. 2003), and IMPACT version 3.3 (Robinson et al. 2015). The analysis focuses on three widely grown crops—wheat (Triticum aestivum), maize (Zea mays), and rice (Oryza sativa)—which represent about 41 percent of the global harvested area and 20 percent of the harvested area in SSA. They also represent about 64 percent of GHG emissions generated by crop production globally (Carlson et al. 2016). The simulations in the ex ante assessment use the same climate scenarios considered under the BAU scenario: GFDL-ESM2M and HadGEM2-ES, with an RCP of 8.5 and SSP 2.

The SPAM model spatially disaggregates subnational statistics on crop production and cropland (for the period 2004–2006) into either 0.08 or 0.5-degree grid cells by analyzing biophysical crop "suitability" assessments, population density, and all other available knowledge regarding the spatial distribution of specific crops or crop systems. We used the model to geographically locate the area allocated to the three considered crops. For each SPAM grid cell, we assembled a database of existing dominant management practices and inputs used (that is, varieties employed, application rates of inorganic fertilizers, organic amendment availability, and water management practices). Furthermore, we linked climate scenario data to each 0.5-degree grid cell (a square of approximately 56 km by 56 km at the equator). Finally, we treated each grid cell as an individual farm, assuming that it can properly represent as many farms as are actually contained in its area.

The DSSAT crop model simulates crop yields by accounting for the interaction between the biophysical elements of crop systems (for example, soil, weather, and crop type) and management options (for example, tillage, nutrient application, and water availability). Data from the SPAM model and climate projections from the GFDL and HadGEM models are used as inputs into DSSAT to simulate changes in yields due to adoption of CSA practices compared with the BAU scenario, the latter assuming a continued use of current agricultural practices. All simulations were performed for a 40-year period (2011–2050; see "Simulation of Technology Adoption" in the appendix[10]).

The yield changes derived from the crop simulation in DSSAT, reflecting climate change effects as well as adoption of CSA technologies, form the basis for the simulations of the adoption of CSA practices carried out in the IMPACT model (see "Yield Responses" in the appendix). IMPACT is a partial equilibrium model of the agricultural sector that approximates the behavior of a global competitive agricultural market and simulates supply, demand, and prices for agricultural commodities at the country level. The model has a long record of application, having been employed in a wide range of analyses, from assessing the potential effects of climate change on global food production and nutrition (Springmann et al. 2016) to evaluating the global effects of biofuel production (Rosegrant 2008). The yield changes simulated in DSSAT that result from adoption of CSA practices function as shifters for the crop-specific supply curves and also change yield growth rates under climate change.

Along with the yield responses, we also calculate changes in GHG emissions. Spatial and temporal changes in soil carbon stocks and direct nitrous oxide (N_2O) emissions, which account for N_2O emitted directly from the soils to which the nitrogen has been added and then released, were simulated in soil organic matter modules embedded into the DSSAT crop model. For the rice production system, we also calculated methane (CH_4) emissions by combining the DSSAT-simulated rice biomass with the approach proposed by Yan and colleagues (2009), whereby emission coefficients from

10 The starting year for the simulations in IMPACT is 2010 but the first year of possible adoption in DSSAT is 2011.

IPCC Tier 1 methods are used to estimate the global CH_4 emissions from rice fields. Finally, we converted all GHG emissions into kilograms of CO_2 equivalent by using the global warming potential over a 100-year time horizon for each GHG: 1, 28, and 265 for CO_2, CH_4, and N_2O, respectively.

Simulation Scenarios

Figures 3.1, 3.2, and 3.3 present results for the BAU scenario. These results determine, although indirectly, the effects of adopting alternative technologies on both yields and GHG emissions.[11]

Calibration of DSSAT for the Business-as-Usual Scenario

The BAU scenario in DSSAT reflects the use of current agronomic practices and technologies, assuming that farmers are not adopting any of the assessed CSA alternatives throughout the simulation period of 2010–2050. We made considerable efforts to calibrate DSSAT to ensure that the simulated yields in the reference year would match national statistical data as accurately as possible (see "Calibration of DSSAT for the Business-as-Usual Scenario" in the appendix).

After calibration, simulated yields for maize and wheat are comparable to yields in the database of the Food and Agriculture Organization of the United Nations (FAO), known as FAOSTAT (FAO 2017), with very good fits—R^2 values of 0.85 and 0.80, respectively. The fit is lower but still adequate for rice, with an R^2 of 0.63 (Figure 3.2). However, when only the SSA region is considered, the fit of the simulated yields is worse, especially for rice. This outcome might be related to higher uncertainties about the model inputs (for example, soil characteristics and highly localized farming practices) compiled for the simulations of the SSA region.

It must be noted that only monoculture systems were simulated, thereby providing a stylized representation of worldwide agricultural systems. This limitation should be addressed in future research through including intercropping and rotation practices.

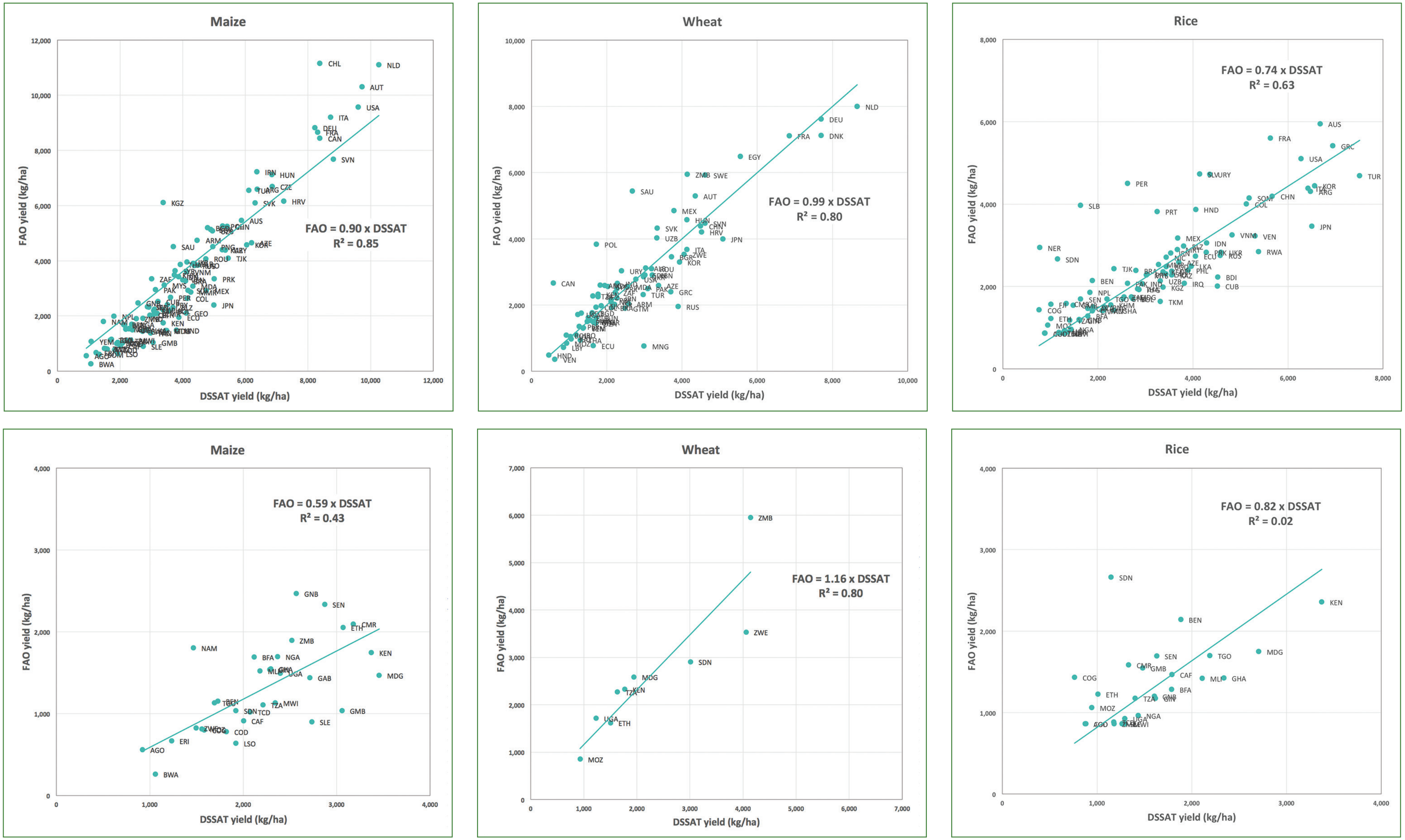
Climate-Smart Alternatives Scenario

We identified four specific technologies to use in simulations for the climate-smart scenario. These are practices with a potential for large-scale adoption, and most of them are already being utilized or tested in some regions, including SSA. The technologies considered for maize and wheat are no tillage (NT) and integrated soil fertility management (ISFM), and those for rice are alternate wetting and drying (AWD) and urea deep placement (UDP) (Table 3.1). For this study, we assume that CSA practices are adopted across the entire SSA region but not the rest of the world. Although this assumption is clearly unrealistic, it allows us to better appreciate the effects of adoption of CSA practices on the African continent.

Examples from SSA and other regions show that unlike continuous tillage, which leaves soils prone to soil erosion and is a major source of soil carbon loss (Reicosky et al. 2005), NT combined with crop rotation and retention of crop residues reduces erosion and improves general soil fertility through retention of water and nutrients as well as benefits to soil aeration and soil biota, with potential direct effects on agricultural productivity (Hobbs, Sayre, and Gupta 2008; Kassam et al. 2009). The existing literature on conservation agriculture, of which NT is an essential component, points

[11] It should be noted that both the BAU and alternative scenarios reflect the yield responses to the projected changes in climate (precipitation and temperature) but do not consider potentially important changes in the incidence and impact of pests and diseases.

FIGURE 3.2—DSSAT CALIBRATION RESULTS FOR THE WORLD (TOP) AND AFRICA SOUTH OF THE SAHARA (BOTTOM), BUSINESS-AS-USUAL SCENARIO



Source: Authors.

Note: The dry-matter weight used in the DSSAT yield was converted into the fresh-matter weight of yield typically reported in FAOSTAT and SPAM by correcting for harvesting and threshing losses and grain moisture contents (see “Calibration of DSSAT for the Business-as-Usual Scenario” in the appendix). DSSAT = Decision Support System for Agrotechnology Transfer; FAOSTAT = the database of the Food and Agriculture Organization of the United Nations; SPAM = Spatial Production Allocation Model.

to an increase in yields, as evidenced by the effects on soil quality, soil moisture, and maize yields gathered at two different farm sites in Zambia (Thierfelder, Mwila, and Rusinamhodzi 2013). In general, however, the effects are quite variable because they depend on a range of location-specific exogenous conditions (such as climate and learning processes) and endogenous conditions (such as soil type) (Erenstein et al. 2012; Lal 2015; Pittelkow, Liang, et al. 2015). In some conditions, short-term productivity may even decrease under conservation agriculture (Pittelkow, Liang, et al. 2015). A review of case studies across SSA (Burkina Faso, Kenya, Madagascar, Malawi, Tanzania, Zambia, and Zimbabwe) showed that yields are more stable and often increase with time under such practices, especially in dry or drought-stressed conditions (Corbeels et al. 2014).

ISFM has been especially studied in SSA (Vanlauwe et al. 2010). ISFM is a set of locally adapted practices that utilize crop residues along with both synthetic fertilizers and organic inputs (such as animal manure, green manure, or both), aiming at increasing productivity through the efficient use of nutrients (Vanlauwe et al. 2011). It has been recognized that ISFM contributes toward improving the resilience of soils and agricultural production to weather variability, but much depends on the different benefits that synthetic fertilizers and organic inputs bring to the soil.

AWD has been used in paddy rice cultivation, which is one of the main sources of non-CO_2 GHG emissions from the agriculture sector, after livestock and soil (Smith et al. 2014), to significantly reduce CH_4 emissions from rice paddies (FAO 2013; Tyagi, Kumari, and Singh 2010) and in some instances also increase yields (Rejesus et al. 2011; Lampayan 2012). The technology has been validated and promoted across several countries in Asia, and adopted widely in Bangladesh, the Philippines, and Viet Nam. The water savings associated with AWD make this technology particularly suited to testing in the SSA context, and some positive results have been already reported in the Sahel region (de Vries et al. 2010; Comas et al. 2012).

TABLE 3.1—CLIMATE-SMART AGRICULTURE TECHNOLOGIES CONSIDERED IN THIS STUDY

Technology	Definition	Crop	Potential effects on yields and GHG emissions	References
No tillage (NT)	Minimal or no soil disturbance; often used in combination with residue retention, crop rotation, and cover crops	Maize, wheat	• Positive or neutral effect on yields • Uncertain effect on GHG emissions	• Erenstein et al. 2008, 2012; Hobbs, Sayre, and Gupta 2008; Pittelkow, Linquist, et al. 2015 • Powlson et al. 2014
Integrated soil fertility management (ISFM)	Combination of chemical fertilizers, crop residues, and manure or compost	Maize, wheat	• Positive effect on yields • Variable effects on GHG emissions	• Agegnehu, vanBeek, and Bird 2014; Chivenge, Vanlauwe, and Six 2011; Vanlauwe et al. 2011 • Gentile et al. 2008
Alternate wetting and drying (AWD)	Repeated interruptions of flooding during the season, causing the water to decline as the upper soil layer dries out before subsequent reflooding	Rice	• Low to no significant changes in yields • High confidence in lower GHG emissions due to reduction of methane emissions	• Devkota et al. 2013; Huda et al. 2016; Rejesus et al. 2010 • Pandey et al. 2014; Tyagi, Kumari, and Singh 2010
Urea deep placement (UDP)	Strategic burial of urea "supergranules" near the root zones of crop plants	Rice	• Positive results on yields • Reduction of GHG emissions	• Bandaogo et al. 2015; Huda et al. 2016 • Gaihre et al. 2015

Source: Authors.
Note: GHG = greenhouse gas.

UDP aims at the efficient use of nitrogen, which is the key to both increased production and reduced emissions (FAO 2013). Broadcast application of nitrogen in rice fields leads to loss of 60 to 70 percent of the nitrogen, directly contributing to both water pollution and GHG emissions. The placement of urea "supergranules" deep in the soil provides a slow release of fertilizer near the root system of rice plants, thereby improving the efficiency of nutrient uptake and limiting nitrogen losses. The result is an increase in yields, combined with a significant reduction in leached nitrates and therefore a lower likelihood of N_2O emissions. At the same time, UDP increases the resilience of agricultural systems by making them less susceptible to economic shocks due to changes in energy prices. The International Fertilizer Development Center reports that UDP was introduced for testing in West Africa in 2009 (IFDC 2011). Experiments conducted in Burkina Faso revealed the potential for a significant increase in rice yields (Bandaogo et al. 2015).

Adoption of Alternative Technologies

The alternatives to the BAU scenario were constructed by assuming that farmers who are cultivating either maize, wheat, or rice are offered a portfolio of alternatives (that is, the four CSA practices considered) from which to choose. We constructed two scenarios based on two alternative conditions for adoption. In the first, the prerequisite for adoption is that the CSA technology or practice must return a yield gain over the status quo (i.e. the BAU scenario). In the second, CSA practices are adopted if they generate higher yields than current practices *and* reduce emission intensity.[12] In both cases, farmers are assumed to choose the alternative that increases yields the most. If none of the alternatives increases yields, farmers retain their current practices.

Clearly, in real-world conditions, adoption of alternatives to the status quo depends on many other factors. Yields, which could be considered a crude proxy for profitability, are only one of the aspects of production that enter the farmer's decision process. The literature on the socioeconomic determinants of adoption is extensive and considers factors related to the characteristics of farmers and their farms, market access, technology, the quality of extension services, and risk factors (Bewket 2007; Enfors and Gordon 2008; Shiferaw, Okello, and Reddy 2009; Teklewold and Kohlin 2011). However, we consider the yield increase assumption to be justified because it is difficult to imagine that countries would favor the widespread use of technologies that reduce yields, given the pressure of population growth and changing diets.

The analysis also assumes that when an alternative provides better yields in a particular grid cell, *all* farmers in that cell adopt the best alternative. This assumption departs significantly from previous studies (such as Rosegrant et al. 2014), in which adoption depends on other socioeconomic factors and has a ceiling lower than 100 percent. It is important therefore to consider the results of this study as an upper bound of the changes induced by the widespread adoption of CSA practices. As a sensitivity analysis, we

12 Emission intensity is defined as emissions per unit of output (yield). There are connections between reduction of emission intensity, efficient use of energy, and total factor productivity (Ayres et al. 2002). These linkages should be explored further, but they are not the target of this analysis. Still, farmers' adoption of CSA practices that reduce emission intensity could be in response to policies that target GHG emission reduction or to more general policies that aim at increasing total factor productivity.

simulated several other scenarios, including (following Rosegrant et al. 2014) lower adoption rates and adoption of AWD based on a reduction of production costs, not just an increase in yields. Although the results are numerically different, there are no qualitative differences between these additional scenarios and the two presented in this chapter.

Greenhouse Gas Emissions and Emission Intensity

One of the pillars of CSA is the reduction of GHG emissions. Even though the CSA practices considered are expected to reduce emissions, given the high heterogeneity of soil characteristics and growing conditions, there is no assurance that adopting these practices actually reduces emissions on a given farm. Furthermore, to appreciate the complexities related to the reduction of GHGs it is necessary to take a closer look at what determines total emissions. Total emissions from crop production (E) are determined by a multiplicative combination of emission intensity (e, emissions per unit of output), yield (y, output per hectare), and area (a, hectares allocated to crop production):

$$E = f(e, y, a) = e * y * a. \quad (1)$$

Equation (1) indicates that reducing total emissions depends not only on the effectiveness of the alternative practices in reducing emissions per unit of output but also on their effects on yields. In principle, it is possible for yields and area to increase sufficiently to offset any reduction in emission intensity.[13]

[13] This can be easily observed by taking the total derivative of equation (1), $dE = \frac{\partial f}{\partial e} de + \frac{\partial f}{\partial y} dy + \frac{\partial f}{\partial a} da$, noting that $\frac{\partial f}{\partial e} > 0$, $\frac{\partial f}{\partial y} > 0$, and $\frac{\partial f}{\partial a} > 0$.

Results

Results for the scenarios that simulate global adoption of CSA practices and technologies are dependent on how widely CSA practices and technologies are adopted. The adoption rates for the two scenarios are shown in Table 3.2.

TABLE 3.2—ADOPTION RATE BY CROP UNDER VARIOUS CLIMATE AND ADOPTION SCENARIOS

Scenario	Adoption rate of alternative practice: MAIZE (GFDL / HadGEM)	Adoption rate of alternative practice: WHEAT (GFDL / HadGEM)	Adoption rate of alternative practice: RICE (GFDL / HadGEM)
Adoption of CSA practices dependent on increased yields	94.0% / 94.2%	90.0% / 90.1%	22.2% / 20.9%
Adoption of CSA practices dependent on reduction of emission intensity *and* increased yields	79.0% / 78.1%	26.8% / 26.5%	20.8% / 20.2%

Source: Authors.

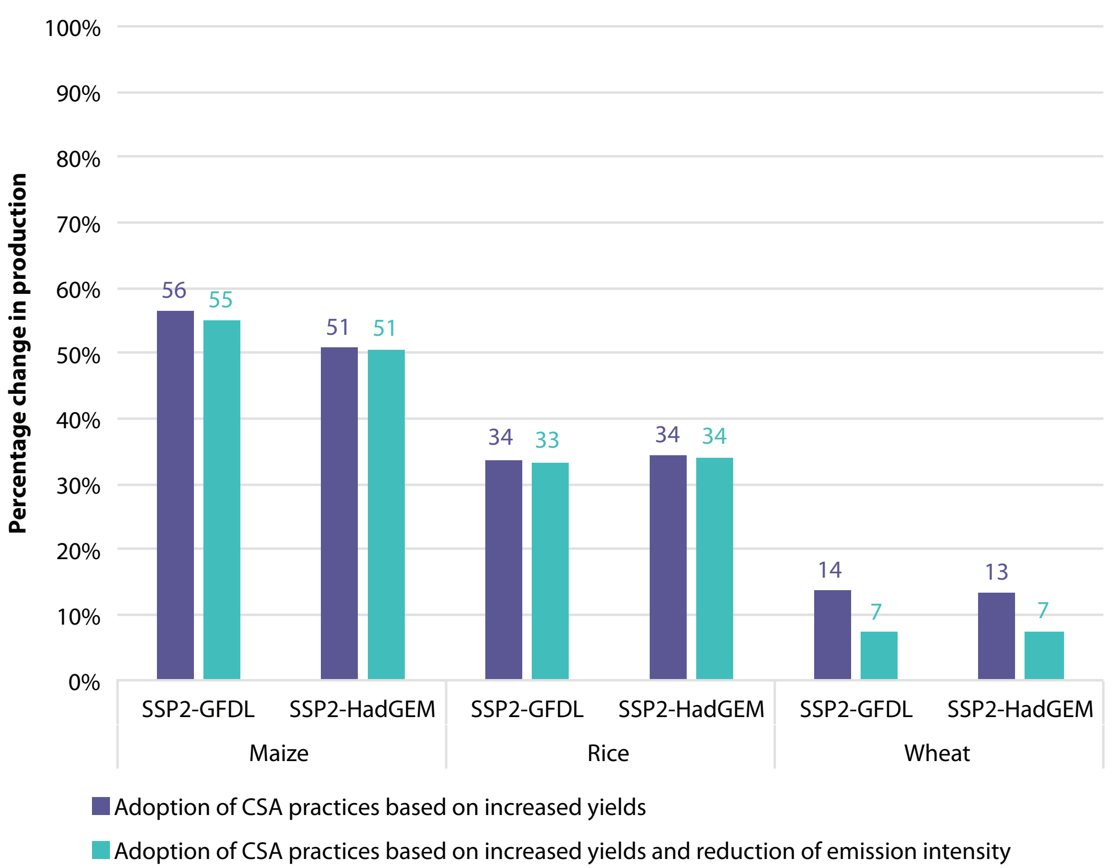
Note: CSA = climate-smart agriculture; GFDL = Geophysical Fluid Dynamics Laboratory Earth System Model version 2M; HadGEM = Hadley Centre Global Environment Model version 2—Earth System.

As expected, adoption rates are lower when two conditions (increase in yields and reduction of emission intensity) must be satisfied. Adoption seems to drop the most for wheat with the addition of a second condition, indicating that the CSA practices considered do not automatically lead to a reduction of emissions for this crop.

Overall, when compared with a BAU scenario, CSA technology adoption in SSA is estimated to increase production of maize by more than 50 percent, wheat production by between 7 and 14 percent, and rice production by more than 30 percent (Figure 3.3). There is almost no difference in effect between the two adoption scenarios, with the exception of wheat, for which production is about 6 percent larger when only yield increases are a condition for adoption. Results for maize are particularly important. CSA technologies appear to be able to offset the negative effects of climate change (Figure 3.3). When CSA practices are adopted under the GFDL simulated climate, for instance, production may increase by 55–56 percent over BAU.

Not surprisingly, because we limit adoption of CSA to SSA, the increase in crop productivity has only a small effect on the world prices of maize, rice, and wheat (Table 3.3), especially when compared with the changes in global prices projected for the period 2010–2050 under SSP2-GFDL or SSP2-HadGEM and BAU (Figure 3.1). A result of the unchanged upward trend in prices is that producers can take advantage of higher productivity by expanding production area. Projections indicate that harvested area for maize, rice, and wheat is expected to increase in SSA with the adoption of CSA practices. The IMPACT simulations show an increase of up to 12 percent for maize, 3 percent for wheat, and 2 percent for rice by 2050 (Table 3.3). These are important changes to consider even though the current model framework does not allow us to discern what other land uses would be affected by this expansion. Further research is necessary to explore these issues.

FIGURE 3.3—PERCENTAGE CHANGE IN PRODUCTION (TOTAL OUTPUT) IN 2050, CLIMATE-SMART AGRICULTURE SCENARIOS COMPARED WITH BUSINESS-AS-USUAL SCENARIO



Source: Authors.

Note: CSA = climate-smart agriculture; SSP2-GFDL = Geophysical Fluid Dynamics Laboratory Earth System Model version 2M under shared socioeconomic pathway 2; SSP2-HadGEM = Hadley Centre Global Environment Model version 2—Earth System under shared socioeconomic pathway 2.

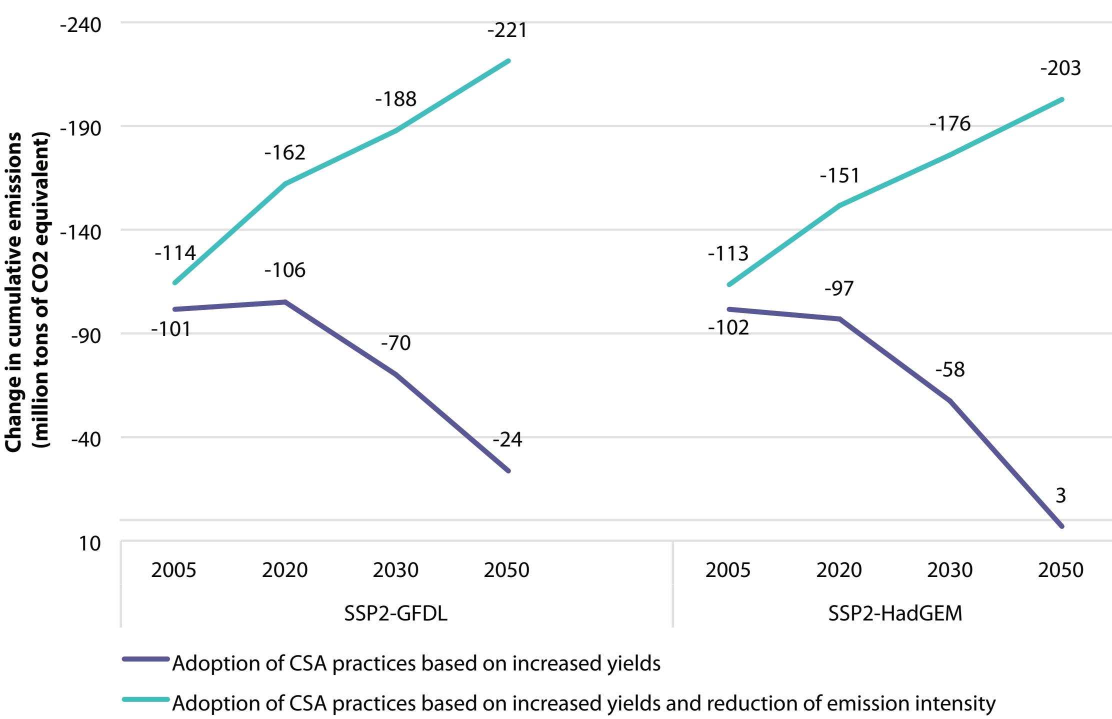
TABLE 3.3—PERCENTAGE CHANGE IN 2050 WORLD PRICES UNDER TWO SCENARIOS, COMPARED WITH BUSINESS-AS-USUAL

Scenario	MAIZE (GFDL / HadGEM)	WHEAT (GFDL / HadGEM)	RICE (GFDL / HadGEM)
Adoption rate of CSA practices predicated on increased yields	-2.80% / -3.00%	-1.30% / -2.00%	-3.20% / -3.40%
Adoption rate of CSA practices predicated on increased yields and reduction of emission intensity	-2.70% / -3.00%	-1.20% / -1.80%	-3.20% / -3.30%

Source: Authors.

Note: GFDL = Geophysical Fluid Dynamics Laboratory Earth System Model version 2M; HadGEM = Hadley Centre Global Environment Model version 2—Earth System.

FIGURE 3.4—CHANGE IN GREENHOUSE GAS EMISSIONS FROM BASELINE UNDER TWO ADOPTION AND TWO CLIMATE SCENARIOS



Source: Authors.

Note: CSA = climate-smart agriculture; SSP2-GFDL = Geophysical Fluid Dynamics Laboratory Earth System Model version 2M under shared socioeconomic pathway 2; SSP2-HadGEM = Hadley Centre Global Environment Model version 2—Earth System under shared socioeconomic pathway 2.

Consistent with the production results,[14] the population at risk of hunger in SSA is projected to decrease by between 1.8 and 2.5 percent, with little difference between the two adoption scenarios. However, the decrease in undernourished children younger than five years is low under both adoption scenarios, ranging between 0.2 and 0.3 percent (equivalent to approximately 100,000 children).

Overall, the considered CSA practices also appear to be beneficial for soil fertility, for sustainability, and potentially for resilience in general. The soil organic carbon concentration, which increases not only fertility but also soil water retention, is estimated to increase by an average of 0.16–0.17 tons/ha^{-1}/year^{-1} over BAU across the area that adopts the alternative practices, depending on which scenario is considered. Soil organic carbon "gains" should be interpreted mostly as avoided soil carbon losses rather than actual gains from the initial conditions.

Significant differences are apparent between the two adoption scenarios when we consider GHG emissions. When the choice to adopt is based only on yields, total GHG emissions remain basically unchanged or decrease minimally, at an estimated 0.01 tons/ha^{-1}/year^{-1} and results depend largely on the climate scenario used (Figure 3.4). Importantly, although CSA practices reduce emissions during the first two decades simulated, during the latter two decades they appear to increase emissions. This happens

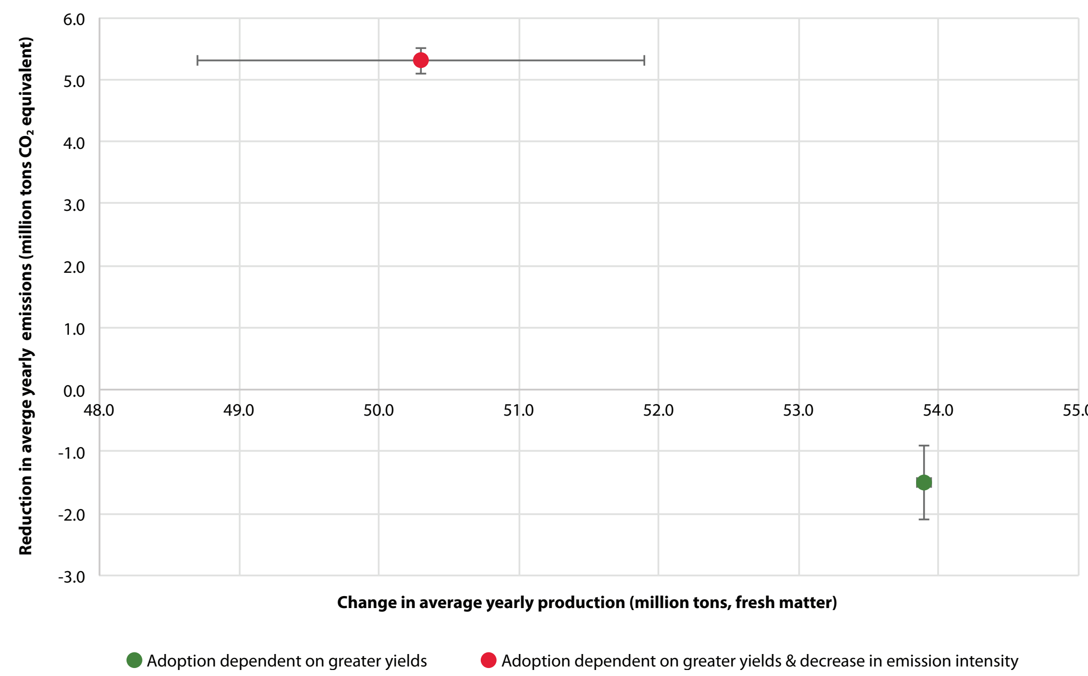
[14] On exception is wheat, for which results change significantly across scenarios. However, wheat area by 2050 is about one-third of rice area and one-seventh of maize area, and therefore its contribution to overall production and calories is limited.

because soils reach a steady-state condition wherein no more soil organic carbon sequestration occurs even though N_2O emissions continue at relatively constant rates over the entire 40 years. This leads to an actual increase in GHG emissions during the final decade simulated, compared with the baseline, estimated at 1.5 million tons of CO_2 equivalent annually.

Results from the second simulation show that it is possible, in principle, to increase production while reducing GHG emissions. By enforcing a reduction of emission intensity, it is possible to reduce GHG emissions by more than 200 million tons for the period under consideration (Figure 3.4), equivalent to an average per-hectare yearly reduction of approximately 0.17 tons of CO_2 equivalent. Significantly, even during the final decade modeled, emissions are reduced at an average rate of 5.5 million tons of CO_2 equivalent annually.

Figure 3.5 summarizes the results of comparing the two adoption scenarios for the final decade under consideration. The change in total production is computed using the cumulative fresh weight of the three crops considered, and yearly GHG emissions are computed using the yearly average for the final decade (2040–2050). The whisker bars indicate the range of simulation results obtained using the two different climate projections, with the average of the two estimates marked by a colored dot. Two messages can be drawn from the results displayed in Figure 3.5. First of all, although the CSA practices and technologies simulated have overall positive effects on production, reducing emissions while also increasing production is possible but depends on being able to enforce a reduction in emission intensity. This result is consistent with field findings reported in the literature indicating that CSA practices do not reduce emissions in all conditions and require careful tailoring to the specific local soil and weather conditions. In other words, there appears to be substantial room for CSA practices to increase yields but not necessarily to reduce GHG emissions. Second, there appears to be a trade-off between crop production and reduction of GHG emissions. Simulation results reveal that total annual output is reduced by some 4 million tons of fresh matter when a reduction in GHG

FIGURE 3.5—EFFECTS OF ADOPTION OF THE BEST CLIMATE-SMART AGRICULTURE PRACTICE DURING THE PERIOD 2040–2050 ON TOTAL ANNUAL YIELD AND GREENHOUSE GAS EMISSIONS



Source: Authors.

emissions is achieved. In order to resolve these trade-offs in an economically efficient manner, a correct pricing of the factors of production and a price for carbon are necessary.

Discussion and Conclusions

A growing body of literature analyzes the effects of CSA practices and technologies in terms of agronomic, economic, and environmental benefits. Though most of the literature focuses on these effects at the farm and household levels, this study takes a broader geographic perspective, performing an ex ante evaluation of the effects of widespread adoption of selected CSA practices on three cereals: maize, wheat, and rice. Household-level analyses are important to determine, among other things, the viability of new practices and their benefits for households' well-being. However, a broader outlook provides insights into issues related to changes in prices, accessibility of food products, and the cumulative effects on GHG reduction. This broader perspective is necessary when the changes in production affect global prices and consequently cause changes in demand, potential substitution among food products, and increases in production area needed to satisfy demand, all of which must be accounted for.

We therefore carried out an ex ante assessment of the effects of widespread adoption of CSA practices and technologies compared with the outcomes of a BAU scenario in which the climate-smart practices are not adopted. Notwithstanding the broad generalizations necessary to carry out such a large-scale analysis, several insights into the benefits and limits of the CSA approach come to light.

Results indicate that widespread adoption of CSA practices has a positive effect on production and total agricultural output, with a consequent reduction in prices and decrease in the number of people at risk of hunger and the number of children younger than five years at risk of malnutrition. Soil organic carbon appears to grow, compared with the BAU scenario, indicating that productivity can be increased while making production more sustainable than it is with current practices.

These results indicate that CSA practices can positively affect yields and production, induce a reduction in prices, and decrease the number of people at risk of hunger and the number of undernourished children younger than five years. Adoption of CSA practices also induces an increase in soil organic carbon content, or at least reduces soil organic carbon losses, indicating that productivity can be increased in a more sustainable manner than with the current practices. Taken together, all of these outcomes suggest an increase in resilience to climate change.

Importantly, however, the relatively modest effect on world prices does not lead to reduced pressure for cropland expansion. Given the increased productivity, producers might find bringing additional land into production profitable even with the projected decrease in prices, potentially endangering environmentally sensitive and carbon-rich areas.

It is important to recall that these results reflect the upper-bound effects of adoption of CSA practices and that the overall-positive outcomes strongly depend on the uptake of CSA practices by farmers, which we purposely assume to be unrealistically high. The effects of CSA practices would be increasingly marginal with lower adoption rates. In addition, CSA alone does not solve long-standing problems related to the adoption of new beneficial technologies, such as the necessity of well-functioning extension services, the amount and quality of the information provided to farmers, and the removal of a host of other barriers to adoption. These caveats point to the importance of putting in place policies and incentives that promote climate-smart agricultural development.

The effects on GHG emissions are mixed and mostly depend on how much emphasis is given to reduction of emissions. Results for the scenario that simulates adoption of alternative practices based only on yield increases suggest that GHG emission reduction is minimal or nonexistent, depending on which climate scenario is used, highlighting the highly context- and location-specific nature of CSA practices as well as the fact that their use alone does not assure a reduction in emissions. Conversely, when adoption depends on yield increase *and* emission intensity reduction, GHG emissions decrease while some increase in productivity is preserved. This result is important because it appears to indicate that the reduction of GHG emissions is compatible with increased productivity—although it depends on how feasible it is to enforce and control the actual achievement of in-the-field emission intensity reductions.

Not surprisingly, simulations point to an overall trade-off between increasing total output and reducing GHG emissions. Resolving this trade-off in an economically efficient manner depends on correctly pricing the factors of production and possibly creating a price for carbon. Given the multi-objective nature of the approach and the highly context-specific performance of CSA practices, simply offering farmers a portfolio of options from which to choose and educating them about their benefits appears not to lead automatically to meeting the goals of CSA—particularly if significant levels of GHG reduction must be achieved.

Although the insights on emission reduction offered by this analysis are limited by construction (that is, the study focuses on three crops and only on crop production), results point to the importance of broadening the interpretation of CSA and making sure its interactions with other land uses (for example, forests and mangroves) are considered and that agroforestry, livestock, and value chains are included in any analysis. The focus on crop production seems to be limiting and could potentially omit other and more important opportunities for carbon sequestration.

Frelat and colleagues (2016) suggested that targeting poverty through improving market access and off-farm opportunities is a better strategy to increase food security than focusing on agricultural production and closing yield gaps. Wheeler and von Braun (2013) suggested that the whole food system (that is, trade, stocks, nutrition, and social policies) needs to adjust to climate change. These authors make important calls for an approach that is much broader than a narrow focus on increasing yields, and this approach can be applied to CSA as well. CSA is too often reduced to a list of viable agricultural practices and technologies identified as acceptable. The results offered by this study suggest that although beneficial, the adoption of a set of CSA practices only marginally addresses poverty, food security, and most of all, emission reduction, indicating that broader interventions are necessary.

Appendix

Simulation of Technology Adoption

In order to simulate changes in yields, crop area, and production due to adoption of CSA practices and technologies compared with the BAU scenario, IMPACT must be linked with the DSSAT crop model through several steps (Robinson et al. 2015).

First, the IMPACT's BAU scenario begins in the year 2005, with yield values taken from FAOSTAT, which contains statistics and data compiled by the FAO Statistics Division (FAO 2017). Whereas early yield trends are calibrated to reproduce observed historical data, long-term yield trends or intrinsic productivity growth rates (IPRs) are estimated using the expected increases in inputs (for example, fertilizers and water) and general improvements in investments in agriculture. These IPRs differ for developing countries, where there is considerable scope to narrow the gap in yields compared with developed countries, and are exogenous to the model. As a result, changes in the IPRs are specified in the definitions of the various scenarios. Second, on top of these IPRs, the effects of temperature and precipitation (climate shocks) and CSA practices and technologies on crop yields (yield responses) are estimated through the DSSAT crop model. These climate shocks and yield responses are combined as shifters and then aggregated from the DSSAT area unit (a 0.5-degree grid cell, a square of approximately 56 km by 56 km at the equator) to the food producing unit (FPU) used in IMPACT. Finally, yield estimates in IMPACT are adjusted by way of an endogenous link between yields and estimated changes in commodity prices. The link hinges on the underlying assumption that farmers will respond to changes in prices by varying their use of inputs, such as fertilizer, chemicals, and labor, which will in turn change yields.

Yield Responses

We analyzed yields estimated through DSSAT runs at global grid levels to calculate yield responses (percentages) due to any CSA practices and technologies, compared with the BAU scenario:

$$\Delta yield^{t,i} = \frac{\left(Yield_{CSA}^{t,i} - Yield_{BAU}^{t,i}\right)}{Yield_{BAU}^{t}} \times 100, \qquad (2)$$

where t indicates time and i identifies the 0.5-degree grid cell.

The yield responses for the first 10 years and the final 10 years were averaged to represent two specific years, 2005 and 2050. Because IMPACT operates on a regional basis, that of FPUs, we aggregated the detailed gridded crop modeling results of each pixel to the FPU level by calculating area-weighted average yield responses and applying them to the IMPACT yields. This approach allowed us to capture the direction and magnitude of change due to technologies (or climate change) seen in the crop models while maintaining the observed agricultural productivity reported in the FAOSTAT database.

Calibration of DSSAT for the Business-as-Usual Scenario

To improve estimates of yield responses calculated from DSSAT-simulated yields under the respective scenarios of BAU and CSA practices/technologies, we calibrated the DSSAT crop model to ensure that its simulated yields would be compatible with those used in IMPACT as baseline yields in any given reference year. Because the yields of both IMPACT and SPAM at the reference year, 2005, are derived from FAOSTAT, we utilized disaggregated yields of SPAM as observed baseline yields for the purpose of calibration.

First, we adjusted the SPAM yields to account for harvesting and threshing losses and grain moisture contents. This step is necessary because FAO crop yield data are for harvested production, defined as production minus harvesting and threshing losses per unit of harvested area. Correcting for grain moisture content is necessary to convert FAO fresh-matter weight yields into the dry-matter weight yields simulated in DSSAT. Second, we selected one model parameter (the soil fertility factor, or SLPF, a growth reduction and fertility factor that accounts for the effects of soil nutrients—other than nitrogen—on the daily plant growth rate, on a scale of 0 to 1) and two model inputs (planting density and nitrogen fertilization rate) that would be sensitive to simulated yields yet could still be derived in spite of some uncertainties in the DSSAT database. Third, we varied the parameter and each input using three levels. For example, the SLPF was assigned a value of either 0.6, 0.8, or 1.0, whereas planting density and nitrogen rates were assigned either the original values derived from the DSSAT database or 50 percent or 150 percent of these original values. These levels resulted in 27 possible combinations of model parameter and input values for each grid cell. Fourth, we ran DSSAT to simulate yields corresponding to all of these combinations for five continuous years, and then selected the combination of parameter and input levels that gave the lowest relative difference between simulated and observed yields ($Yield_{sim}$ and $Yield_{obs}$):

$$\text{Relative difference} = \frac{Yield_{sim} - Yield_{obs}}{\frac{Yield_{sim} + Yield_{obs}}{2}}. \qquad (3)$$

Finally, within the irrigated and the rainfed grid cells, respectively, for each crop, we identified SPAM cells that were statistically deemed as outliers based on the method by Leys and others (2013). To do so, we calculated the relative difference (positive or negative) between simulated and observed yields and then removed grid cells with too large a relative difference, assuming that DSSAT would not be capable of simulating yields comparable to the observed yields for those grid cells.

CHAPTER 4

Climate-Smart Agriculture Options in Mixed Crop-Livestock Systems in Africa South of the Sahara

Philip K. Thornton, Todd Rosenstock, Christine Lamanna, Patrick Bell, Wiebke Förch, Benjamin Henderson, and Mario Herrero[15]

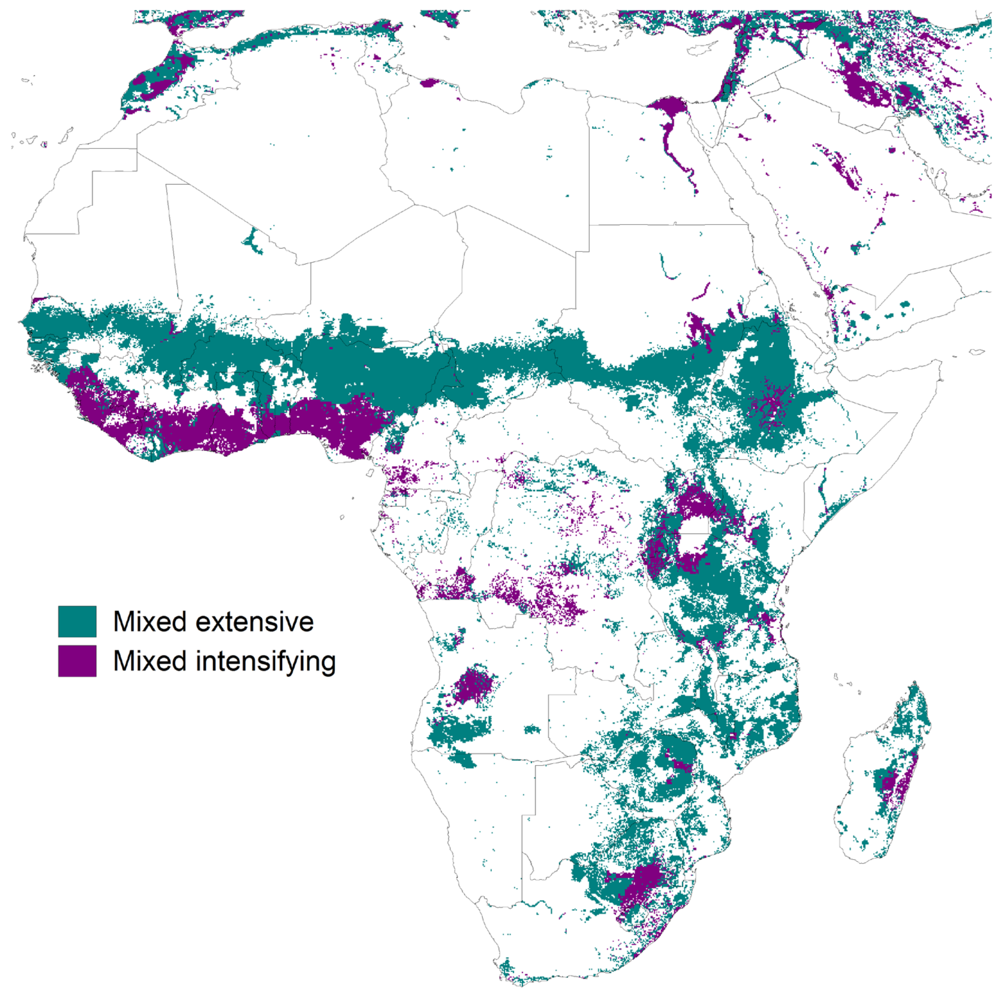
[15] The authors acknowledge funding from the CGIAR Fund Council, Australia; the International Fund for Agricultural Development; the Netherlands; Switzerland; and the United Kingdom to the CGIAR Research Program on Climate Change, Agriculture and Food Security.

This is chapter is drawn from P. K. Thornton, P. K., T. Rosenstock, C. Lamanna, P. Bell, W. Förch, B. Henderson, and M. Herrero, "Evaluating Climate Smart Adaptation Options in Mixed Crop-Livestock Systems in Developing Countries," in *Climate Smart Agriculture: Building Resilience to Climate Change*, edited by D. Zilberman, N. McCarthy, S. Asfaw, and L. Lipper (New York: Springer Science & Business Media, forthcoming).

Mixed crop-livestock systems, in which crops and livestock are raised on the same farm, are the backbone of smallholder production in most of Africa south of the Sahara. They have considerable potential for increasing agricultural production for food security, helping farmers adapt to a changing climate, and providing mitigation benefits: these benefits constitute the three pillars of climate-smart agriculture (CSA). The synergies and trade-offs among these three pillars are not well studied or understood; there is very little robust information in the published literature that evaluates all three pillars of CSA practices. This chapter presents a qualitative analysis that prioritizes investments in CSA in Africa south of the Sahara on a broad scale and concludes with a brief discussion of some of the associated technical and policy implications of current knowledge as well as key knowledge gaps.

Mixed crop-livestock systems are central to smallholder production in the developing countries of the tropics (Herrero et al. 2010). Globally, they produce 69 percent of the world's milk and 61 percent of the meat from ruminants; in Africa south of the Sahara (SSA), they produce more than 90 percent of the milk and 80 percent of the meat from ruminants (Herrero et al. 2013). Figure 4.1 shows the location of mixed systems in Africa, defined as those in which more than 10 percent of the dry matter fed to animals comes from crop by-products or stubble, or more than 10 percent of the total value of production comes from non-livestock farming activities (Seré and Steinfeld 1996). This map distinguishes two types of mixed systems: "extensive," with lower agroecological potential (an annual length of growing period [LGP] of fewer than 180 days per year) and "intensifying," with higher agroecological potential (having an LGP of 180 or more days per year) coupled with better access to urban markets (less than 8 hours' travel

FIGURE 4.1—MIXED CROP-LIVESTOCK SYSTEMS IN AFRICA



Source: Herrero et al. (2009), using a mapped version of the livestock classification system of Seré and Steinfeld (1996).

time to an urban center with a population of more than 50,000). The great majority of these mixed systems are rainfed.

In mixed systems, livestock provide draft power to cultivate the land and manure to fertilize the soil, and crop residues are a key feed resource for livestock. Appropriate integration of crop and livestock activities can lead to greater farm efficiency, productivity, and sustainability (Sumberg 2003), as well as increasing farmers' incomes (Descheemaeker, Amede, and Haileslassie 2010). Mixed systems offer key livelihood diversification options to smallholders in developing countries who aim to minimize the risk associated with agricultural production, liquidity constraints, and high transaction costs, all of which can result in income and consumption fluctuations (Dercon 1996; Davies et al. 2009; Barrett, Reardon, and Webb 2001). These diversification options offer alternatives for addressing some of the challenges posed by a changing climate and increasing climate variability in the future (Thornton and Herrero 2015). The mixed systems also have a role to play in mitigating greenhouse gas (GHG) emissions from the agriculture, forestry, and land-use sectors. Although livestock systems are a considerable source of GHG emissions, the emissions intensities of mixed systems are 24–37 percent lower than those of grazing systems in Africa (Herrero et al. 2013), mostly because of higher-quality ruminant diets. Other mitigation opportunities are afforded by manure amendments for crop production and carbon sequestration in soils and biomass (Liu et al. 2010; Seebauer 2014).

Mixed farming systems have various characteristics that may be advantageous in some situations and disadvantageous in others (van Keulen and Schiere 2004). For example, when conditions are appropriate, the use of draft power allows larger areas of land to be cultivated and planting to be completed more rapidly. On the other hand, these advantages may mean that extra labor (often women's) is required for weeding. On a mixed farm, crop residues can be mulched, thereby helping to control weeds and conserve water, and they are an alternative source of low-quality roughage for livestock. But again, feeding crop residues to livestock may compete with other uses of this material, such as mulching, construction, and nutrient cycling. A major constraint to increased crop-livestock integration is that these systems can be complex to operate and manage (van Keulen and Schiere 2004; Russelle, Entz, and Franzluebbers 2007). Nonetheless, integration may offer one pathway whereby smallholders can increase their livelihood security while reducing their vulnerability to food insecurity as well as to climate change (Thornton and Herrero 2015).

Comprehensive evaluations of the costs and benefits, and the synergies and trade-offs, of different options in African mixed systems are underway, drawn from extensive searches of published literature (Rosenstock et al. 2015, 2016). To date, very few studies have included quantitative evaluation of all three components, or pillars, of climate-smart agriculture (CSA): increasing agricultural production for food security, helping farmers adapt to a changing climate, and providing mitigation benefits. Generalization is thus difficult, and local context has a considerable effect on whether trade-offs or synergies will arise when CSA options are implemented (Rosenstock et al. 2015). This chapter outlines crop and livestock management interventions that may be able to deliver multiple benefits (food security as well as improved climate change mitigation and adaptation) in different situations in SSA. To evaluate how these farm-level CSA management practices and technologies may affect food production, adaptive capacity, and climate change mitigation, we use the protocol of Rosenstock and colleagues (2016), supplemented by a survey of experts, to determine whether the practice has a positive, negative, or undetermined impact on productivity (production per hectare or per animal), resilience (via variables that help buffer the system against shocks and stresses, such as soil organic carbon and input use efficiency, for example), and mitigation (via emission reductions or avoidance). The next sections provide brief descriptions and evaluations of CSA interventions, and discuss constraints to the uptake of these interventions and the potential for their adoption at scale. A simple spatial analysis of potential domains of adoption of these interventions is then presented. The chapter concludes with some of the technical and policy implications of current knowledge as well as knowledge gaps concerning CSA interventions in the mixed crop-livestock systems of SSA.

Climate-Smart Agriculture Interventions in Mixed Systems

Climate-smart options for mixed crop-livestock systems vary widely in their potential impacts on agricultural productivity, climate change resilience, and GHG mitigation. Table 4.1 shows results of an expert survey on 17 CSA options delineated by the Food and Agriculture Organization of the United Nations (FAO 2013). Although most options will improve productivity, impacts on resilience and mitigation are particularly variable due to context specificity. The nine experts surveyed felt that it was particularly difficult to generalize about mitigation impacts, in view of the importance of the precise context and the local situation, and this feeling is reflected in the number of options in Table 4.1 for which the mitigation impacts are judged to be uncertain. It should be stressed again that for some of the interventions, the strength of evidence to support the assessments is quite limited, hence the reliance on expert opinion. The 17 options are very briefly described below.

TABLE 4.1—CLIMATE-SMART OPTIONS AVAILABLE TO SMALLHOLDERS IN MIXED CROP-LIVESTOCK SYSTEMS IN DEVELOPING COUNTRIES: POTENTIAL IMPACTS AND STRENGTH OF EVIDENCE

Region	Potential impacts			Strength of evidence
	Production	Resilience	Mitigation	
Changing crop varieties	+	+/-	+/-	***
Changing crops	+	+	+/-	*
Crop residue management	+/-	+	-	**
Crop management	+	+/-	+/-	*
Nutrient management	+	+	+	***
Soil management	+	+	+/-	**
Changing livestock breed	+	+	+	*
Manure management	+	+/-	+/-	*
Changing livestock species	+	+/-	+/-	*
Improved feeding	+	+/-	+/-	**
Grazing management	+	+	+/-	**
Altering integration within the system	+	+	+	*
Water use efficiency and management	+	+	+/-	**
Food storage	+	+	+	*
Food processing	+	+/-	+/-	*
Use of weather information	+	+	+/-	-
Weather-index insurance	+	+/-	+/-	*

Source: Scoring based on authors' assessment of the articles found in a systematic review of climate-smart agriculture literature (described in Rosenstock et al. 2016), supplemented with an informal survey of nine experts. CSA options from FAO (2013).
Note: The results of the survey were averaged to determine the impact of the practice on the key climate-smart agriculture indicators. Potential impacts: + = positive; - = negative; +/- = uncertain. Strength of evidence: *** = confident; ** = likely; * = poor, - = speculation.

Changing crop varieties: Adaptation strategies such as improved varieties may reduce projected yield losses under climate change, particularly for rice and wheat in the tropics (Challinor et al. 2014). High-yielding varieties can improve the food self-sufficiency of smallholders and increase their income without the need to cultivate extra land. Drought-tolerant varieties have helped to stabilize yields, particularly of cereal crops in rainfed systems (La Rovere et al. 2014). As droughts, pest and disease outbreaks, and water salinization become more common with climate change and increasing demands on natural resources, shifts in crop varieties will continue to be among the first lines of defense for improving productivity and resilience in mixed crop-livestock systems. However, research on crop improvement and resilience has been limited to staple grains for the most part. Within mixed systems, many different crops, including feed and forage species as well as trees or fodder shrubs, contribute to the resilience of the system, but their climate resilience and contribution to smallholder well-being are not always well understood.

Changing crops: Climate change will modify the areas suitable for cultivation of staple crops, requiring farmers to switch crops in some places (Vermeulen et al. 2013). Maize, beans, bananas, and finger millet, staple crops in much of SSA, could experience a reduction of 30–50 percent in areas suitable for cropping (Ramirez-Villegas and Thornton 2015). Changing from less suitable crops to those more suitable in future climates is an effective strategy for maintaining productivity and may increase resilience to climate change. Though many studies have looked at climate impacts on staples, information on the likely impacts of climate change on forages such as Napier grass that are typically used in mixed systems is practically nonexistent. In areas that are projected to see improvements in crop suitability, such as a relaxation of current cold temperature constraints in parts of the tropical highlands in East Africa, for example, mixed crop-livestock farmers may be able to capitalize by planting crops appropriate to the changing climatic conditions.

Crop residue management: Crop residue management practices determine the destination and use of stover and other crop by-products. Some effective residue management solutions retain plant residues and use practices that minimally disturb the soil. In addition to potential increases in soil organic carbon and subsequently increased water infiltration and storage within the soil, effective crop residue management can dramatically decrease soil erosion by protecting the soil surface from rainfall (Lal 1997). Cover cropping typically includes the growing of a nonharvested or partially harvested crop, either in a crop rotation or outside the main growing season. Cover cropping with leguminous crops can be very beneficial to the typically low-fertility and highly weathered soils common in smallholder systems (Snapp et al. 2005). Mulching can increase soil aggregation (Mulumba and Lal 2008) and thus enhance its physical quality, as well as protect soils from direct impact by rainfall, greatly reducing the loss of nutrients and organic matter through soil erosion (Barton et al. 2004).

Crop management: As local weather patterns become more unpredictable with climate change, farmers may need to adjust planting seasons accordingly. Changes in planting dates can have profound impacts on farm productivity (Shumba, Waddington, and Rukuni 1992). However, for some farmers, effective earlier planting may require adjusting cultivation practices in ways such as using pesticides and minimal tillage techniques. Multicropping involves the growing of multiple crops within the same growing season and can include intercropping (within the same field at the same time) with both leguminous and nonleguminous crops and trees (agroforestry). Intercropping can reduce risk substantially: crops in intercropping systems typically access different soil water and nutrient resources, have different water requirements, and have varying growth and maturity rates, all of which can reduce the risk of total crop failure (and the associated risk of food insecurity) due to erratic or decreased precipitation (Ghosh et al. 2006).

Nutrient management: Smallholders on mixed crop-livestock farms can control the distribution of nutrients by applying inorganic and organic fertilizers and composts, growing trees, recycling waste, and improving animal diets. These all have benefits for improving productivity, boosting water and nutrient use efficiency, and reducing the GHG intensity of production (Kimaro et al. 2015; Bryan et al. 2013; Zingore et al. 2007). The transfer of nutrient-rich materials (manure, residues, and feeds) between production activities may have cascading effects across the farm due to changes in available nutrients (van Wijk et al. 2009). For example, conservation agriculture may help to maintain soil chemical and physical properties, but crop residues in mixed systems are often fed to livestock, serving as a vital feed resource during periods of low supply (Giller et al. 2015). Conserving crop residues for soil fertility purposes may reduce the nutrients available to other subcomponents of the system, such as livestock.

Soil management: Managing the soil for climate-related risks often involves increasing its physical quality while maintaining or improving its fertility. Increased soil organic carbon and soil aggregation can lead to increased water infiltration and water storage for plant use. Climate change may negatively affect soil fertility and the mineral nutrition of crops (St. Clair and Lynch 2010). These aspects of soil quality can be addressed through the effective use of crop rotation and leguminous plants and via livestock density management. Crop rotation with leguminous plants may decrease disease incidence, suppress weed infestation, and enhance nutrient cycling (Mureithi, Gachene, and Ojiem 2003). Leguminous plants and trees can be effectively incorporated into smallholder systems through intercropping, relay cropping, and planting boundaries, with their nitrogen-fixing capabilities increasing soil fertility (Kerr et al. 2007).

Changing livestock breed: Local animal breeds in the developing world are generally well adapted to their environments in terms of disease resistance, heat tolerance, and nutritional demand. Their productivity is often low, however, and the emissions intensity of production (the amount of GHG emissions produced per kilogram of milk or meat) can be high. The utilization of more productive animals can provide not only higher productivity but also reduced emissions intensity. Livestock populations exhibit natural genetic variation, and selection within breeds of farm livestock may produce genetic changes in trait(s) of interest in the range of 1–3 percent per year (Smith 1984). Within-breed selection poses challenges because appropriate infrastructure such as performance recording and genetic evaluation programs may be lacking. Cross-breeding is usually more feasible. Locally adapted breeds can be utilized that are tolerant to heat, poor nutrition, and parasites and diseases, and these traits can be transferred to crossbred animals. Cross-breeding coupled with diet intensification can lead to substantial efficiency gains in livestock production and methane output (Thornton and Herrero 2010; Galukande et al. 2013).

Manure management: The utilization of livestock manure to add nutrients back to the soil is a key crop-livestock interaction in mixed farming systems. When used as a soil amendment, manure can benefit the soil, resulting in crop production and resilience benefits for smallholders via increased nutrient supply to crops and improved soil structure and water-holding capacity. Manure has well-documented impacts on soil chemical and physical properties (Srinivasarao et al. 2012; Taddesse et al.

2003). The GHG emissions dimension associated with manure is complex. When stored, manure can release significant amounts of nitrous oxide and methane. Nitrous oxide and other GHGs are also released when manure is applied to the land (Smith et al. 2008). In tropical mixed farming systems, the opportunities for manure management, treatment, and storage are often quite limited, although they may exist in zero-grazing smallholder dairy systems, for example (FAO 2013).

Changing livestock species: The substitution of one species of livestock for another is one strategy that can be used to increase resilience to climatic and economic shocks: risk can be spread by having a more diverse species portfolio, and for a farm with small stock, it will often be easier to shift between small stock species than between larger, less "liquid" stock. In parts of the Sahel, dromedaries have replaced cattle, and goats have replaced sheep in the wake of the droughts of the 1980s (Hoffman 2010). In other areas, smallholders are adopting goats and sheep rather than cattle in response to market opportunities: there is strong urban demand for meat, it is easier to sell small animals, and profits accrue more quickly and are generally less risky with small animals than with larger ones. Traditional cattle keepers in parts of northern Kenya and southern Ethiopia have adopted camels as part of their livelihood strategy as a result of drought, cattle raiding, and epizootics.

Improved feeding: Interventions that target improved feed resources can result in faster animal growth, higher milk production, earlier first calving, and increased incomes. Better nutrition can also increase the fertility rates and reduce the mortality rates of calves and mature animals, thus improving animal and herd performance and system resilience to climatic shocks. For cattle, such interventions may include the use of improved pasture, higher-digestibility crop residues, diet supplementation with grain, small areas of planted legumes ("fodder banks"), the leaves of certain agroforestry species, and grass species that can be planted on field boundaries or in rehabilitated gullies (with added erosion control benefits). Such supplements can substantially increase productivity per animal while also increasing resilience by boosting income (Thornton and Herrero 2010) and reducing the amount of methane produced by the animal per kilogram of meat or milk produced (Bryan et al. 2013).

Grazing management: Native grasses in rangelands and mixed systems are often of relatively low digestibility. Pasture productivity can be increased through adding nitrogen and phosphorus fertilizers, adjusting the frequency and severity of grazing, changing plant composition, and utilizing irrigation. Particularly in the humid and subhumid tropics, substantial improvements in livestock productivity and soil carbon sequestration are possible, as well as reductions in enteric emission intensities, by replacing natural vegetation with deep-rooted pasture species. For example, in Latin America, where Brachiaria grasses have been widely adopted, animal productivity can be increased by 5–10 times compared with diets of native savannah vegetation (Rao et al. 2014). Such options will not always reduce GHG emissions, however (Henderson et al. 2015). Another way in which grazing management may deliver productivity, adaptation, and mitigation benefits is by balancing and adapting grazing pressure on land, though the effects are highly dependent on the context, such as plant species and soil and climatic conditions (Smith et al. 2008).

Altering integration within the system: Smallholders in mixed systems have various options involving changes to the proportion of crops to livestock, and additions or subtractions to the enterprises in which farmers are engaged. Such changes can directly and indirectly affect the integration of the different elements in the farming system with respect to feed, manure, draft power and labor, and cash. Integrated crop-livestock systems offer some buffering capacity for adaptation, with mitigation and resilience benefits too (Thornton and Herrero 2015). In many places, risk reduction may be more important than productivity increases per se (Kraaijvanger and Veldkamp 2015). In dry spells, farmers may reduce their investment in crops or even stop planting altogether and focus instead on livestock production (Thomas et al. 2007). Others may increase off-farm income in poor seasons via trading or some other business activity (Thornton et al. 2007; Deshingkar 2012). Depending on the context, these kinds of transitions may be permanent or semipermanent (Thornton and Herrero 2015; Rufino et al. 2013).

Water use efficiency and management: Improving water use efficiency and water management on mixed farms can have substantial benefits (Harris and Orr 2014). The ability to supply water; mitigate the impacts of variable rainfall on crops, pasture, and animals; and extend growing seasons can all have significant impacts on smallholder livelihoods, increasing yields and economic returns (Burney and Naylor 2012; Kurwakumire et al. 2014; Thierfelder and Wall 2009; Gebrehiwot, Mesfin, and Nyssen 2015). Water harvesting can include practices such as digging zai pits for individual plants and constructing ditches, terraces, or stone lines to direct water to where it is needed, thus conserving soil moisture and improving productivity (Amede, Menza, and Awlachew 2011; Zougmoré, Mando, and Stroosnijder 2004). Investments in soil and water conservation in northern Ethiopia, combined with collective action and a conducive policy environment, have transformed semiarid, degraded lands into productive farming systems that are far less prone to droughts than before, thus transforming smallholder livelihoods and food security (Walraevens et al. 2015).

Food storage: Food losses in SSA generally occur during and after harvest; harvesting techniques, inadequate storage facilities, and pests and diseases cause losses of 30–40 percent, a figure similar to the amount of consumer waste in developed countries (Affognon et al. 2015). Postharvest losses can be reduced by using existing low-cost technologies and methods, many of which have been adopted rapidly in Asia but are not widely used in SSA. Though the appropriate strategy to reduce losses needs to be tailored to the specific agricultural enterprise (in terms of resources available, market orientation, and commodity), several approaches are already available for cereal grains, even for small-scale producers (Kitinoja and Kader 2003). Storage of highly perishable animal products—milk and meat—as well as of higher-value vegetables and fruits presents unique challenges in resource-limited and small-scale producer environments, yet it has received markedly less attention than that of cereals.

Food processing: Like improved postharvest storage methods, food processing presents an opportunity to extend the shelf life of perishable farm products. Food processing also provides a mechanism for smallholders to add value to products at the farmgate. In mixed systems, farmers typically have the potential to create fermented milk and dried meat products as well as derivatives from crop products. By reducing the speed of food degradation, food processing increases or at least maintains the level of consumable farm output. Food processing also typically generates value addition or an extra product that can be sold on the market, facilitating livelihood diversification by creating an alternative revenue stream. Improved longevity and increased marketability of farm production may make smallholders less susceptible to the annual cycles of food insecurity and less vulnerable to shifting weather patterns. The impacts on GHG emissions may depend on context: increased food availability may decrease production-related emissions, but processing may require energy and off-farm transportation.

Use of weather information: Smallholders in rainfed mixed systems deal with rainfall variability in several ways, usually building on long experience. Uncertainty can be reduced through the use of weather information and climate advisories, enabling smallholders to better manage risks and take advantage of favorable climate conditions when they occur (Hansen et al. 2011). The provision of appropriate weather information and associated advisories can help smallholders make more informed decisions regarding the management of their crops and livestock, leading to increased productivity. The effective use of weather information may also be able to contribute to resilience by helping smallholders better manage the negative impacts of weather-related risks in poor seasons while taking greater advantage of better-than-average seasons. Use of weather information may also contribute to GHG mitigation in some situations—for example, by better matching the use of fertilizer and other crop and pasture production inputs with prevailing weather conditions.

Weather-index insurance: Agricultural insurance is one approach to managing weather-related risks; it normally relies on direct measurement of the loss or damage suffered by each farmer, which can be costly and time consuming. An alternative is index-based insurance that uses a weather index (for example, the amount of rainfall in a specified period) to determine payouts for the targeted hazard. In remote areas, the index may be based on satellite imagery of vegetation ground cover as a proxy for fodder availability to insure livestock keepers against drought (Chantarat et al. 2013). Index insurance is often bundled with access to credit and farm inputs, allowing farmers to invest in improved practices that can increase their productivity and food security, even in adverse weather conditions, thereby increasing their resilience (Greatrex et al. 2015). Index insurance may have few direct mitigation co-benefits, but smallholders may be able to enhance carbon sequestration or reduce GHG emissions via the management decisions they make as a result of being insured.

Adoption Constraints and the Potential for Uptake of Climate-Smart Agriculture Interventions

As outlined above, a wide range of options exists for mixed crop-livestock farmers in developing countries, and many of them have positive impacts on at least one or two of the three CSA pillars, some on all three. The evidence base is mixed, however: the scientific literature for some of these options is very scanty, and the results of the expert opinion survey presented here clearly show that local context can have an overriding influence on whether particular practices have positive or negative effects in a certain situation, given that some 40 percent of the impacts shown in Table 4.1 are adjudged to be uncertain. One key message from this analysis is that broad-brush targeting of CSA interventions is not appropriate, from a technical standpoint, given that the impacts are often not clear or are highly context specific.

Independent of context, we can identify common elements that are important to facilitate the adoption of CSA in developing countries. These elements tend to be similar to those that characterize the adoption of other types of sustainable agricultural development or natural resource management strategies. In light of their limited capacity to bear risk, many smallholders tend to select farm portfolios that stabilize income flows and consumption (Barrett, Reardon, and Webb 2001). Under climate change, smallholders' ability to select such portfolios is determined by high-level factors such as conducive enabling policy environments and public investment; the assurance of peace and security; stable macroeconomic conditions; functioning markets and appropriate incentives (or the development of these, including financial, labor, land, and input markets); and the ability and willingness of farmers to invest their own human, social, natural, and physical capital (Ehui and Pender 2005; Westermann, Thornton, and Förch 2015). Sociocultural traditions, including structural social inequalities, marginalization of specific groups, and gender relations, as well as local institutions (with informal rules and regulations) that guide resource use, the division of labor, and household decision making also play a key role in determining whether climate-smarter practices are feasible in specific locations.

As for agricultural technology adoption and uptake in general, many of the CSA interventions outlined above have different constraints. These are laid out in Table 4.2 by intervention, for the following constraints:

- **Investment cost:** Farmers may face up-front infrastructural or technological costs before some types of interventions can be implemented, such as costs for fencing material or irrigation equipment.
- **Input and operating cost:** These are the recurring costs of the needed inputs, including labor, fertilizer, and hybrid seed.
- **Risk:** Certain technologies in some situations (for instance, higher levels of purchased inputs in places with high rainfall variability) may have unintended impacts on production or income variability, which can severely constrain adoption.
- **Access to technology:** Adoption may well be constrained in situations in which smallholders have limited physical access to the technology (such as the seeds of improved crop or pasture varieties).
- **Technical know-how:** Some interventions require high levels of technical knowledge about their implementation and management, which may act as a powerful deterrent to adoption.
- **Temporal trade-offs:** Sometimes trade-offs may need to be made in the short term to realize medium- or longer-term benefits (for instance, losing access to a piece of land while waiting for certain cash crops to produce harvestable yield), and farmers may not have the wherewithal to wait for these benefits to materialize.
- **CSA trade-offs:** In some situations, some interventions may involve trade-offs among the three CSA pillars (that is, the production, resilience, and mitigation objectives). Productivity-enhancing technology (such as adding nitrogen fertilizer, under some circumstances) may, for instance, increase resilience by improving household cash flow but at the same time increase GHG emissions or their intensities.
- **Information:** Some interventions have recurring informational needs, such as seasonal weather forecasts.
- **Acceptability:** Some CSA interventions (for example, practices that may affect a location's communal grazing governance or investments in areas with weak land tenure arrangements) may go against sociocultural norms, directly affecting a technology's acceptability in a community.
- **State of evidence base:** Insufficient evidence to make robust statements about the relative climate smartness of different alternatives in differing contexts may indirectly constrain their uptake.

Table 4.2 demonstrates clearly that all interventions are associated with some constraints that may affect adoption, depending on the circumstances. Despite the constraints, all of these interventions may be suitable in some

TABLE 4.2—CONSTRAINTS TO THE WIDESPREAD ADOPTION OF CLIMATE-SMART OPTIONS AVAILABLE TO SMALLHOLDERS IN MIXED CROP-LIVESTOCK SYSTEMS IN DEVELOPING COUNTRIES

Option	Constraint									
	Investment cost	Input and operating cost	Risk	Access to technology	Technical know-how	Temporal trade-offs	CSA trade-offs	Information	Acceptability	State of evidence base
Changing crop varieties		*		**				*		
Changing crops		*	*	*	*			*	*	
Crop residue management		*	*			**	*		**	
Crop management		*	*					**	*	
Nutrient management		**			*	*	*			
Soil management	*	*			*	*	*			
Changing livestock breed	**	*	*	*	**	*		*	**	*
Manure management	*(*)			*	**		*	**	*	**
Changing livestock species	**	*	*	*	**	*		**	**	*
Improved feeding	*	**		*	*		*	*	*	
Grazing management	**	*		*	**	*	*	**	*	
Altering integration within the system	*		**		*	**	*	**	**	**
Water use efficiency and management	**	**		*	*	*	*		**	
Food storage					*			*	*	**
Food processing	*	*			*		?		*	**
Use of weather information				*	*	*	*?	*	*	**
Weather-index insurance	*		*	**	**	*	*?	**	*	**

Source: Authors' evaluation. CSA options from FAO (2013).
Note: Importance of constraint: ** = major; * = moderate; ? = unknown or highly context specific. CSA = climate-smart agriculture.

circumstances, but currently there is only limited information concerning the potential uptake of CSA interventions at scale, in terms of geographic or other domains.

Toward Prioritizing Investments in Climate-Smart Agriculture in Africa South of the Sahara

One preliminary step toward generating the information needed to prioritize investments in CSA is to identify those locations where different interventions may be profitable and feasible for smallholders given their biophysical, informational, and socioeconomic constraints. As an illustration, we mapped the 17 interventions outlined above to spatial domains in SSA based on the mixed-system classification shown in Figure 4.1. We used the potential impacts of each intervention from Table 4.1 and the nature of the constraints to adoption from Table 4.2 to subjectively evaluate the suitability of each intervention as 0, low, medium, or high in each system. One way to evaluate suitability is to look at potential adoption rates. To date, adoption rates of agricultural technology in SSA have not often exceeded 30 percent over one or two decades (Thornton and Herrero 2010). Accordingly, we used a potential adoption rate of 5 percent (low suitability), 15 percent (medium suitability), or 30 percent (high suitability), nominally for the period to 2030, for each of the 17 CSA interventions. For each intervention, we calculated the size of the rural area and the current number of rural people in each system, crudely multiplied this by the associated adoption rate, and summed the results to give a highly approximate indication of the relative size of the "suitability domain" (in terms of geographic size and rural population) for each intervention. Results are shown in Table 4.3.

Improved feeding and altering the enterprise balance may be suitable over relatively large areas and for large numbers of people living in rural areas, not all of whom are engaged in agriculture, of course (Lowder, Skoet, and Singh 2014). Food storage, grazing management, and changes in livestock species (particularly from large to small ruminants or from ruminants to nonruminants) are also options with relatively large domains, according to this analysis. The results for food storage are noteworthy; this intervention appears to have solid CSA benefits, particularly those related to increased food availability, but also resilience and mitigation benefits, burdened with only moderate (rather than major) technical and informational constraints (Table 4.2). Considerable effort and resources might well be warranted to increase the uptake of simple food storage technologies and the availability of appropriate information.

Table 4.3 also reveals some interesting differences among systems. The crop-related options generally have higher potential in the intensifying mixed systems, as might be expected. In the extensive mixed (agropastoral) systems, the social acceptability of changing livestock breeds may be a big constraint, with the new breeds offering considerably less potential in these systems than in the intensifying mixed systems, where increasing market orientation may be modifying traditional views on livestock's role

TABLE 4.3—AGRICULTURAL SYSTEM DOMAINS WHERE CLIMATE-SMART OPTIONS MAY BE SUITABLE FOR SMALLHOLDERS IN MIXED CROP-LIVESTOCK SYSTEMS IN AFRICA SOUTH OF THE SAHARA

CSA option	"Suitability"		Total area (in million km²)	Total rural population (2000, in millions)
	EM	IM		
Changing crop varieties	1	3	0.67	60.62
Changing crops	2	3	1.12	85.78
Crop residue management	0	1	0.07	8.01
Crop management	1	2	0.45	36.60
Nutrient management	1	2	0.45	36.60
Soil management	1	2	0.45	36.60
Changing livestock breed	2	3	1.12	85.78
Manure management	2	2	0.91	61.76
Changing livestock species	3	2	1.59	99.50
Improved feeding	3	3	1.81	123.52
Grazing management	3	2	1.59	99.50
Altering integration between crops & livestock	3	3	1.81	123.52
Water use efficiency and management	2	1	0.76	45.75
Food storage	3	2	1.59	99.50
Food processing	1	2	0.45	36.60
Weather information	3	1	1.45	83.49
Weather-index insurance	2	2	0.91	61.76

Source: Population data from CIESIN (2005). Suitability ratings are the authors' own estimates. CSA options from FAO (2013).

Note: Relative suitability: 0 = not suitable; 1 (low) = 5 percent potential adoption; 2 (medium) = 15 percent potential adoption; 3 (high) = 30 percent potential adoption. EM = extensive mixed systems; IM = intensifying mixed systems (from Herrero et al. 2009; see Figure 4.1). CSA = climate-smart agriculture.

in livelihood systems. Similarly, nutrient management options may have substantial input and operating costs, particularly related to labor, so their potential in the extensive mixed systems is likely to be low, but they show higher potential in the intensifying mixed systems. It is worth noting that some of these potentials may already be changing as climate-targeted financing becomes increasingly available for adaptation and mitigation purposes. From the mitigation perspective, livestock may well be an increasing priority because of their high emissions and also their considerable potential to reduce the emissions intensity of livestock products in SSA, principally through improved diets (Thornton and Herrero 2010).

There are several obvious weaknesses with this analysis: the subjective nature of the suitability index, the fact that potential adoption rates are likely to be context- and intervention-specific, and the lack of specificity as to what the exact intervention actually is in each category (for instance, "improved feeding" is a broad term covering many different types of interventions). Nevertheless, this type of broad-brush analysis, if done on a regional basis in relation to specific interventions and with as much quantifiable information as possible, could be very helpful as a first step in prioritizing investments in CSA over the next few years.

Conclusions

The analysis presented here is largely qualitative because at present we lack comprehensive information on the costs, benefits, synergies, and trade-offs of many of the interventions examined. This lack of information is partly because the current state of science for CSA in the mixed systems in SSA is sparse, notwithstanding the efforts of Rosenstock and colleagues (2016) to seek out information through a very extensive review of the literature. There are gaps in our understanding of some of the key biophysical and socioeconomic interactions at the farm level. At the same time, we do not lack for analytical tools and methods that could be used for quantitative priority setting to help allocate the resources needed to stimulate widespread adoption of CSA. To overcome the dearth of field-based evidence on CSA practices and their interactions, modeling tools for the ex ante evaluation of these practices will be particularly useful in these early stages of CSA programming. The outputs of these models can in turn be used to help specify the biophysical relationships in bioeconomic models suited to the ex ante assessment of CSA practices. Although such assessment is important, field-based research and ex post analyses of the adoption of interventions and their economic impacts will also be needed to expand the evidence base as to what works where and why.

Despite the limitations of the analysis presented here, some conclusions can be drawn. First, from a technical perspective, there are no "silver bullets" for climate smartness in the mixed systems. Though this statement echoes the conclusions of the semiquantitative analysis in Thornton and Herrero (2014), the present analysis looked at a much wider range of possible interventions. Table 4.1 indicates that triple wins undoubtedly exist (for example, certain nutrient management practices, changing livestock breeds, and improved ruminant diets can all lead to productivity gains, increased resilience, and mitigation benefits compared with business as usual, in some situations). But technical recommendations over broad domains covering all or even most circumstances may not be appropriate.

Second, from an adoption perspective, a range of different constraints exist that may impede the widespread adoption of all these innovations. These constraints may involve investment or running costs, access to technology and knowledge of how to implement it, social acceptability, or local governance issues. In different contexts, these concerns may conspire to prevent the incremental and transformational shifts toward CSA that may be needed.

Third, some of the interventions evaluated present significant trade-offs between shorter-term food production or food security objectives and longer-term resilience objectives. Such trade-offs apply particularly to crop residue management and altering the integration of crops and livestock within the system, but also to several other interventions (nutrient, soil, and water management; grazing management; changing livestock species and breeds; and use of weather information and weather-index insurance). These temporal trade-offs may be difficult to resolve in many local contexts, making the triple wins these interventions promise sometimes elusive.

Fourth, the analysis has highlighted several CSA options for which the evidence base is severely lacking. Food storage and food processing appear to have relatively few constraints, although their impacts are uncertain and largely unquantified. As noted previously, these options appear to be heavily under-researched and would benefit from well-targeted research efforts. For these options, as for the use of weather information and weather-index insurance, the evidence base as to their impacts is weak, highlighting the need for robust impact studies that can help guide future research-for-development investment.

Despite some key knowledge gaps, the lack of a silver bullet, the constraints to adoption, and the trade-offs that may arise between shorter- and longer-term objectives at the household level, much is being done. Although more comprehensive information could help target interventions more effectively and precisely, in many situations appropriate information already exists, for example, regarding interventions that fit well within current farming practices and do not significantly increase labor demands and household risk. Evidence is also accumulating of the kinds of approaches that can support the scaling up of CSA interventions. Multistakeholder platforms and policy making networks are key, especially if paired with capacity enhancement, learning, and innovative approaches to support farmers' decision making (Westermann, Thornton, and Förch 2015). Modern information and communications technology offers efficient and cost-effective ways to disseminate and collect information at a massive scale, as well as an infrastructure for developing and utilizing new and diverse partnerships. A certain level of local engagement may still usually be needed, paying attention to farmers' needs and their unique situations (Westermann, Thornton, and Förch 2015).

CHAPTER 5

Trade, Climate Change, and Climate-Smart Agriculture

Beliyou Haile, Carlo Azzarri, Jawoo Koo, and Alessandro De Pinto[16]

16 The authors acknowledge the generous support of the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), which is carried out with support from CGIAR Fund Donors and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors. We also thank the CGIAR Research Program on Policies, Institutions, and Markets (PIM) for supporting previous initiatives upon which we have built our modeling work.

The eradication of poverty in Africa south of the Sahara (SSA), whose poverty rate is the highest in the world, and of its food and nutrition insecurity necessitates structural transformation of the agricultural sector. Meanwhile, global climate change models suggest an overall warming trend and increased incidence of extreme weather events that vary by altitude (Serdeczny et al. 2017). These changes are expected to have a significant impact on agricultural productivity and the availability of productive resources globally and in SSA, a region that relies heavily on rainfed agriculture (Knox et al. 2012; Müller and Robertson 2014).

At the same time, agriculture affects climate change through anthropogenic greenhouse gas (GHG) emissions and by acting as a greenhouse gas sink. GHG emissions result, for instance, from enteric fermentation, application of synthetic fertilizers, land use change, and deforestation, while a sink removes atmospheric GHG by storing (sequestering) it in other forms through photosynthesis. Africa accounted for 15 percent of the world's agriculture-related GHG emissions in 2012, making it the third most important contributor, after Asia (45 percent) and the Americas (25 percent) (Tubiello et al. 2014). Considering the pressure on agricultural production driven by population growth, growth in gross domestic product (GDP) and a consequent change in diets toward higher consumption of animal-source foods, and the risks posed by climate change, farmers need options to sustainably increase production.

Climate-smart agriculture (CSA) is one approach that has been promoted to enhance agricultural productivity, food security, and adaptive capacity, while at the same time reducing GHG emissions and increasing carbon sequestration (Campbell et al. 2014; Huang, Lampe, and Tongeren 2011). The CSA approach, which became prominent during the First Global Conference on Agriculture, Food Security and Climate Change (FAO 2013), is an umbrella term that includes many strategies built upon location-specific solutions that are expected to contribute toward achievement of the Sustainable Development Goals (SDGs). It relies on agricultural systems that contribute to three outcomes: (1) sustainable and equitable increases in agricultural productivity and income; (2) greater resilience of food systems and farming livelihoods, and (3) reduction and removal of GHG emissions associated with agriculture, wherever possible. Agricultural production systems that follow the tenets of CSA are expected to be not only more productive and efficient, but also resilient to short-, medium-, and long-term shocks and risks associated with climate change and variability.

The CSA approach represents a departure from the single-objective approach that underlies most work to ensure food and nutrition security. CSA's multi-objective approach facilitates important conversations, negotiations, and coordination of interventions among different ministries. Many operational aspects of CSA, however, are still under investigation. Local contexts determine the enabling environment, the trade-offs, and the synergies of CSA, so practices and technologies may be climate smart in some circumstances and conditions but not in others. Therefore, how these practices deliver across the three pillars of CSA, and the conditions for their adoption, are highly specific to contexts and locations, with fundamental implications for the operational aspects of CSA (McCarthy, Lipper, and Branca 2011). Indeed, short-term productivity may even decrease under CSA (Pittelkow et al. 2015), with more stable and often increasing yields observed over time, especially under dry or drought-stressed conditions (Corbeels et al. 2014; Pittelkow et al. 2015).

Another approach being promoted to ensure the eradication of extreme poverty and promote inclusive and sustainable development, especially in the face of climate-induced changes in the amount and distribution of production, is trade (Sommer and Luke 2016). Trade is recognized as a cross-cutting means of implementing the 2030 Agenda for Sustainable Development under SDG 17. Agricultural commodity trade in Africa has increased steadily over the past 30 years, with net exports (exports minus imports) rising from 2 to 6 percent of GDP between 1980 and 2014 (IMF 2016). Despite these improvements, the region not only accounts for a small share of the global commodity trade but has one of the lowest intraregional trades in goods (16 percent, versus 17 percent for South and Central America, 42 percent for North America, 62 percent for the European Union, and 64 percent for Asia) (Davis 2016; Khandelwal 2005; Tamiotti et al. 2009).

Although a number of regional economic communities (RECs) have been established to promote economic integration and trade, including the Common Market for Eastern and Southern Africa (COMESA),[17] the Economic Community of West African States (ECOWAS),[18] and the Southern African Development Community (SADC),[19] intraregional trade remains staggeringly low. For example, between 2001 and 2010, intraregional trade grew at 2 percent, 1.3 percent, and 0.9 percent per year, on average, for ECOWAS, SADC, and COMESA, respectively, and intraregional trade accounted for 9 percent, 9.8 percent, and 5.6 percent of the total trade, on average, for ECOWAS, SADC, and COMESA, respectively (Seid 2013). But intraregional trade is expected to increase in the coming decades, thanks to an emerging favorable trade environment including the establishment of the African Continental Free Trade Area (UNCTAD 2016); the Malabo declaration, aimed at tripling intracontinental trade in agricultural commodities and services by 2025; and the African Union's Agenda 2063, which aims to increase intracontinental trade from 12 percent to 50 percent and the continent's share of global trade from 2 percent to 12 percent between 2013 and 2045 (African Union Commission 2015).

This chapter examines the role of CSA in mitigating the negative effects of climate change on yields and commodity trade flows in SSA. The analysis is disaggregated by the three RECs—SADC, ECOWAS, and COMESA—to capture possible region-specific factors that could mediate the interaction between agricultural production and trade flow as well as potential location specificity in the effectiveness of CSA practices. We simulate the expected effects of adoption of four CSA practices for the period 2018–2025: no tillage (NT) and integrated soil fertility management (ISFM) for maize, and urea deep placement (UDP) and alternate wetting and drying (AWD) for rice. These practices are found to increase agricultural productivity and net exports, highlighting the potential that CSA has in mitigating climate-induced risks in agricultural production, food security, and foreign currency.

---

17 COMESA includes Burundi, Comoros, Democratic Republic of the Congo, Djibouti, Egypt, Eritrea, Ethiopia, Kenya, Libya, Madagascar, Malawi, Mauritius, Rwanda, Seychelles, Sudan, Swaziland, Uganda, Zambia, and Zimbabwe.

18 ECOWAS includes Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

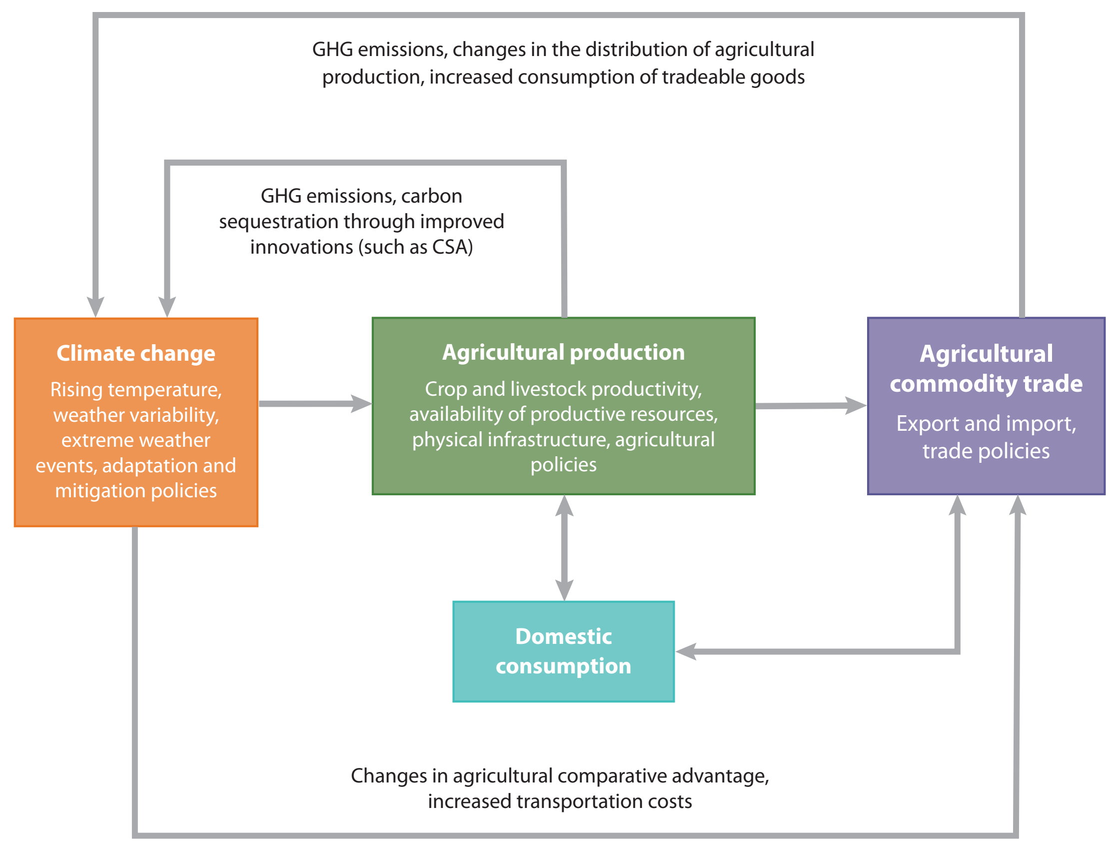
19 SADC includes Angola, Botswana, Democratic Republic of the Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, United Republic of Tanzania, Zambia, and Zimbabwe, of which eight also belong to COMESA.

Conceptual Framework

The linkage between climate change, agricultural production, and trade flow is quite complex, as summarized in Figure 5.1. Given the reliance of Africa's agriculture on weather and its role in the region's trade, climatic changes such as rising temperature, weather variability, and extreme weather events (such as El Niño and La Niña) will have a significant impact on the availability of productive resources, productivity, food security, foreign exchange, and physical infrastructure (Müller and Robertson 2014). Important drivers of the relationship between agriculture and trade in the region are the production landscape and the biophysical conditions. Favorable climatic and weather conditions increase net exports by affecting the supply of exportable commodities, whereas climate changes and variability that reduce the supply of agricultural production have the opposite effect, given the possibility of substitution between internally produced and externally procured goods.

Climate change affects not only yields but also the pattern of production, the latter by changing countries' comparative advantage in the production of certain crops. By changing precipitation patterns and reservoir storage, it will also impact water availability for power production and irrigation (You et al. 2011). The effects of climate change will vary by agroecology and by countries' adaptive capability (Hebebrand 2009; Kang et al. 2009;

FIGURE 5.1—LINKAGES BETWEEN CLIMATE CHANGE, AGRICULTURAL PRODUCTION, AND AGRICULTURAL COMMODITY TRADE



Source: Authors, based on review of relevant literature.
Note: CSA = climate-smart agriculture; GHG = greenhouse gas.

Wheeler 2011). For example, rising temperatures will lengthen the growing period in mid- and high-latitude areas, with lower temperatures having the opposite effect in low-latitude areas. In this regard, a widespread adoption of improved agricultural technologies and management practices that reduce GHG emissions, improve the sequestration of carbon in agricultural soils, and curtail undesirable land use changes could play a crucial role in mitigating the effects of climate change.

Unlike continuous tillage, which leaves soils prone to erosion and is a major source of soil carbon loss (Reicosky et al. 2005), NT practices improve general soil fertility through retention of water and nutrients, at the same time benefiting soil aeration and biota, with potential direct effects on agricultural productivity (Hobbs, Sayre, and Gupta 2008; Thierfelder, Mwila, and Rusinamhodzi 2013). The existing literature on conservation agriculture, of which NT is an essential component, points to an increase in yields, but the effects are notably variable, dependent on a range of location-specific factors such as climate and soil type (Pittelkow et al. 2015; Lal 2015; Erenstein et al. 2012). Similarly, ISFM, a set of locally adapted practices using residues along with both organic and inorganic inputs (for instance, animal manure and green manure) to promote the efficient use of nutrients, can significantly increase productivity (Vanlauwe et al. 2011).

Given that agriculture is a crucial foreign exchange earner in SSA, climatic changes that affect productivity and the distribution of production will ultimately impact the region's trade flow. In addition, extreme weather events such as La Niña and El Niño, which interfere with ship navigation and port operations as well as damaging physical infrastructure, could hamper the flow of trade locally, regionally, and internationally. At the same time, trade contributes to climate change through increased GHG emissions due to the transportation of commodities and increased consumption of tradable goods. Free trade can help offset climate-induced changes in agricultural production and food supply, and trade liberalization and investments can encourage the introduction of more (energy-) efficient production processes that emit fewer GHGs per unit of output produced and traded. Thus, trade can serve as both a mitigation and an adaptation strategy to climate change.[20]

Finally, trade and agricultural policies can either worsen or mitigate climatic changes, depending on whether they encourage or limit the production and distribution of GHG-intensive goods (IPCC 2007). Similarly, large-scale adoption of improved technologies and practices can cause an agricultural glut if local, regional, and international markets are too weak to absorb the boost, potentially inducing suboptimal adoption in subsequent cropping seasons. Although disentangling these complex linkages between climate change, agriculture, and trade is beyond the scope of this study, the chapter examines the potential role of CSA in enhancing yields and trade flow in SSA in the face of expected climatic changes.

Data and Summary

The analysis uses secondary data from several sources. A time series (1993–2010) of country-level data on the gross value of agricultural production in purchasing power parity (PPP) (constant 2004–2006 international

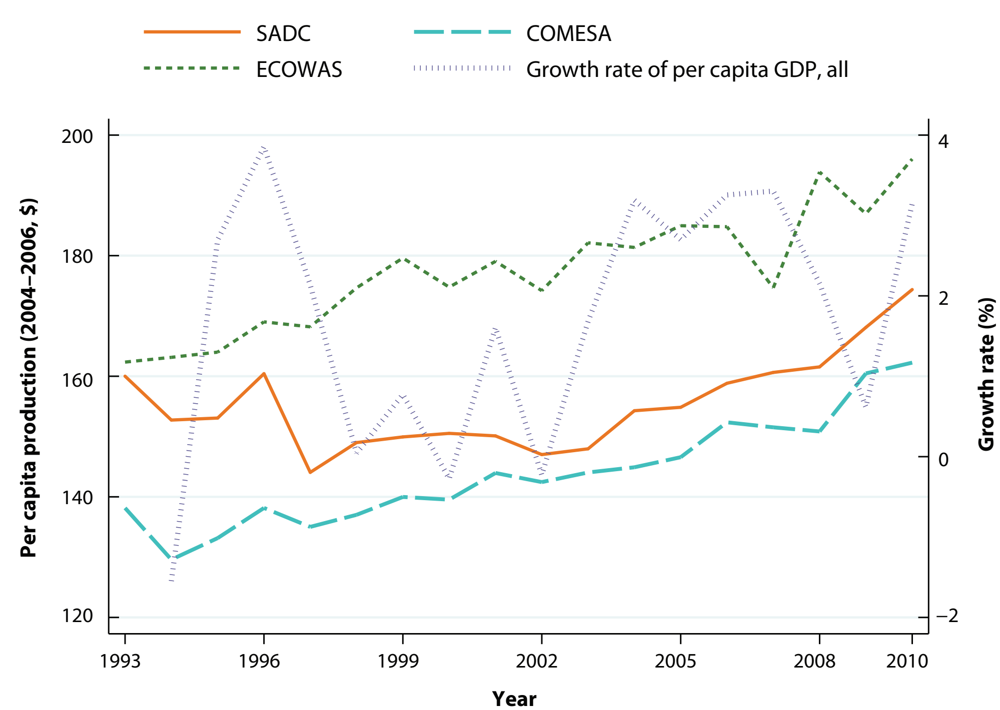
[20] Mitigation aims at reducing GHG emissions sources or enhancing GHG sinks, whereas adaptation refers to adjustments to mitigate detrimental effects of actual or anticipated climatic changes and to seize opportunities induced by climate change (IPCC 2007).

dollars)[21] and trade flow in US dollars comes from the Food and Agriculture Organization's trade statistics database, FAOSTAT (FAO 2017). Data on population and GDP per capita in PPP (constant 2011 international dollars) are obtained from the World Bank (World Bank 2017a, 2017b).

For crop modeling, we use a time series of site-specific weather data from the US National Aeronautics and Space Administration's (NASA's) AgMERRA database (Ruane, Goldberg, and Chryssanthacopoulos 2015). AgMERRA (based on NASA's Modern-Era Retrospective Analysis for Research and Applications, or MERRA) compiles satellite-measured weather data for 30-arc-minute grid squares, including minimum temperature, maximum temperature, solar radiation, and precipitation. Our source for high-resolution (in 5-arc-minute grid squares) soil property data is the Global High-Resolution Soil Profile Database (IRI et al. 2015). The geography of the two crops we simulate (maize and rice) is based on the Spatial Production Allocation Model (SPAM) (IFPRI and IIASA 2016).[22]

Figure 5.2 summarizes the per capita gross value of agricultural production (constant 2004–2006 international dollars). Per capita gross value has been rising steadily over the years, with ECOWAS reaching consistently higher production than the other two RECs. The population of the region grew at about 2.3 percent per year, whereas per capita GDP (constant 2011 international dollars) grew at about 1.7 percent, with a much faster growth observed from the first years

FIGURE 5.2—HISTORICAL PER CAPITA GROSS PRODUCTION VALUE (LEFT AXIS) AND GROWTH RATE OF PER CAPITA GROSS DOMESTIC PRODUCT (RIGHT AXIS), SELECTED AFRICAN REGIONAL ECONOMIC COMMUNITIES, 1993–2010



Source: Authors' own calculations based on agricultural production data from FAO (FAO 2017) and population data from the World Bank (World Bank 2017b).

Note: COMESA = Common Market for Eastern and Southern Africa; ECOWAS = Economic Community of West African States; GDP = gross domestic product; I $ = international dollars; SADC = Southern African Development Community.

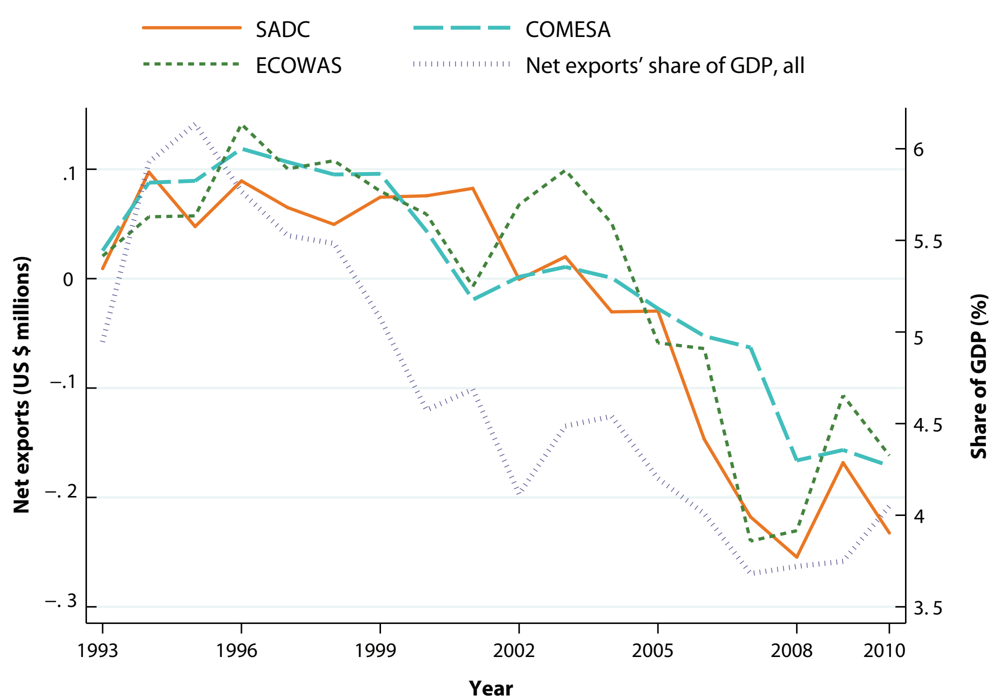
21 An international dollar has the same purchasing power as the U.S. dollar has in the United States. Values and costs in local currency are converted to international dollars using purchasing power parity (PPP) exchange rates. The PPP between two countries A and B measures the amount of A's local currency needed to purchase a basket of commodities in A as compared to one unit of B's currency needed to purchase a similar basket of commodities in B (World Bank, 2017c).

22 The analysis excludes the following countries due to incomplete data on trade, simulated yields, or both: Benin, Cabo Verde, Comoros, Djibouti, Egypt, Liberia, Mauritius, Seychelles, and Sierra Leone.

of the new millennium until the dip in 2009, following the 2007–2008 financial crisis.

Figure 5.3 summarizes net agricultural exports (in millions of US dollars) by REC. Overall, the region has been a net importer of agricultural commodities since just after the turn of the 21st century, with net exports (in absolute value) accounting for about 4.5 percent of GDP, on average. Although the gross value of agricultural production has been rising, the relatively faster economic growth since the early years of the century has created a strong demand for consumer-oriented agricultural products such as prepared foods, dairy, poultry, and vegetables (USDA 2014). What is more, many of the net importers were unable to pay for their imports. For example, the export revenues of only one-third of African countries were large enough to pay their food import bills, with the rest of them resorting to external funding (Rakotoarisoa, Iafrate, and Paschali 2011). Cereals, oilseeds, and dairy products accounted for more than 60 percent of the region's total imports, whereas coffee, cocoa, tea, and fruits and vegetables accounted for more than 55 percent of total exports (Rakotoarisoa, Iafrate, and Paschali 2011).

FIGURE 5.3—HISTORICAL TOTAL AGRICULTURAL NET EXPORTS, SELECTED AFRICAN REGIONAL ECONOMIC COMMUNITIES, 1993–2010



Source: Authors' own calculations based on trade flow data from FAO (FAO 2017) and GDP data from the World Bank (World Bank 2017a).
Note: COMESA = Common Market for Eastern and Southern Africa; ECOWAS = Economic Community of West African States; GDP = gross domestic product; SADC = Southern African Development Community.

Method

Climate-Smart Agriculture and Yields

Crop growth is affected by several factors, including weather condition, soil type, and farmers' management practices. Process-based crop models simulate crop growth by dynamically interacting these factors. Since the 1970s, as plant science has rapidly advanced with a better understanding of how plant photosynthesis and respiration processes work, various forms of dynamic crop models have been developed and used to support farm management decision making. Given the complex nature of CSA implementation in the fields and its potential impacts, this study uses the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom et al. 2015; Jones et al. 2003) to simulate the effects of the adoption of selected CSA practices.

DSSAT combines a suite of complex and dynamic crop system models to estimate the biophysical responses of crops under various scenarios, in our case, scenarios of large-scale CSA technology adoption by farmers. DSSAT integrates the effects of crop system components and management options to simulate the states of all the components of the cropping system and their interactions. DSSAT crop models are designed based on a systems approach, which provides a framework for users to understand how the overall cropping system and its components function throughout cropping season(s) on a daily basis. Table 5.1 summarizes the CSA practices we focus on.

TABLE 5.1—SUMMARY OF CLIMATE-SMART AGRICULTURAL PRACTICES CONSIDERED

CSA technology	Definition	Crop
No tillage	Minimal or no soil disturbance, often in combination with residue retention, crop rotation, and use of cover crops	Maize
Integrated soil fertility management	Combination of chemical fertilizers, crop residues, and manure or compost	Maize
Alternative wetting and drying	Repeated interruptions of flooding during the season, causing water to decline as the upper soil layer dries out before subsequent reflooding	Rice
Urea deep placement	Strategic burial of urea "supergranules" near the root zones of crop plants	Rice

Source: Authors' review of the relevant literature.
Note: CSA = climate-smart agriculture.

It has been shown that ISFM improves the resilience of soils and agricultural production systems to weather variability (Roobroeck et al., 2016). This finding is dependent on the fact that synthetic fertilizers and organic inputs bring diverse benefits to the soil. AWD has been used in paddy rice cultivation, one of the main sources of non–carbon dioxide GHG emissions from the agriculture sector, after livestock and soil (Smith et al. 2014), to significantly reduce methane emissions from rice paddies (FAO 2013; Tyagi, Kumari, and Singh 2010) and, in some instances, also to increase yields (Rejesus et al. 2011).

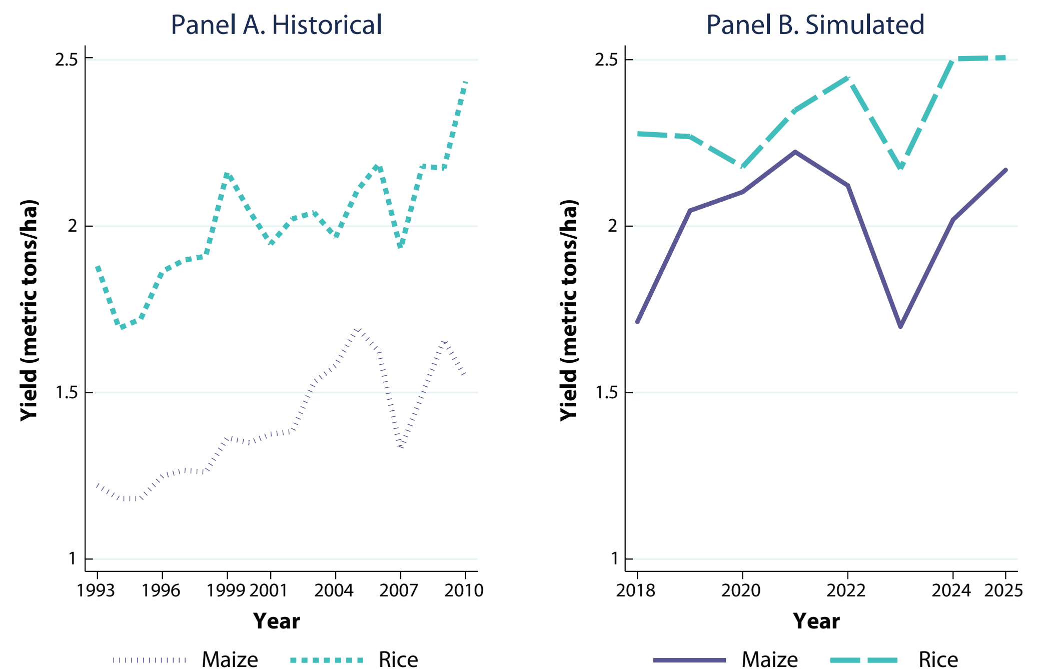
UDP aims at the efficient use of nitrogen, key to both increased production and reduced emissions (FAO 2013). Broadcast application of nitrogen in rice fields leads to 60 to 70 percent nitrogen losses, directly contributing to both water pollution and GHG emissions. The placement of urea "supergranules" deep in the soil provides a slow release of fertilizer near the root system of rice plants, thereby improving the efficiency of nutrient uptake and limiting nitrogen losses. The result is an increase in yields combined with a significant reduction in leached nitrates and therefore a lower likelihood of nitrous oxide emissions. At the same time, UDP increases the resilience of agricultural systems by making them less susceptible to economic shocks due to changes in energy prices.

Conditions for adoption of CSA practices are highly context and location specific, highlighting the need for information and data to make a true CSA approach to agricultural development operational (McCarthy, Lipper, and Branca 2011). From the farmers' perspective, however, the problem is quite different. Adoption of practices and technologies that are alternatives to the status quo depends on many factors. An extensive literature has investigated the socioeconomic determinants of adoption of alternative practices, attempting to account for farmers' and farms' characteristics by considering access to markets and credit, the characteristics of the technology, the quality of extension services, and risk factors as important factors of adoption (Bewket 2007; Enfors and Gordon 2008; Shiferaw, Okello, and Reddy 2009; Teklewold and Kohlin 2011).

We assume that farmers who are currently using a determinate set of practices to produce either maize or rice have the option to choose from a portfolio of alternatives (that is, the four CSA practices considered). In addition, we assume that they have complete information regarding potential yields and are able choose the alternative that provides the highest yield for their grid square compared with business-as-usual practices, a scenario we refer to as a "smart farmer option." Depending on the location, therefore, the CSA practice that corresponds with the smart farmer option could be one of the four CSA practices we are considering (NT or ISFM for maize and UDP or AWD for rice). In cases in which the alternatives are not projected to produce yield gains, farmers are assumed to retain the current practices. Although these assumptions are an extreme simplification of the conditions for adoption of alternative practices, it is difficult to imagine that countries would favor the widespread use of technologies that reduce yields in the face of high population growth rates and changing diets. Therefore, the yield-increase assumption on which adoption is based is considered justified with the understanding that the analysis could overestimate CSA adoption rates and hence their effects.

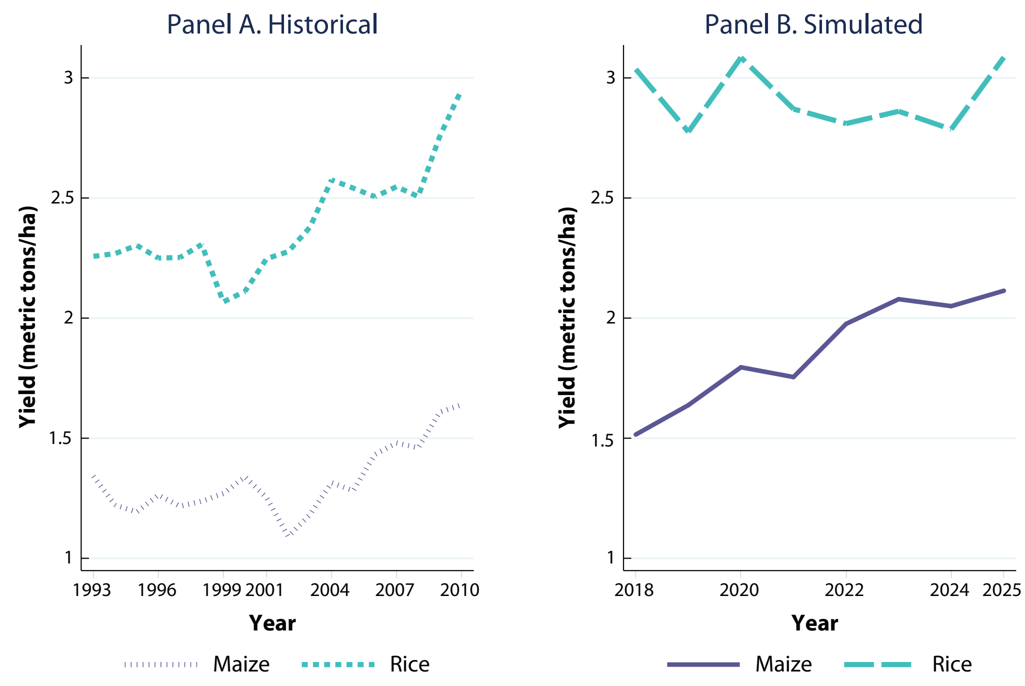
For each grid-cell level and crop, yields were simulated for alternative CSA practices for 2018–2025 based on AgMERRA weather data for 2003–2010, assuming the weather patterns for 2018–2025 will be identical

FIGURE 5.4—HISTORICAL (1993–2010) AND SIMULATED (2018–2025) YIELDS UNDER THE SMART FARMER OPTION, ECOWAS



Source: Authors' own calculation based on historical yield data from FAO (FAO, 2017) and DSSAT-simulated yields.

FIGURE 5.5—HISTORICAL (1993–2010) AND SIMULATED (2018–2025) YIELDS UNDER THE SMART FARMER OPTION, COMESA



Source: Authors' own calculation based on historical yield data from FAO (FAO, 2017) and DSSAT-simulated yields.

to those of the earlier period. To simulate the effects of CSA on agricultural commodity trade flow, simulated yields are converted into monetary values using crop-specific FAOSTAT data on cultivated area and a PPP conversion factor.[23]

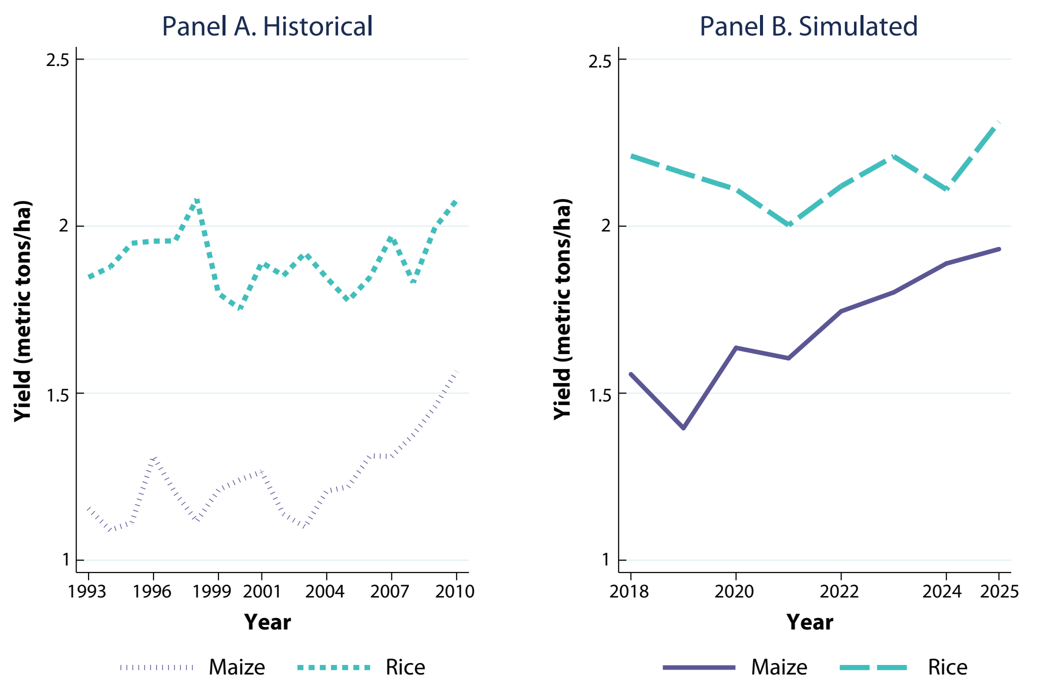
A summary of historical and simulated yields (in tons/hectare)[24] associated with the smart farmer option for each REC is shown in Figures 5.4–5.6. The ECOWAS region has witnessed a steady increase in maize yield over the years, except for 2007 (Figure 5.4, panel A), whereas the increasing trend in maize yield observed for COMESA (Figure 5.5, panel A) and

23 The PPP conversion rate is calculated as the ratio between production value in thousands of constant 2004–2006 international dollar per metric ton and the quantity of production in metric tons.

24 Throughout the chapter, tons refers to metric tons.

SADC (Figure 5.6, panel A) begins after the early years of the 21st century. Compared with maize yields, rice yields show more temporal variation. Nonetheless, given the projected climatic changes, these increasing trends in yields may not be sustained (Lesk and Ramankutty 2016). On the other hand, large-scale adoption of CSA practices has the potential to increase yields, as summarized in panel B of the respective figures.

FIGURE 5.6—HISTORICAL (1993–2010) AND SIMULATED (2018–2025) YIELDS UNDER THE SMART FARMER OPTION, SADC



Source: Authors' own calculation based on historical yield data from FAO (FAO, 2017) and DSSAT-simulated yields.

Climate-Smart Agriculture and Trade Flow

To examine the link between agricultural production and trade flow, we estimate Equation (1) using historical data:

$$NX_{ct}=\alpha_0 + \alpha_1 Y_{ct} + \Lambda' Z_{c(t)}+\gamma t + \varepsilon_{ct} , \qquad (1)$$

where *c* and *t* are country and year indexes, respectively; *NX* is the gross value of total agricultural net exports (in millions of US dollars); *Y* is the logarithm (log) of the gross value of agricultural production (in constant 2004–2006 international dollars, thousands); *Z* is a matrix of time-varying or time-invariant factors that could affect net exports, including the log of per capita GDP (in constant 2011 international dollars), population (in millions), price indexes of agricultural imports and exports, and crop land area (millions of hectares); *t* is a linear time trend to capture overall temporal trends in *NX*; and ε is the (composite) error term.

For the sake of comparability, Equation (1) is estimated using pooled ordinary least squares (OLS) and random-effects (RE) estimators, the latter assuming *Y* and *Z* to be exogenous (see Cameron and Trivedi 2005 and Wooldridge 2010 for general discussions). Since we are estimating a level-log model, a percent increase in *Y* is associated with $\widehat{\alpha_1}/100$ change in *NX*, where $\widehat{\alpha_1}$ is the coefficient estimate of *Y*. Robust standard errors are clustered at the country level to correct for intracountry serial correlation and cross-country heteroscedasticity. Next, OLS point estimates from Equation (1) and the projected increase in the gross value of agricultural production are used to simulate the effects of CSA on net agricultural exports for the period 2018–2025. To simulate net exports, we assume that the values of Z during the forecast period will remain the same as those during 2003–2010. A similar assumption is made about the value of all other agricultural commodities (except maize and rice) that constitute Y, so that simulated Y (Y^s) is calculated as $Y_s = Y - Y_c^b + Y_c^s$, where b, s, and c index baseline, simulation, and crop (either maize or rice), respectively.

Results and Discussion

Table 5.2 presents OLS and RE estimates of Equation (1). Overall, coefficient estimates are jointly significant, although only at the 10 percent level for the RE estimator. The model fitness statistic from the OLS estimation shows that the conditioning variables explain about 40 percent of the model variance. The overall model fitness in the RE estimation (R-squared overall) is about 23 percent and the fact that "R-squared overall" and "R-squared within" are not quite close suggests the importance of country fixed effects. The fraction of the variance due to country fixed effect (rho) is 0.76. Depending on the estimator, a 1 percent increase in the gross value of agricultural production (in constant 2004–2006 international dollars, thousands) increases total agricultural net exports by about US$4,000 to US$4,500. Alternatively, climatic changes that cause a 1 percent reduction in the value of agricultural production will reduce net agricultural exports by about the same amount.

TABLE 5.2—NET AGRICULTURAL EXPORTS (IN MILLIONS OF US DOLLARS) AND GROSS VALUE OF AGRICULTURAL PRODUCTION, SELECTED AFRICAN REGIONAL ECONOMIC COMMUNITIES,1993–2010

Dependent variable: agricultural net exports (millions of US $)	OLS		Random-effects	
	Coef.	Std. err.	Coef.	Std. err.
Log. gross production value (thousands of constant 2004–2006 international $)	0.410***	0.139	0.448**	0.180
Population (millions)	-0.000	0.000	-0.000**	0.000
Per capita gross domestic product (2011 international $)	0.000	0.000	-0.000	0.000
Import value index (2004–2006 = 100)	-0.002	0.002	-0.002*	0.001
Export value index (2004–2006 = 100)	0.001	0.001	0.001**	0.001
Total cereal area harvested (millions of hectares)	-0.105**	0.044	0.037	0.060
Linear time trend	-0.005	0.007	0.008	0.008
Constant	3.862	14.109	-21.846	15.385
Number of observations (N*T)	450		450	
Adjusted R-squared	0.407		n.a.	
R-squared within	n.a.		0.367	
R-squared between	n.a.		0.224	
R-squared overall	n.a.		0.228	
Chi-squared	n.a.		13.104	
F-statistic	3.959		n.a.	
Panel-level std. dev.	n.a.		0.520	
Rho	n.a.		0.767	
Log-likelihood	-379.13		n.a.	

Source: Authors' own calculation.
Note: *** p < 0.01, ** p < 0.05, * p < 0.1. n.a. = not applicable; OLS = ordinary least squares; Std. err. = cluster-robust standard error.

This increase amounts to about 0.27 percent, 0.39 percent, and 0.02 percent, in absolute value, of the yearly average total agricultural net exports for COMESA, ECOWAS, and SADC, respectively, for 1993–2010. Indeed, as noted above, climate change is projected to have an overall negative effect on yields of major food-security crops across SSA, with effects on yields expected to experience significant spatial variation (Berg et al. 2013; Sultan et al. 2013). Thus, the adoption of yield-enhancing CSA practices could be one promising approach to mitigate these effects.

Summaries of simulated production values and net exports under the smart farmer option for maize and rice, disaggregated by REC, are shown in Table 5.3. The average production value of maize under the smart farmer option is 0.33 million (in constant 2004–2006 international dollar) (Table 5.3, column 4), whereas that of rice is 0.21 million (in constant 2004–2006 international dollar) (Table 5.3, column 8). Using average annual production values during 2003–2010 as a benchmark scenario, these results represent a 73 percent (from 0.19 million to 0.33 million for maize) and 40 percent (from 0.15 million to 0.21 million for rice) increase in production value, on average, for the whole sample. For both maize and rice, the percentage increase in production value from the benchmark scenario is highest for SADC and lowest for ECOWAS.

Compared with the benchmark scenarios, the simulated net exports under the smart farmer option are significantly higher, especially for SADC, yet ECOWAS's net exports appear to decline (Figures 5.7 and 5.8). Further research is needed to identify possible factors behind these inter-REC differences in the elasticity of net agricultural exports to CSA-induced increases in the value of agricultural production.

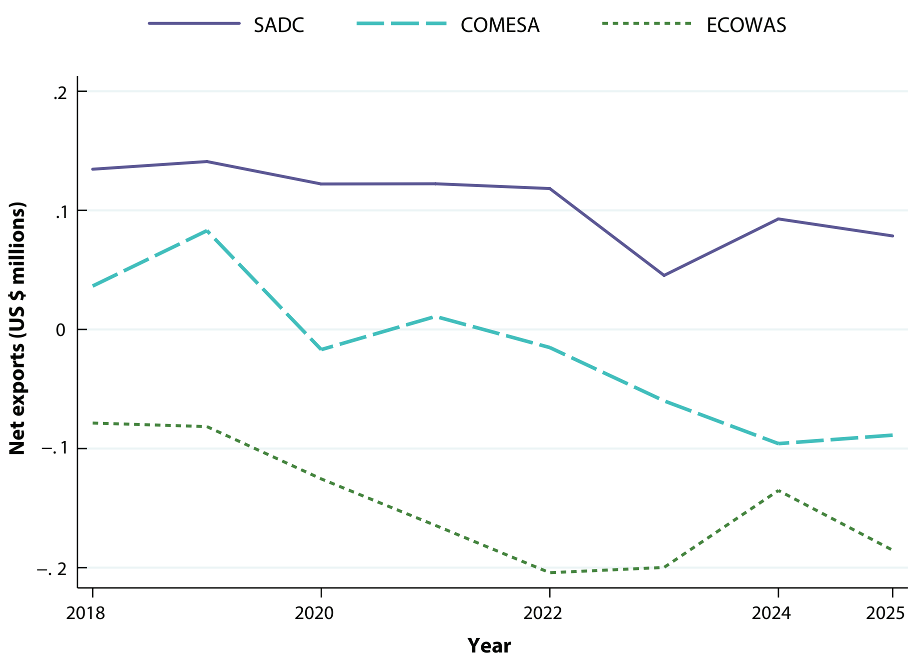
TABLE 5.3—CLIMATE-SMART AGRICULTURE PRODUCTION VALUE AND NET EXPORTS, SELECTED AFRICAN REGIONAL ECONOMIC COMMUNITIES, 2018–2025 PROJECTIONS

	1	2	3	4	5	6	7	8
	Smart farmer option—maize				Smart farmer option—rice			
	2018–2025				2018–2025			
	ECOWAS	*SADC*	*COMESA*	*All*	*ECOWAS*	*SADC*	*COMESA*	*All*
Maize production value	0.22	0.47	0.28	0.33	n.a.	n.a.	n.a.	n.a.
	(0.40)	(0.61)	(0.32)	(0.49)				
Rice production value	n.a.	n.a.	n.a.	n.a.	0.22	0.49	0.22	0.21
					(0.31)	(0.69)	(0.51)	(0.39)
Gross production value	5.32	3.63	3.81	4.60	5.29	3.44	3.76	4.49
	(9.57)	(3.84)	(3.25)	(6.97)	(9.44)	(3.77)	(3.21)	(6.88)
Total agricultural net exports	-0.15	0.11	-0.02	-0.06	-0.15	0.18	0.04	-0.04
	(0.64)	(0.20)	(0.38)	(0.50)	(0.64)	(0.18)	(0.37)	(0.52)

Source: Authors' own calculation.

Note: Production values expressed in millions (in constant 2004–2006 international dollars). Agricultural net exports expressed in millions of US dollars. COMESA = Common Market for Eastern and Southern Africa; ECOWAS = Economic Community of West African States; n.a. = not applicable; SADC = Southern African Development Community.

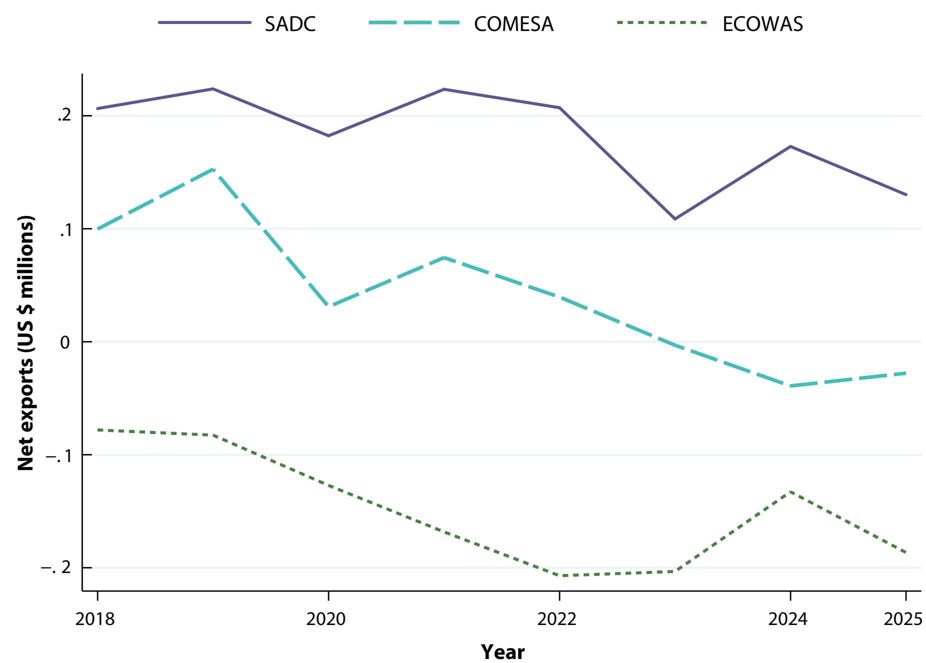
FIGURE 5.7—SIMULATED TOTAL AGRICULTURAL NET EXPORTS WITH SMART FARMER OPTION, MAIZE, SELECTED AFRICAN REGIONAL ECONOMIC COMMUNITIES, 2018–2025



Source: Authors' own calculation.

Note: COMESA = Common Market for Eastern and Southern Africa; ECOWAS = Economic Community of West African States; SADC = Southern African Development Community.

FIGURE 5.8—SIMULATED TOTAL AGRICULTURAL NET EXPORTS WITH SMART FARMER OPTION, RICE, SELECTED AFRICAN REGIONAL ECONOMIC COMMUNITIES, 2018–2025



Source: Authors' own calculation.

Note: COMESA = Common Market for Eastern and Southern Africa; ECOWAS = Economic Community of West African States; SADC = Southern African Development Community.

Conclusion

Given its heavy reliance on rainfed agriculture and projected climatic and weather changes, SSA faces multidimensional challenges in ensuring food and nutrition security as well as preserving its ecosystems. In this regard, CSA can play an important role in addressing the interlinked challenges of food security and climate change. The dominance of agricultural commodities in the region's exports also implies that agroclimatic changes will affect countries' ability to fully benefit from international trade.

This chapter combines crop modeling and econometric analysis to simulate the effects of CSA on maize and rice yields and net agricultural exports (exports minus imports) in SSA, with a focus on three RECs: ECOWAS, COMESA, and SADC. The analysis assumes that farmers have complete information regarding potential yields associated with alternative CSA practices and can choose the alternative that produces the highest yields for their agroecology. Expected effects of CSA are simulated for the period 2018–2025, by the end of which countries have committed to tripling intra-Africa trade in agricultural commodities and services as part of the 2014 Malabo Declaration. We find that CSA significantly increases both yields and agricultural trade flow, suggesting a potential role for CSA in improving resilience and spreading out agricultural production risks. The evidence also suggests a heterogeneous response of trade flows to CSA by REC.

Finally, although these findings are informative, it is worth noting that even if famers have complete information about a portfolio of CSA practices and their agronomic potential, adoption may be suboptimal due to, for example, limited budget, missing or imperfect markets, and institutional barriers (see Barrett 2008; Dillon and Barrett 2016; Foster and Rosenzweig 2010; and Suri 2011 for some discussions). Given that CSA practices have more complex sets of tangible and intangible components, relative to a single and discrete class of technologies, adoption of all the components is necessary to benefit from all the synergistic effects of CSA on productivity and sustainability. Additional research is therefore needed to examine the possible general equilibrium effects of large-scale adoption of CSA practices and to identify location-specific factors that mediate the interaction between climate change, agriculture, and trade.

CHAPTER 6

Insurance Opportunities against Weather Risks for Smallholder Farmers in Africa

Francisco Ceballos, John M. Ulimwengu, Tsitsi Makombe,
and Miguel Robles

In Africa, agriculture is the dominant source of livelihood for the poor, particularly in rural areas, where the majority resides. This sector employed about 60 percent of Africa's labor force in 2010, and more than 80 percent in some countries (FAO 2017). African agriculture is typically rainfed and occurs predominantly on smallholder farms of less than 2 hectares. In Africa south of the Sahara (SSA), rainfed agriculture accounts for more than 95 percent of farmed land (Wani, Rockström, and Oweis 2009), and smallholder farms represent 80 percent of all farms and up to 90 percent of production in some countries (Wiggins 2009). Smallholder farmers largely grow for subsistence purposes, usually using few to no modern inputs (such as fertilizer, high-yielding seeds, or irrigation), with some growing cash crops for income or engaging in livestock rearing, a combination of crop and livestock farming, or off-farm activities.

Extreme weather events can devastate crop yields and food production, adversely impact food security and nutrition, and erode the livelihoods and assets of the poor. The rainfed nature of African agriculture is often characterized by low productivity and thus subject to a wide range of weather risks such as extreme temperatures or rainfall, as well as weather-related hazards such as pests, diseases, and reduced accessibility to cultivated fields and roads. Weather-related hazards can also be transmitted to other segments of the agricultural supply chain, such as processors, wholesalers, and transporters, and also to other sectors that support agriculture, such as banking, for instance through loan defaults (Ceballos and Robles 2014).

In this context, the poor are disproportionately affected by extreme weather. Total crop and livestock loss can threaten the food security and nutritional status of entire communities. Moreover, the poor are at higher risk from vector- and waterborne diseases. Through their effects on health condition and nutritional intake, temporary weather shocks can thus induce permanent negative shocks to human capital.[25] Finally, a decrease in nonfarm employment availability may follow extreme weather events, further damaging the poor's livelihoods and their ability to recover.

For instance, the 2011/2012 drought in the Horn of Africa severely impacted food production as well as livestock and pastoral systems. The drought induced alarming rates of malnutrition among young children and an estimated 13 million people in need of humanitarian assistance (Slim 2012). The 2015/2016 El Niño cycle was related to both droughts in southern and eastern Africa and flooding in parts of eastern Africa, devastating agricultural production and threatening the food security and well-being of millions of people. Extreme weather events can also cause long-lasting damage to poor communities through the destruction of infrastructure (roads, schools, and hospitals), with staggering costs of recovery and rebuilding. For example, the 2013 flooding in Mozambique damaged health clinics and resulted in humanitarian and recovery costs estimated at US$30.6 million (UNRCO Mozambique 2013). In Kenya, the 2008–2011 drought caused a total of US$10.7 billion in damages and losses, of which nearly US$9.0 billion was in the livestock subsector alone, US$91.0 million in the food processing industry, US$1.5 billion in crops, US$53.0 million in fisheries, and US$85.0 million in nutrition (FAO 2015).

Climate change is projected to result in more frequent and intense droughts and heat extremes in central and southern Africa as well as

25 McIntosh (2015) highlighted considerable drops in consumption and food security resulting from the effects of severe weather shocks on the agricultural sector in Uganda.

increased precipitation and flooding in the Horn of Africa and other parts of eastern Africa (World Bank 2013). Moreover, climate change will likely exacerbate cyclical weather events such as La Niña and El Niño, resulting in even more frequent and severe droughts and floods. In addition, climate change is projected to increase risks from vector- and waterborne diseases in Africa (World Bank 2013).

In this context, it is crucial for smallholder farmers to rely on efficient protection mechanisms against these impending risks. But traditional indemnity agricultural insurance has not been able to reach rural communities in Africa at a large scale, mainly due to high distribution and loss verification costs and information asymmetry problems between farmers and insurers.

In the absence of well-functioning weather insurance markets, African smallholder farmers have typically resorted to informal and semi-formal risk-coping strategies to deal with weather-related shocks. However, traditional informal strategies such as savings, credit, borrowing from friends and relatives, and diversifying income sources have shortcomings. Savings can easily be diverted to more pressing household demands before weather shocks occur, credit can be expensive and out of reach for poor farming households, and extreme weather events can affect entire geographic areas and thus preclude the possibility of seeking help from social networks or off-farm activities.

Therefore, innovative strategies and insurance mechanisms are needed to help smallholder farmers adapt to the effects of extreme weather events. Over the past few decades, weather index insurance has been increasingly regarded as an important alternative for protecting farmers against weather shocks and for enabling investment and growth in the agricultural sector (Greatrex et al. 2015). Weather index insurance can thus become an important part of the climate-smart tool kit for increasing agricultural productivity and incomes by allowing smallholder farmers to adapt and build resilience to weather shocks. In addition, the safeguards provided by insurance may enable farmers to access credit and adopt riskier but higher-yielding technologies, raising their productivity and improving their incomes.

Against this backdrop, this chapter highlights insurance opportunities for protecting smallholder farmers against weather-related risks. It is organized as follows: the next two sections outline the different types of, respectively, traditional and formal coping strategies against weather risk. Subsequent sections discuss Africa's experience with formal risk-coping strategies, including weather index insurance, and explore linkages and complementarities between weather-related risk-coping strategies and climate-smart agriculture, as well as new developments and opportunities for scaling up weather index insurance. The final section highlights key messages and policy implications for achieving the Malabo Declaration goal of enhancing the resilience of livelihoods to weather shocks.

Traditional Risk-Coping Strategies

In the absence of efficient and widespread tools to cope with weather risks, rural households in developing countries have traditionally resorted to a number of different informal risk-coping mechanisms for protecting their livelihoods from unexpected shocks.

The most universal of these is probably savings. Households around the world understand the benefits and generally pursue the holding of savings. Savings, however, can take several forms: although many people save in cash, others save by building up assets (even small-scale assets, such as poultry or livestock); although many prefer saving in a bank, some still choose saving under a mattress. A buffer of savings can certainly help when a negative event affects the household. Yet there are drawbacks. Banks fail; animals age and become sick; money stuck away can catch fire, get flooded, or become food for insects and other creatures. In addition, households exist socially, and readily available stocks of money are regularly under pressure for alternative uses by the household or for the needs of others.

A second strategy, closely related to savings, is formal or informal credit. Savings and credit are both mechanisms that turn a stream of small amounts of money into one larger lump sum. The difference is that in credit, the lump sum comes first, with the stream of small payments following it, whereas for savings, the process is the reverse. In addition, credit bears a cost in the form of interest, but so do savings, which are prone to the above-mentioned risks and subject to loss of value through inflation (in the case of cash) and price fluctuations (in the case of savings in kind).

However, neither credit nor savings is a good form of insurance, principally for reasons of timing: when needs arise unexpectedly, credit may be in high demand or simply not available, and savings stocks may not yet be sufficient to be of help. Moreover, formal credit is not available to all, particularly the poorest households, who often lack required collateral. Informal credit (that is, from local moneylenders) generally comes with high interest rates that can quickly turn a small, temporary shock into an untenable burden if not handled appropriately—particularly a problem in poor rural communities with low education levels and a lack of overall financial literacy.

To overcome these limitations, households resort to other types of informal mechanisms when disaster strikes, usually borrowing from other households in their social network, including family and friends. This type of informal insurance can be effective, timely, and overall, inexpensive relative to other alternatives. Nevertheless, though loans and gifts from other households have the potential to protect from idiosyncratic shocks (that is, unexpected losses that affect a limited number of households within a locality or social network), they are ill suited to protect against systemic (or generalized) shocks, which affect most households in a given region and thus undermine their capacity to support each other.

Certain types of semiformal insurance have sprouted over the last few decades (though they have much older historical roots). One example is burial societies, particularly common in Africa, whereby households come together into informal groups and regularly contribute a small amount in exchange for a—generally fixed—larger payment in the event of a death in the family. Unfortunately, these kinds of institutions are rarely available to handle agricultural risks. Other semiformal institutions prolific in Africa are rotating savings and credit associations (ROSCAs), which consist of a self-organized group of individuals who contribute a small amount of money at fixed periods of time (such as every week), the total of which is assigned each period to a different member of the ROSCA as a lump sum to be used at the individual's will. Even though several variations exist on the ROSCA model, they all generally suffer from the same issues as the other strategies mentioned above, such as imperfect timing and an inability to help under systemic shocks that affect all households.

A final important way in which agricultural households regularly protect themselves from weather and other risks is by diversifying their income sources. Diversification can take shape either through carrying out different agricultural activities (such as staggering the planting of crops or choosing a mix of crops with different sensitivities to weather events) or through engaging in other agricultural and rural nonfarm activities. A related strategy is that of reducing agricultural risk exposure by either planting crops less vulnerable to weather risks or choosing more resilient crop varieties. Unfortunately, these alternatives often generate lower profit and have lower yield potential, thus precluding the household from increasing its income and escaping poverty.

All in all, though they are important and essential for dealing with a large array of shocks, most traditional risk-coping strategies are costly and have limited risk-mitigation potential for systemic weather risks (Townsend 1994). Informal savings are perhaps too costly for a population that probably should better invest its resources in assuring adequate food intake for household members, in improving human capital, and in seizing productive opportunities. In addition, diversification strategies may come at an efficiency cost—that is, they may impede rural farmers from capturing the full range of benefits from specialization or keep them from investing in risky capital and technology with higher expected incomes.

Formal Risk-Coping Strategies

Formal risk-sharing mechanisms take advantage of the fact that, across a large enough population, only a fraction of individuals may suffer a negative shock. For example, in a given year, only a small fraction of drivers will be involved in a car accident. By pooling risks within a large population, formal insurance programs can provide an efficient risk-sharing mechanism in which all contribute with premiums but only those who experience a loss get compensated. Furthermore, because insurance markets can pool risks across a broad scope of activities and large geographic areas, they can lower the costs of dealing with systemic risks through diversification. The most common type of insurance is known as *indemnity insurance*, whereby compensation relies on identifying specific losses and indemnifying the individual against them.

Although in theory, the same principles should be applied to weather risks and rural populations, the reality is that most countries lack standard indemnity agricultural insurance markets (with the exception of certain developed countries or large subsidized systems in a few developing ones, usually involving considerable public intervention). Multiple-peril crop insurance, for example, which can protect against any source of risk affecting yields, has been unsuccessful commercially without large subsidies. Single-peril crop insurance, which covers against a specific factor affecting the crop (such as hail or wind), has had more success, though it has been developed only at modest scales (Smith and Goodwin 2010).

There are a number of reasons why agricultural indemnity insurance has failed to expand successfully in developing countries, including those in Africa. Possibly the most important is that among small farmers the costs of loss verification, which typically requires a site visit, can be substantial relative to the sum being insured, especially when rural infrastructure is inadequate. Moreover, the lack of formal financial service networks and legal records may add to the cost of premium collection and compensation disbursement. Second, indemnity insurance is prone to significant information asymmetry problems, such as adverse selection (whereby only the most at-risk farmers purchase insurance) and moral hazard (whereby an insured farmer may not exert optimal effort to reduce risk or mitigate its impact), both of which generally result in an increased cost (Hazell, Pomareda, and Valdes 1986).

In view of these market failures, an increasing trend has been to explore an alternative type of weather insurance product for smallholder farmers (Hazell et al. 2010). Under weather index insurance, a somewhat recent innovation that is possibly more suitable for rural areas in developing countries, farmers get a pre-specified compensation according to the value of a particular weather variable (the index).[26] For instance, an index insurance product against drought would pay farmers when rainfall (as measured at a specific weather station or by satellite images) is less than a certain predefined "trigger," generally with higher payments the lower the recorded rainfall is. The key assumption is that by carefully selecting a weather index, one should be able to estimate agricultural losses with a sufficient level of confidence.

Some regard index-based insurance as having great potential to reach smallholder farmers in developing countries because (1) payouts are based only on publicly observed data (the index), drastically reducing loss verification costs; (2) adverse selection and moral hazard problems are minimized;[27] and (3) compensations can be automatically determined and thus disbursed quickly to farmers, making insurance easier and cheaper to administer, and thus potentially more affordable for the rural poor. These characteristics of index insurance have attracted donors and governments alike. Over the past two decades, many international organizations, researchers, and microfinance institutions have conducted pilots in developing countries, including several African ones, to demonstrate the advantages of index insurance and learn the best implementation practices, with the general aim of scaling up these pilots (Hazell et al. 2010).

In general, index insurance pilots in developing countries have repeatedly experienced low uptake, which has been linked to certain constraints such as lack of trust in the insurance company, lack of understanding of the product, and liquidity constraints (Cole et al. 2013, Matul et al. 2013). Though all of these constraints are also applicable to traditional indemnity insurance, there is one disadvantage that is unique to index insurance: basis risk. Basis risk arises due to an index's inadequacy to perfectly capture the individual losses of an insured farmer, which can be related to a number of factors. First, the index is generally measured at a local weather station (or through not-fully-accurate satellite imagery), not at the farmer's plot.

---

26 A slightly different type of index insurance, area-yield insurance, does not rely on a weather variable as its index but instead focuses on whether the average yield over a specified area is greater or less than a threshold.

27 Because losses are assessed not directly but only through the value of an objective index, the farmer's effort does not affect the probability of a payout—thus moral hazard considerations are dealt with. Additionally, because the probability of a payout is assessed objectively from the historical values of the index, the insurance company should not be concerned about which type of farmer buys this insurance—thus adverse selection is dealt with. However, under some circumstances, temporal adverse selection may still be present, whereby farmers buy the insurance product only in seasons in which payouts are expected to be higher (relying, for instance, on weather forecasts or levels of soil moisture at the beginning of the season). Although such behavior would tend to undermine an insurance product's sustainability, it can be generally dealt with by, for instance, controlling the time frame during which farmers can purchase insurance.

Second, a simple weather index cannot capture the interplay of weather variables (temperature, rainfall, humidity, evapotranspiration, winds, and the like), nor can it account for variability in crop variety, soil quality, and farming practices. Third, other, nonweather events, such as pests and diseases, may impact crop growth. Hence there is a chance that a farmer, after having paid the premium, will not get a compensation even after experiencing a loss. On the other hand, it is also possible that a farmer will get compensation without experiencing a loss.

Despite these obstacles, there have indeed been a number of seemingly successful implementations of index insurance. In India alone, more than 9 million farmers annually purchase these hedging products to insure against weather risk (Clarke et al. 2012), although this high uptake can be partly explained by the fact that agricultural insurance is mandatory in order to gain access to subsidized agricultural loans from the government. In the United States, a large federal index-based insurance program protects farmers against a variety of weather risks, although the system is highly subsidized. In Africa, some index insurance experiences have been relatively successful, such as the R4 Rural Resilience Initiative, which has helped to increase the resilience of farming households to weather-related shocks in Ethiopia and Senegal. This and other examples of Africa's experience with risk-coping strategies are discussed next.

Africa's Experience with Risk-Coping Strategies

Insurance services are still very much underprovided in Africa. According to Assah and others (2017), in Senegal, 18,540 producers benefited from a policy against drought in 2015, whereas close to 700,000 farmers remained without coverage. In Mali, only 30,000 farmers, fewer than 1 percent of the total, were insured in 2014. In addition to information asymmetry problems, other factors constraining the development of insurance markets in Africa include illiteracy among farmers, their inability to service loans, limited solvency among insurers, and a hostile regulatory environment in some countries (Assah et al. 2017). Mahul and Stutley (2010) reported that government support for agricultural insurance premiums is very small in Africa. For example, governments cover only 3 percent of agricultural insurance premiums on the African continent, compared with 50 percent in Asia and 73 percent in the United States and Canada.

Nonetheless, promising examples are burgeoning across Africa, thanks to financial and technological innovations in the insurance sector, as well as overall economic progress. As argued above, one of the most promising innovations in agricultural insurance is index-based insurance. Therefore we focus below on successful index insurance case studies on the continent.

R4 Rural Resilience Initiative in Ethiopia, Malawi, Senegal, and Zambia (Formerly Horn of Africa Risk Transfer for Adaptation Project–HARITA)

In Ethiopia, several projects tackling agricultural resilience have incorporated index-based insurance (Table 6.1). Examples of these programs include the R4 Rural Resilience Initiative, the Horn of Africa Risk Transfer for Adaptation project (HARITA), and the Rural Resilience Enhancement Project, which have been implemented by the Ethiopian Insurance Corporation, the World Bank, the UN World Food Programme (WFP), Oxfam America, and the Japan International Cooperation Agency.

TABLE 6.1—PILOT AGRICULTURE INSURANCE PROJECTS IN ETHIOPIA

Subsector	Weather index insurance	Indemnity insurance
Crops	• World Bank initiative for maize in Alaba *woreda* • Nyala Insurance Company (NISCO) / World Food Programme / Lume Adama Farmers Cooperative Union for beans in Bofa (Boset *woreda*) • Horn of Africa Risk Transfer for Adaptation program by Oxfam America and consortium of partners in Tigray Region • International Food Policy Research Institute and consortium of partners for bundle of prevalent crops in SNNPR and Oromia regions	NISCO multiperil crop insurance for teff, wheat, lentils, beans, and chickpeas in Oromia Region
Livestock	International Livestock Research Institute's (ILRI) index-based livestock insurance (IBLI)	Pilot of high-value livestock insurance by World Bank and Association for Ethiopian Microfinance Institutions

Source: Bhushan et al. (2016).
Note: A *woreda* is a local administrative division in Ethiopia. SNNPR = Southern Nations, Nationalities, and Peoples' Region.

TABLE 6.2—EXPANSION OF HORN OF AFRICA RISK TRANSFER FOR ADAPTATION (HARITA) PROJECT / R4 RURAL RESILIENCE INITIATIVE

Year	Number of farmers insured	Total premiums (in US$)	Total sum insured (in US$)	Total payouts (in US$)	Countries
2009	200	2,500	10,200	0	Ethiopia
2010	1,300	27,000	73,000	0	Ethiopia
2011	13,000	215,000	940,000	17,000	Ethiopia, Senegal
2012	18,000	275,000	1,300,000	320,000	Ethiopia, Senegal
2013	20,000	283,000	1,200,000	24,000	Ethiopia, Senegal
2014	26,000	306,000	1,500,000	38,000	Ethiopia, Senegal
2015	32,000	370,000	2,200,000	450,000	Ethiopia, Senegal, Malawi, Zambia

Source: WFP (2017).

R4, in Ethiopia and Senegal, is perhaps one of the most successful initiatives for enhancing agricultural resilience. Before launching R4 in 2011, however, the Ethiopian Insurance Corporation, in partnership with the World Bank, had launched an index insurance program for Ethiopian farmers in the form of a deficit rainfall index insurance for maize in 2006. Unfortunately, this initiative encountered many challenges—especially lack of sufficient data—that limited its expansion. Greatrex and others (2015), for instance, highlighted inefficiencies in data collection from weather stations, limited financial capacity of cooperatives, and limited bank involvement due to the cost and time associated with incorporating weather risk assessments into their procedures.

Then in 2009, Oxfam America and the Relief Society of Tigray launched HARITA, initially covering 200 Ethiopian farmers. Building on the success of HARITA, Oxfam America and partners launched R4 in Ethiopia in 2011 and eventually expanded it to Senegal (Greatrex et al. 2015). By 2014, growth of the program was impressive: more than 24,000 farmers in Ethiopia and 2,000 in Senegal were covered (Table 6.2). And in 2015, R4 distributed about US$450,000 in payouts to 43,000 farmers in Ethiopia, Senegal, and Malawi. One of the key features that R4 borrowed from HARITA that is perhaps responsible for a large portion of its success was the concept of "insurance for work," which allowed poor farmers to afford insurance by paying for it through their own labor in resilience-related community projects.

Currently operating in Ethiopia, Malawi, Senegal, and Zambia, the R4 program is based on four risk-management strategies: building risk reserves (savings); promoting risk reduction (through growth of assets); prudent risk taking (relying on microfinance and diversification); and risk transfer (index insurance), which allows for the transfer of components of risk that cannot be mitigated by using the other strategies. In addition, the program is complemented by training for farmers on the properties and application of index insurance and on risk management principles.

Madajewicz, Tsegay, and Norton (2013) evaluated the impact of the R4 program and found that among insured farmers, the level of grain reserves had increased, savings had more than doubled (a 123 percent increase on average), and the number of oxen owned had increased by 25 percent. Vulnerable groups, particularly women farmers, had benefited significantly from the program. In comparison, uninsured farmers did not fare as well. In Senegal, an impact evaluation by WFP and Oxfam America (2015) revealed that in the presence of the same shocks, farmers who had enrolled in the R4 initiative fared better in maintaining their food security than those who had not enrolled.[28]

[28] In particular, enrollees' food consumption score (FCS) dropped from 59.02 to 56.24 between 2013 and 2015, whereas nonparticipants' FCS witnessed a decrease from 56.2 to 28.6 in the same period.

Agriculture and Climate Risk Enterprise (ACRE) in Kenya, Rwanda, and Tanzania (formerly Kilimo Salama)

In 2009, the Syngenta Foundation launched Kilimo Salama in Kenya, with a pilot project offering index insurance to 200 farmers. By 2012, the insurance program had more than 51,000 subscribers in Kenya and 14,000 in Rwanda (IFC 2013). In Kenya, premium payments averaged 19 million Kenya shillings (KSh) in 2011 and KSh 33 million in 2012. In 2014, the program was transferred to Agriculture and Climate Risk Enterprise Inc. (ACRE), a for-profit enterprise. By 2016, ACRE had more than 1 million subscribed farmers in Kenya, Rwanda, and Tanzania, insuring more than US$56 million in crops against various types of weather risks (ACRE 2017).

ACRE is an insurance agent and surveyor based in Kenya, Rwanda, and Tanzania. It operates as an intermediary institution among different stakeholders along the agricultural insurance value chain. ACRE's primary goal is to help insurance companies add index products to their portfolios, using actuarial and product development expertise. Participating stakeholders include local insurers (who carry risk, document policies, and pay claims), reinsurers (who price policies and reinsure risk), farmers (who access insurance services), and farmer aggregators (organizations insured on behalf of farmers, such as banks, microfinance institutions, and agribusinesses).

ACRE is considered the largest commercial (that is, with farmers paying a market premium) index insurance program in developing countries and the largest agricultural insurance program in SSA (Greatrex et al. 2015). It is also the first-ever agricultural insurance program to reach smallholder farmers using mobile phones. ACRE offers a wide range of products, such as indemnity coverage, dairy insurance, hybrid seed index insurance, and multiperil crop insurance, and uses several data sources for its indexes, including automatic weather stations and remote sensing technologies. Targeted crops under the program include maize, sorghum, coffee, sunflowers, wheat, cashew nuts, and potatoes, with coverage against drought, excess rain, and large storms. The insurance operates through three main channels: the distribution of seeds via mobile phone network location services; agribusinesses; and banks, microfinance institutions, and credit cooperatives along the agricultural value chain. By facilitating enrollment and electronic payment, M-Pesa[29] is arguably one of the most important factors behind the program's success. Overall, ACRE's success is credited to the involvement of a wide range of partners, including government institutions (ministries of agriculture and national meteorological services), financial institutions, mobile network companies, research institutions, and insurance and reinsurance companies.

Index-Based Livestock Insurance (IBLI) in Kenya and Ethiopia

The index-based livestock insurance (IBLI) program in Ethiopia and Kenya was launched in 2010 with the objective of improving the resilience of pastoralist households against droughts and facilitating investments in livestock and access to credit (Mude et al. 2010; Miranda and Mulangu 2016). The International Livestock Research Institute (ILRI) teamed up with the University of California, Davis, to design an index-based livestock insurance relying on the normalized difference vegetation index (NVDI). The NVDI is calculated from remotely sensed satellite measurements and used to estimate the availability of forage for livestock. The project derived a statistical relationship between the NVDI and livestock mortality data to serve as a basis for insurance payouts. In February 2017, the government of Kenya, in partnership with Kenyan insurers, announced payments to more than 12,000 pastoral households under IBLI.

At least 4,000 pastoralists in both Ethiopia and Kenya were covered by IBLI in 2015. The program provided substantial benefits to households, who were less likely to sell their livestock and in some cases increased their number of livestock and improved their overall food security (Janzen and Carter 2013). Thanks to the substantial learning process from experiences on the ground, the IBLI initiative keeps expanding across Kenya. After the historic 2016 drought in northern Kenya, which caused the worst forage scarcity in the region for 16 years, more than KSh 214 million was disbursed in payouts to 12,000 pastoral households in 6 counties.

In 2015, the government of Kenya, supported by the World Bank, launched the Kenya Livestock Insurance Program (KLIP) using a design based on the NVDI. In October 2015, KLIP covered the livestock of 5,000 pastoralists in 2 counties (ILRI 2017). Further expansions are planned in 2017.

Other Index Insurance Experiences in Africa

As a whole, the African continent has been at the vanguard of index insurance's upward trend during the past decade. Though the previous subsections have focused on the most important experiences, a detailed account of the remaining ones is beyond the scope of this chapter. In order to fill this gap, Table 6.3 summarizes other weather index insurance projects conducted across a number of African countries.

[29] M-Pesa is a mobile phone–based money transfer, financing, and microfinancing service, launched in 2007 by Vodafone for Safaricom and Vodacom, the largest mobile network operators in Kenya and Tanzania.

TABLE 6.3—SUMMARY OF KEY AGRICULTURAL INSURANCE INITIATIVES IN AFRICA

Country	Description
Ghana	• Under the Ministry of Food and Agriculture, the government launched the Ghana Agricultural Insurance Pool in 2011, with 19 Ghanaian insurance companies participating. • Pool products focus on drought index insurance for maize, soybeans, sorghum, and millet; however, there are few multiperil crop insurance plans for risk experienced by commercial farmers and plantations.
Kenya	• In addition to the projects described above, the government of Kenya launched the Kenya National Agricultural Insurance Program (KNAIP) in March 2016, focusing on insurance for maize and wheat crops and for livestock. • KNAIP will follow the area yield–based approach: the farming area is divided into insurance units, and if the average production in an insurance unit falls below a threshold yield (based on the historical average yield for that unit), the insured farmers within the insurance unit receive a payout. • Implementation of the program started in three counties, Bungoma, Embu, and Nakuru, and will be extended to 33 of the country's 47 counties by 2020.
Malawi	• In 2005, the World Bank, in collaboration with Malawi's National Association of Small Farmers, developed an index-based crop insurance contract. • The pilot was implemented in the areas of Kasungu, Nhkotakota, Lilongwe North, and Chitedze. • In 2005, 892 groundnut farmers purchased weather-based crop insurance policies for total premiums of US$36,600. • In 2007, the pilot was expanded to cash crops. By 2008, the number of participants had increased significantly, with 2,600 farmers buying policies worth US$2.5 million.
Mali	• PlaNet Guarantee (an international microinsurance facilitator) sold its first insurance products in 2011 for maize crops; roughly 14,000 farmers were insured in 2014. • A second product was launched in 2011, a satellite-based index insurance for maize and cotton in partnership with Allianz; 17,481 policies were sold in 2014.
Mozambique	• In late 2012, two pilot projects were started by Guy Carpenter & Company LLC in conjunction with the Asia Risk Centre, including weather index–based insurance products covering two crops: maize in the district of Chimoio and cotton in the districts of Lalaua and Monapo. • 43,000 cotton farmers and a small number of maize farmers were insured in 2012/2013; a total of 43,500 policies were sold. • In the future, the Cotton Institute of Mozambique plans to expand index insurance coverage to all cotton farmers in Mozambique, numbering approximately 200,000.
Nigeria	• The Nigeria Agricultural Insurance Corporation (NAIC) is the primary agency providing insurance. • Crop insurance packages currently cover 17 crops, including maize, rice, cassava, yams, and sorghum. • Livestock insurance packages currently cover 14 types of livestock, including cattle, poultry, pigs, rabbits, and sheep. • In May 2013, NAIC paid more than 500 million Nigerian naira (N) in claims to insured farmers who had suffered losses in the floods in 2012. • In 2014, NAIC paid N 80 million in compensation to a sugar farm in Adamawa State following natural disasters.
South Africa	• In South Africa, agriculture insurance began in the 1970s, operating at two levels: commercial and subsistence farming. • The government has implemented subsidized crop insurance to make it affordable to farmers. • Currently, South Africa has insurance against hail and winds, but not drought. Under the existing scenario, farmers in good agricultural areas with low risk do not need subsidized insurance. • Agri SA, a federation of South African agricultural organizations, focuses its insurance efforts on commercial farmers, who number about 40,000, representing 20 percent of the farming population and producing 80 percent of the country's food. • The livestock insurance market in South Africa, although limited, is growing; racehorses are insured, and there is a market for insurance of wildlife in game parks.
Tanzania	• Apart from the pilot projects mentioned above, agricultural insurance for smallholder farmers is generally absent from the market. • The National Insurance Corporation launched a livestock insurance product in 1996 targeting only zero-grazing livestock keepers. The program failed because the majority of livestock herders were migratory pastoralists.

Source: Authors' summary from Bhushan et al. (2016).

Africa's successful experiences with smallholder agricultural insurance against extreme weather events shows the importance of investments in weather station infrastructure, widespread and inexpensive distribution networks for collecting premiums and disbursing payouts, and reliable and timely data collection and analysis to help reduce basis risk (Hill 2010). Educating smallholder farmers on weather insurance and its benefits is key to increasing its uptake and thus making insurance less costly. In cases in which selling insurance on its own has been less successful, the example of Malawi shows the potential benefits of tying insurance to credit, which can encourage a virtuous cycle of credit, enabling farmers to purchase modern agricultural inputs and increase their productivity (Leftley 2009).

Despite these successful experiences, agricultural insurance is still largely at the pilot stage in several countries, including Benin, Ethiopia, Mali, Mozambique, Senegal, and Tanzania (Bhushan et al. 2016). Moreover, countries continue to depend on international assistance to deal with the effects of extreme weather, and governments have not made the much-needed investments to help develop effective insurance markets. Among these investments, creating an enabling policy and regulatory environment that supports the expansion of insurance markets and programs should be high on the agenda, including developing insurance products that better serve the needs of smallholder farmers. Governments will also need to lead the way in insurance infrastructure investments (such as weather stations and product distribution networks), building the capacity of insurance companies, and training farmers on insurance products (Hill 2010). Finally, some form of government insurance subsidy may be required to enable higher uptake of insurance, such as the uptake rates seen in developed countries with highly subsidized insurance programs.

The Road Ahead and Opportunities

The African experience shows that index insurance has potential as a formal, efficient risk management tool for farmers in developing countries. However, for it to be truly brought to scale globally, its limitations have to be addressed. This section describes a broad set of issues related to the opportunities for index insurance and the main innovations to consider in the future.

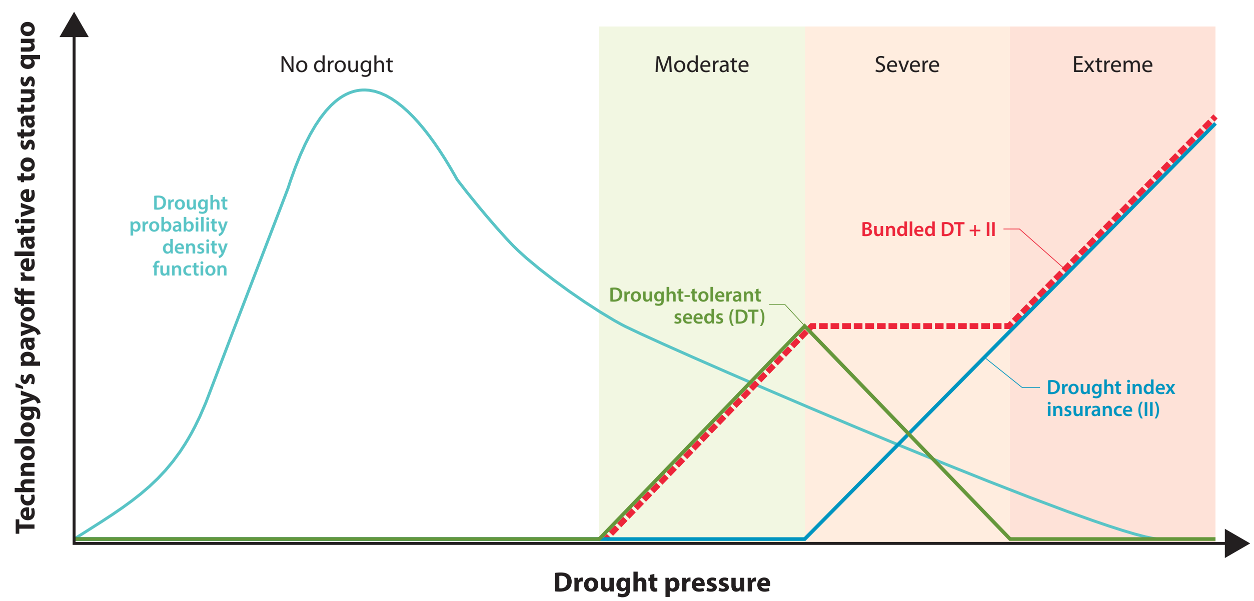
Complementarities with climate-smart agriculture. Climate-smart agriculture (CSA) has gained popularity during the past decade as an essential step toward climate adaptation by rural farming communities. CSA refers to agricultural technologies that are well suited to increase farmers' livelihoods in the face of a changing climate by (1) raising agricultural productivity, (2) building the resilience of livelihoods and farming systems, and (3) reducing carbon emissions. In some cases, these technologies involve reducing the vulnerability of crops to certain weather risks. In this regard, CSA shares a similar objective with crop insurance. Due to the similarities between these two families of technologies, a recent strand of work has focused on evaluating the potential for complementarities between them.

One of the most important examples of a complementarity between weather index insurance and a CSA technology is drought-tolerant (DT) seed varieties. DT seed varieties represent an important avenue of progress in seed breeding and are now available for a number of crops across several agroclimatic zones. DT seeds are particularly interesting from a development point of view because they can potentially bring about improved food security and protect rural livelihoods in the face of prolonged droughts.

Although the main characteristic of such seed varieties is their resistance to mild or moderate lack of soil moisture, crop failure is generally an inevitable result under an *extreme* drought, with the added consequence of farmers' being worse off due to having to repay the higher cost of DT seeds. Weather index insurance, on the other hand, is not very well suited to handle moderate drought because it tends to be expensive under a high frequency of loss (insurance premiums must be high to account for frequent payouts). Nevertheless, because extreme drought events occur much more rarely and are generally easier to identify through an index (compared with more moderate events that may or may not damage crops), weather index insurance boasts natural comparative advantages to handle this layer of risk. It is natural to see, thus, that a holistic system—wherein farmers rely first on DT seeds to inexpensively cover more frequent and milder drought risks, and in addition rely on reduced-cost catastrophic index insurance against extreme events—could provide farmers with more complete protection against all potential scenarios, thus more efficiently handling drought risk at a much lower cost than any of the above stand-alone technologies would be able to achieve (Lybbert and Carter 2015; Ward et al. 2015). Figure 6.1 shows a visual representation of this complementarity.

Other aspects of the synergies between CSA and index insurance are starting to be explored. One such exploration looked at a CSA practice known as conservation agriculture (CA) in a project in the wheat-rice system in the Indo-Gangetic Plain of India. Under CA, rice residue is left on the field at harvest and wheat seeds are sown directly through the residue into the soil using special machinery. Sowing the wheat seeds through this layer of residue has several advantages, including increased tolerance to high temperatures and reduced risk of lodging (bending of the plant due to wet soil and winds), because the plant sits deeper in the soil than under other planting methods. Similar to the DT scenario described above, adopting CA technology can inexpensively protect wheat from mild but frequent risks, and index insurance can complement this advantage by providing less expensive coverage against more extreme events.

FIGURE 6.1—COMPLEMENTARITY BETWEEN DROUGHT-TOLERANT SEEDS AND DROUGHT INDEX INSURANCE



Source: Adapted from Lybbert and Carter (2015).

Finally, another way in which index insurance can partner with CSA technologies is by encouraging CSA adoption. Many farmers generally refrain from adopting CSA practices due to the inevitable uncertainty and higher perceived risks than keeping to more traditional practices. In these contexts, index insurance can give a farmer the necessary peace of mind to try out a new technology. Such an approach could either complement or substitute for standard subsidies for encouraging CSA adoption; more research is needed to understand the optimal interplay between the two mechanisms.

New developments in index insurance. Confronted with the issue of low uptake and high basis risk, index insurance researchers and practitioners have developed some promising new ways to deal with these limitations.

An interesting new project led by the International Food Policy Research Institute (IFPRI) is Picture-Based Crop Insurance (PBI), currently being tested in the states of Punjab and Haryana, India. Under PBI, farmers take pictures of their insured plots every week using their own smartphones and a specially designed app that keeps the frame of view fixed on the same portion of the field. Using the pictures recorded over time, a farmer can then make a claim for any loss experienced, which can be assessed by agronomic experts or an automated machine-learning algorithm, based on the pictures and auxiliary information. This type of product can greatly reduce basis risk and encourage uptake by instilling in the farmer a sense of ownership of the insurance product and its results. Initial results are very promising, in terms of both the feasibility of the approach (Kramer, Ceballos, Hufkens, et al. 2017) and its sustainability, with no evidence of moral hazard or adverse selection (as would be expected from the product's resemblance to indemnity-based insurance), nor of picture tampering or fraud (Kramer, Ceballos, Krupoff, et al. 2017).

Another strand of projects has explored the potential of allowing for more flexibility as an alternative to current rigid, one-size-fits-all index insurance designs. Traditionally, index insurance products have involved a number of parameters and predetermined payout functions. These features sometimes make a product difficult to understand for farmers lacking sufficient education. More important, because the payout functions are fixed, the insurance product cannot adapt to the risk profile of many farmers the way an indemnity product would. In this context, a team at IFPRI has proposed a novel approach, wherein an array of much simpler products is offered, each covering against a specific timing and intensity of risk. Under such an approach, a farmer can create a portfolio of products (with different triggers, calibrated to protect against weather events of various intensities, and for different coverage periods) to suit his or her individual crop risk profile. Evidence from three projects suggests that farmers do indeed value this simplicity and flexibility.[30]

Gap insurance, consisting of a second tier of indemnity insurance on top of a regular index product, has been considered as a promising alternative to traditional index products.[31] Under such a program, when the first-tier index product is not triggered, farmers have the right to call for

30 For a theoretical framework and evidence from field experiments in Ethiopia, see Hill and Robles (2011). A pilot application of this approach in India is described in Hill, Robles, and Ceballos (2016). For a description of a commercial rollout in Uruguay, together with a structural analysis of the demand for these products, see Ceballos and Robles (2017).

31 For an application of gap insurance in Ethiopia, see, for instance, Berhane et al. (2015).

crop cuts in a reduced geographic area in order to assess losses locally.[32] A related idea is multiscale (or double-trigger) area yield insurance, under which a product combines two area yield indexes measured at different geographic levels—a broader geographic index with a higher trigger and a local index with a lower trigger—with payouts occurring when both indexes fall below their corresponding triggers.[33] Measuring yields at a very local level reduces basis risk, and the broader area index helps reduce moral hazard.

Finally, the increasing affordability of automatic weather stations and the expanding technologies for remote sensing of weather variables and crop growth (such as microsatellites and unmanned aerial vehicles) have an enormous potential to underpin innovative insurance products with reduced basis risk in the near future.

Meso-level products. A different approach to minimizing basis risk that has gained traction recently entails a shift from insuring individual farmers to insuring so-called aggregators—such as farmer associations, other formal or informal groups, and microfinance institutions.[34] For instance, an institution holding a significant portfolio of agricultural loans may be interested in insuring it against severe systemic shocks that may otherwise result in large loan write-offs. An advantage of such systems is that, with efficient mechanisms to identify individual losses and appropriate payout practices by the aggregators, individual (idiosyncratic) negative and positive basis risks can largely offset each other in the aggregate portfolio.

32 Taking crop cuts is a procedure to obtain an objective measure of crop yield by cutting a small, random sample of the field (for example, 1 square meter) right before harvest and weighing the produce in this sample. The process is repeated across random samples in an area to obtain an objective estimate of the area's yield for a given crop.

33 See, for instance, Elabed et al. (2013).

34 See de Janvry, Dequiedt, and Sadoulet (2014) and Dercon et al. (2014).

Macro-level products. One of the most important elements behind limited crop insurance uptake in developing and developed countries alike has perhaps been the state's traditional role as risk absorber of last resort. Once a major weather shock hits, it is fairly common for national, regional, or local governments to give in to the pressure for emergency assistance. This type of assistance is generally inefficient, difficult to administer, and prone to political favoritism and corruption. Most important, it is often uncertain—there is no guarantee that adequate assistance will be provided when there is a crop failure or livestock loss. Moreover, in many of these emergencies the state's budget capacity is also reduced due to lower economic activity and tax revenues. In this context, there has been an increasing trend around the world toward ex ante budgeting for natural disasters (through risk-coping instruments such as insurance), to the detriment of ex post assistance after a disaster strikes (Clarke and Dercon 2016).

One natural option has been macro-level insurance against weather risks, whereby the insured parties can be either different government levels (from national to local) or specialized government agencies. This type of insurance generally relies on an index and, upon the occurrence of an extreme weather event, makes a direct payout to the insured agency or local government to implement emergency relief and food security programs. Such arrangements are already being implemented in developed countries and are expanding into developing countries, particularly those prone to natural catastrophes (Hazell et al. 2010). Sometimes this type of instrument can be channeled directly through the international financial markets, through the issuing of so-called catastrophe (or cat) bonds. Such instruments resemble regular sovereign bonds in that the issuing government promises to pay the bearer (generally attractive) interest under normal scenarios, but under disaster scenarios, determined through well-specified conditions tied to the index, investors forgo the interest and some or all of the principal, in an arrangement resembling the structure of a typical insurance product.

The creation of regional risk pools is another approach that has been gaining steam. Under such a system, subscribing sovereign states commit funds, receiving in return a type of macro-level insurance. These regional risk pools are generally funded through specialized trust funds supported by international donors, or through reinsurance agreements. The way they work is similar to the macro-level products described above, whereby upon the occurrence of a negative weather event (generally defined in terms of and captured through specific weather indexes), the sovereign state receives financial assistance to put toward social protection and reconstruction costs. African Risk Capacity (ARC), established in 2012 as an agency of the African Union, is an example of such a pool. In addition to covering member states against the devastating consequences of droughts, it provides technical and financial assistance to state governments for early response systems and emergency management plans.

Conclusions

In the face of climate change, improving the resilience of African smallholder farmers should constitute a top priority in policy makers' agendas. In this regard, CSA constitutes a crucial step in the right direction. However, formal insurance mechanisms are needed to complete farmers' tool kit to cope with weather shocks.

Even though traditional crop indemnity insurance has not really taken off on the continent, other options have been brought forward in recent decades. Weather index insurance is a promising alternative with several advantages. First, it avoids moral hazard issues by decoupling insurance payouts from the farmer's behavior. Second, it is not subject to adverse selection: payouts depend on objective, readily and publicly available information, and are independent of the characteristics of the pool of insured farmers. Furthermore, the implementation and administration of index insurance is cheaper than that of traditional indemnity insurance because it does not require the insurance company to verify loss claims before making payouts.

Nevertheless, index insurance has its own limitations, especially in relation to basis risk: because payouts are based on the observed index, any given farmer's actual loss may not be completely compensated. Although a number of new developments intend to sort out this and other obstacles, it is perhaps too soon to take stock and understand whether they will be able to help improve smallholder farmers' resilience in an efficient and sustainable way.

Evidence from several insurance pilot programs shows that although the potential for innovative insurance mechanisms is real, additional work to understand their effectiveness and substantial scale-up efforts will be needed to achieve a sustainable expansion of efficient agricultural insurance markets in Africa. Across the continent, a growing pool of experts and professionals from both public and private institutions are actively engaged in bringing in innovations, improving index products, and finding effective ways to scale up insurance programs. Importantly, in the face of shifting weather patterns due to climate change, rating methodologies for index insurance products must adapt or run the risk of encouraging oversubscription and thus undermining long-term sustainability.

Governments, in particular, have an important role to play in creating an enabling policy and regulatory environment for the expansion of insurance markets and development of insurance products that better serve the needs of smallholder farmers. They will also need to lead the way in investing in weather stations, building the capacity of insurance companies, and training farmers on insurance products. By supporting the implementation of innovative weather insurance products aimed at addressing prevailing challenges, policy makers can actively contribute to the resilience of the rural poor facing weather extremes and provide them with much-needed opportunities to escape poverty through farming.

In this context, African policy makers should consider innovative weather index insurance tools as part of a comprehensive CSA package to help African farmers manage weather risks, especially in light of the potential complementarities between weather index insurance and agricultural technologies aimed at raising productivity and incomes. Such efforts can go a long way in helping the continent meet the Malabo Declaration commitment to enhance the resilience of farming livelihoods by 2025.

CHAPTER 7

Climate-Smart Agriculture Practices Based on Precision Agriculture: The Case of Maize in Western Congo

John M. Ulimwengu and Aziza Kibonge

Precision agriculture (PA) is an appealing concept, referring to a package of technologies that can reduce input costs by providing the farmer with the detailed information necessary to optimize field management practices, resulting in improvements in yields and profits as well as environmentally less burdensome production (National Research Council 1997; Schimmelpfennig 2016). For small farmers in developing countries in particular, PA holds the assurance of substantial yield improvement with minimal external input use (Florax, Voortman, and Brouwer 2002).

Although the US Department of Agriculture (USDA) reported that PA technologies were used on roughly 30 to 50 percent of US corn and soybean acres during the period 2010–2012 (Schimmelpfennig 2016), it appears that adoption of PA technologies is limited in Africa and Asia (Swinton and Lowenberg-DeBoer 2001). One reason for the low adoption rates may be that, as some studies reveal, increased input efficiencies result in rather modest profitability increases (Kilian 2000; Cook, Adams, and Bramley 2000). Although precision farming can include simple practices, it does imply complex and intensely managed production systems, such as the use of Global Positioning System (GPS) technology to spatially reference soil, water, and yield (NRCS 2007). The human capacity required to master the use of these technologies is not yet readily available in Africa.

In the Democratic Republic of the Congo (DRC), agriculture is the most important economic sector, accounting for 44.9 percent of the gross domestic product and employing more than 70 percent of the population (62 percent of males and 84 percent of females). Undoubtedly, the agricultural sector remains the largest sector in terms of employment and thus constitutes the most promising foundation for achieving food security as well as overall economic development. However, this huge agricultural potential remains largely unexploited, with only about 10 percent of arable land being cultivated (Herdeschee, Kaiser, and Samba 2012).

Although food security is at the heart of economic and social development priorities in the DRC, and despite the country's great agricultural potential combined with government efforts to alleviate poverty, the threat of food insecurity is still present. The country has been ranked first on the Global Hunger Index for several years; average daily food consumption is estimated at less than 1,500 kilocalories per person, well below the minimum of 1,800 per person required to maintain good health (USAID 2012, 2014). Food insecurity has been exacerbated by decades of conflict, reduced agricultural productivity, and migration out of rural areas.

The growing population constitutes an additional constraint to achieving food security in the DRC. In 2017, the United Nations estimated a population of 82 million, with a growth rate of 3 percent per year (World Population Review 2017). The increasing competition for land by multiple users suggests that available land suitable for agriculture is likely to decrease. In order to meet the food demand of a growing population, efficient and sustainable cropland management is therefore crucial to increase crop productivity without further degrading the soil and depleting resources.

The vast majority (70 percent) of the rural population that depends on agriculture for its livelihood relies mainly on rainfall. Indeed, agriculture is primarily rainfed in the DRC and also characterized by crop rotation and slash-and-burn farming that leaves land fallow for up to five years and typically managed to only a very low output per hectare (World Bank 2010). Maize, for instance—crucial to food security because it is the most frequently eaten cereal in the country (World Food Programme 2014)—is grown by small-scale farmers, typically under rainfed conditions with low or no inputs. As a result, yields are very low and at risk to changes in weather patterns.

In general, extreme weather events and increasing unpredictability in African weather patterns are already having serious consequences on crop yields for farmers who rely on rainfall. Though the western part of the DRC has good rainfall compared with the southern part, the area is still vulnerable to climate change as a result of changes in rainfall and temperature patterns, as well as extreme weather events. Climate predictions suggest that some areas will get warmer and others wetter by 2050 (Harvey et al. 2014).

In addition to changes in weather patterns, the agricultural sector faces other serious challenges that will require Congolese farmers to monitor and manage their farming operations more effectively using climate-smart agriculture (CSA) practices. There have been proposals to address concerns of food security and climate change using an integrated framework (FAO 2013a; Harvey et al. 2014). According to the Food and Agriculture Organization of the United Nations (FAO), CSA refers to land management practices that increase food security, boost the resilience and adaptive capacity of farmer households to climate variability, and mitigate climate change (FAO 2013a). Conservation agriculture, a combination of soil management practices including minimal soil disturbance, permanent soil cover, and crop rotation, is promoted across Africa south of the Sahara (SSA) and often labeled as "climate smart" (FAO 2013a). In fact, conservation agriculture practices have been found to address some of CSA's goals under certain conditions (Sithole, Magwaza, and Mafongoya 2016). In short, CSA practices seek to increase agricultural production and incomes by adapting and building resilience to climate change.

Similarly, the implementation of PA practices in farming operations has the potential to provide solutions to climate-related challenges and promote sustainable farming operations. For example, variable-rate application of seeds and nutrients based on inherent soil properties can increase yield in high-producing areas, maintain yield in low-producing areas, and reduce the use of costly inputs. Likewise, precision nitrogen (N) management can balance soil nutrient content, preventing unwanted nitrate leaching that can impair surface water and groundwater quality (Colorado State University Extension 2012). Indeed, established advantages of implementing improved cropland management practices include not only higher and more stable yields but also increased resilience, which will further improve food security (Abberton, Conant, and Batello 2010; Vallis et al. 1996; Pan et al. 2006; Woodfine 2009; Thomas 2008).

Although there is a great potential to increase agricultural production in the DRC, it is crucial for farmers to adopt these PA practices in order to increase their productivity while managing climate risks, thus improving their livelihoods. In order to achieve and maintain food security, agricultural systems need to be transformed to increase the efficiency and capacity of agricultural production. Though the realization of this potential requires high levels of commitment, resources, and consideration of climate risks, it is crucial to answer the question of which technologies and practices are the most appropriate to reach these objectives. Special funding mechanisms are needed to improve smallholders' access to PA. Moreover, PA practices should be included as a requirement for every new agriculture agricultural development project.

For this purpose, the government of the DRC has taken some steps toward developing a complete agricultural transformation strategy through agricultural special economic zones (ASEZs) that take the form of agricultural business parks (ABPs). The ABPs are perceived as the foundation for sustainable and inclusive development in the DRC. As Ulimwengu (2017) pointed out, the development of spatially targeted ASEZs has the highest potential among strategies being considered to induce a higher level of innovation and its fundamentals (human, social, manufactured, and knowledge capital). The pilot ABP, created in 2014 and called Bukanga Lonzo Agricultural Business Park, is located 250 kilometers from Kinshasa (the capital city of the DRC). It stretches over more than 80,000 ha, between two major rivers (the Kwango and the Lonzo) in the western part of the country.

The purpose of this study is to examine the effects of PA on maize yields in western DRC by comparing input application with and without PA recommendations. We argue that PA recommendations are the core of CSA practices. This study will focus on maize because of its extended upstream and downstream value chains and because in the DRC, maize production serves both animal and human consumption.

While estimating the impacts of PA-induced CSA practices on maize yields, this study is an attempt to explicitly analyze the use of soil knowledge to guide optimal input use and cultivation methods in order to improve yields and farmers' income. The study also examines how such knowledge can reinforce sustainable farming activities with respect to climate change. The goal is not only to report on changes in PA-induced maize yield but also to provide a better understanding of how PA helps determine the optimal cultivation method and the most efficient crop management practices to adopt in an area, given its specific soil conditions. The study uses georeferenced data on soil characteristics, inputs, and yield to assess the effects of CSA practices on a 10,000-ha plot in western DRC.

The sections that follow give an overview of CSA and PA; describe the application of PA for agricultural development; discuss the implications of PA results for site-specific CSA practices; and look at expected benefits from implementing CSA practices. Policy implications are laid out in the concluding section.

Climate-Smart and Precision Agriculture

Previous work on climate change impacts conducted in Africa suggests that maize, sorghum, and millet production is expected to decline significantly (by -5 percent, -14.5 percent, and -9.6 percent, respectively) (Knox et al. 2012). A recent study (Ramirez-Villegas and Thornton 2015) has indicated that during the 21st century, maize output is projected to decrease at a rate of 3–5 tons[35] per decade from historical levels as a result of climate change. The authors add that if no adaptation occurs, in the best scenario, total maize production in Africa will have decreased by 12 percent per year by the end of the century, whereas in the worst-case scenario it could be as low as 25 million tons per year, a 40 percent reduction. Considering all these challenges, countries such as the DRC should invest in technologies that promote sustainable intensification and adaptation to emerging climatic variability while also mitigating greenhouse gas (GHG) emissions.

CSA has been promoted as a way to overcome the challenge of increasing food supply and improving food security in an environmentally sustainable way. The FAO describes CSA technologies, practices, and services as options that sustainably increase productivity, enhance resilience to climatic stresses, and reduce GHG emissions (FAO 2010). In the DRC,

35 Throughout the chapter, *tons* refers to metric tons.

enhancing food security will require agricultural production systems to move toward higher productivity and lower output variability due to climate factors. The goals are to make production systems resilient and to assure good management of natural resources.

One study (Porter et al. 2014) pointed out that the most cost-effective CSA options have been assumed to be cropland management, grazing land management, and restoration of organic soils. Several regions in Africa are experiencing degraded and poor soils, which cause a decline in productivity. Using a probabilistic cost-benefit analysis, Sain and colleagues (2017) assessed the introduction of CSA options in Guatemala and found that all examined practices except one were profitable over their life cycles, but those that were expected to be ideal for drought-prone areas presented higher risks for adoption.

One example of an agricultural method for restoring organic soils and improving fertility is conservation agriculture (CA), with the following key characteristics: (1) minimal mechanical soil disturbance (that is, no tillage and direct seeding), (2) maintenance of much of the farm's carbon-rich organic matter (that is, use of cover crops), and (3) rotations or sequences and associations of crops including trees. CA thus augments climate change adaptation and mitigation solutions while improving food security through sustainable production, intensification, and enhanced productivity of resource use (FAO 2010).

Several meta-studies have attempted to quantify the average benefits of CA practices. Lal (2009), for instance, concluded that mulching and no-till farming clearly improved soil health, sometimes improved yields, and usually improved profits due to lower inputs. Pretty and others (2006) gathered evidence on the effect of CA from 286 developing-country case studies of "best-practice" sustainable agriculture interventions, finding the average yield improvement to be more than 100 percent. Branca and colleagues (2011) undertook a comprehensive, empirical meta-analysis of 217 individual studies on CA from around the globe and showed that reduced tillage and crop residue management was associated with a 106 percent increase in yield. A study conducted in southern Africa using the Agricultural Production Systems Simulator concluded that in semiarid environments, CA can improve yields in drier seasons and thus improve climate change resilience (FAO 2011). In subhumid environments, on the other hand, the same study found that CA offered little yield benefit, at least in the short term, due to the wet-season danger of waterlogging (FAO 2011), also mentioned by Thierfelder and Wall (2009, 2010). Other evidence of increased productivity with reduced- and no-tillage practices under rainfed agriculture is mixed. Meta-analyses show higher yields under CA than under conventional practices in a few cases, but benefits have varied based on soil type, precipitation, and application of N fertilizer (Rusinamhodzi et al. 2011; Farooq et al. 2011). Although the literature offers some evidence that CA has a positive effect on yields, the magnitude of this effect and how it interacts with climatic variables are still unclear.

Another example of a soil-restoring and fertility-improving method is PA, encompassing a series of technologies for applying water, nutrients, and pesticides only where and when they are required, thus optimizing the use of inputs (Day, Audsley, and Frost 2008). Farmers using PA manage their crops based on the site-specific conditions in variable fields (Seelan et al. 2003). PA provides the data necessary for farmers to make guided decisions about fertilizer and pesticide applications, seed distribution densities, irrigation metrics, and tillage patterns (Daberkow and McBride 1998).

Researchers have studied several aspects of PA, including technologies, environmental effects, economic outcomes, adoption rates, and drivers of adoption (Tey and Brindal 2012). Although many have acknowledged the method's environmental and economic benefits, a low rate of PA adoption is still reported, especially in developing countries (adoption efforts have been initiated in Brazil, China, India, and Uruguay in recent years), and adoption has focused on cash crops.

Indeed, research has revealed that increased input efficiencies result in rather modest profitability increases (Kilian 2000), which could explain the rather low adoption rates (Cook, Adams, and Bramley 2000). Another obstacle could be the failure to apply fertilizers that appropriately match individual site characteristics (Florax, Voortman, and Brouwer 2002; Stewart and McBratney 2002; Bullock et al. 2009).

Regarding profitability, Tey and Brindal (2012) noted that for farmers who have access to accurate information about the nutrient needs on their land, the precise application of fertilizer could reduce input costs. This conclusion is based on the assumption that the net savings from precise fertilizer application more than offset the cost of additional labor or the use of specialized equipment.

Studies on the profitability of PA application have led to mixed results. In contrast to the studies mentioned above, showing that information-led application of pesticides would result in input cost savings, others (Carr et al. 1991; Biermacher et al. 2009) have found no significant difference in returns. Some studies also show that soil sampling tests for fertility do not lead to profitability (Lowenberg-DeBoer and Aghib 1999; Swinton and Lowenberg-DeBoer 1998). In an attempt to explain the mixed results, some authors have suggested that PA application may involve too high a level of complex data management and interpretation (Robertson et al. 2012).

Research has shown that PA has the potential to reduce environmental impacts caused by agricultural activities (Fuglie and Bosch 1995; Khanna and Zilberman 1997; Hudson and Hite 2003). Consistent with one of the CSA objectives, improving the match of fertilizer application with crop needs prevents excess application (Reichardt and Jurgens 2009). Indeed, a study by Biermacher and colleagues (2009) demonstrated that applying the necessary amount of N needed for crops to reach their maximum potential yield could reduce nitrate contamination in groundwater and the pollution of downstream water.

Tey and Brindal (2012) noted that a number of studies have demonstrated the economic and ecological superiority of PA over conventional approaches (Tey and Brindal 2012; Silva et al. 2007; Sylvester-Bradley et al. 1999; Takacs-Gyorgy 2008).

Precision Agriculture in Practice

The Case for Precision Agriculture

The use of PA in BL was aimed at improving farmers' understanding of the variability of soil properties and crop requirements, which we expected to allow more informed decision making (Maohua 2001). We argue that decisions made by farmers under PA are better than those that would be made with conventional agricultural practices (that is, the national recommendations), and therefore that PA has the potential to promote efficient use of resources (through site-specific information), reduce input (fertilizer and pesticide) costs, and minimize environmental degradation caused by agricultural activities (by preventing excess application). In addition, we expected PA to improve soil condition and crop quality, and increase crop yield.

Data Collection Methods

The ASEZ of Bukanga Lonzo (BL) spans more than 80,000 ha. The South African agricultural company Agri Xcellence[36] was engaged to perform soil analysis and classification at BL to identify land suitable for crop cultivation (mainly maize for the first year) and provide a better understanding of maize yield response to fertilizers. Based on topography limitations and physical aspects of the soil, the land identified as suitable for cultivation was about 56,000 ha, and this arable land was later arranged into 9 parcels.

The government started its first phase of PA implementation in BL with parcel 1 (10,575 ha). First, Agri Xcellence conducted complete soil chemistry and classification on 1,500 soil samples—2 samples per 20–50 ha grid—to establish the presence of the major elements, such as calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), and sodium (Na). Soil chemical characteristics were also determined by measuring cation exchange capacity and pH. Researchers used technology such as GPS to map topography as well as soil and plant deficiency or excess characteristics, indicated by chemical and physical attributes. Rainfall patterns, temperatures, and evaporation tendencies were also studied to determine the best times to plant and harvest maize. The rainy season starts around September and lasts until around March, and the dry season runs approximately from June to August. September was therefore targeted as the ideal planting date to allow the maize plants to be developed enough to withstand the heavy showers that usually fall in November. Similarly, March, which usually marks the end of the short dry season (February-March), was determined to be the ideal time to commence harvesting.

The soil analysis was followed by yield simulations, which determined that a portion of the parcel (3,742.7 ha) presented very low productivity prospects (less than 2 tons/ha); it was therefore deemed not profitable and excluded from the planting area. The remaining part of the parcel (6,832.6 ha) was then divided into two areas: 1a (1111.1 ha) and 1b (5721.5 ha).

In BL, the government opted to use precision farming to optimize the use of required nutrients based on good knowledge of crop requirements and local soil, terrain, and climatic conditions. We argue that PA provides farmers with spatial information that reduces uncertainty and improves decision making. Cook and others likewise indicated that site-specific information—"for example, the knowledge that fertilizer should be applied to one location but not another; the decision that a cropping system variety is suitable for one area, but not another" (2003, n.p.)—reduces the chance of both type I and type II errors.

Physical Properties of the Soil

The soil survey conducted by Agri Xcellence assessed the physical properties (texture, structure, water-holding capacity, and dispersion) and chemical properties (potential in hydrogen, or pH, as well as nutrients and salinity). The planting area is composed of only four types of soil, making it quite homogenous considering its size. Each soil type represented (Cartref, Clovelly, Constantia, and Fernwood) presents a different depth and clay

36 https://www.triomfsa.co.za/index.php/home/agri-xcellence

content, both of which play an important role in water storage capacity.[37]

Both areas 1a and 1b were dominated by the Constantia soil type, which consists of an orthic A horizon followed by an E horizon and then a third horizon consisting of a yellow-brown apedal soil. The soil analysis also indicated a high organic material content in the form of carbon, which helps in the retention of nutrients. The E horizon is formed by water that drains laterally out of this horizon and is an indication of a highly leached horizon. Thus, the high carbon content is perceived as a positive factor because it counters the effects of highly leached soils. The USDA reported that soil organic matter serves as a reservoir of nutrients for crops, provides soil aggregation, increases nutrient exchange, and increases water infiltration into soil (NRCS n.d.). The Constantia soil type is also considered a sandy soil because of the sandy nature of its E horizon. The remaining soil types found in the area suitable for cultivation were far less represented (Summary of Soil Analysis, Parc Agro Industriel de Bukanga-Lonzo, Part 1. n.d.).

Characteristics of the Soil

The soil analysis performed in BL on parcel 1 (10,575 ha) indicated a wide variation in soil characteristics. It also identified areas of nutrient deficiency, suggesting the need for nutrient adjustment over time to reach the optimal levels required for efficient farming in terms of both environmental sustainability and profitability (Table 7.1).

TABLE 7.1—SOIL CHARACTERISTICS

Parameter	Soil in sampled area	Normal range	Recommendations
pH (potential in hydrogen)	4.4 KCl (low)	5.5–6.5 KCl	Indication of highly leached soil. Dolomitic lime should be used to correct the pH in the soil.
Exchangeable acids	≥ 2.33 cmol/kg in 1a (very high) ≥ 0.30 cmol/kg in 1b (very high)	0.00 cmol+/kg	The high level of exchangeable acids is very toxic to plants and plant roots.
Magnesium (Mg)	8 mg/kg in 1a 6 mg/kg in 1b	100–120 mg/kg	Highly leached soils cannot physically retain enough Mg in the clay complex. The deficiency in Mg can be corrected by using dolomitic lime.
Acid saturation	42% in 1a 51% in 1b	0%–7%	This very high level may result in poor root development and stunted growth.
Potassium (K)	12 mg/kg	70–90 mg/kg	Deficiency can be corrected by using a K source such as KCl 50 fertilizer. Or it can be corrected over time by applying a higher rate of a fertilizer blend high in K.
Calcium (Ca)	51 mg/kg in 1a 39 mg/kg in 1b	200–220 mg/kg	If the physical amount of Ca in the soil is corrected, the pH will also start to stabilize at greater than 5 Kcl. Deficiency in Ca can be corrected by using either dolomitic or calcitic lime.

Source: Agri Xcellence

Note: cmol = centimole (1 cmole = 10^{-2} moles); KCl = potassium chloride.

[37] Soil texture varies by depth, and so does water-holding capacity. To determine water-holding capacity for the soil profile, the depth of each horizon is multiplied by the available water for that soil texture, and then the values for the different horizons are summed (Plant & Soil Sciences eLibrary 2017).

The first 30 cm of the topsoil was high in organic carbon, which has positive effects by reducing the leaching of cations. Nevertheless, the report suggested the importance of building up organic matter in the soil by using a no-till or strip-till system of cultivation. Indeed, organic matter production is affected radically by conventional tillage, which decreases soil organic matter and increases the potential for erosion by wind and water (FAO 2005).

Overall, the soil analysis results suggested the following:

- Low pH and high levels of exchangeable acidity were the most yield-limiting factors in the first year of cultivation and were expected to especially hamper production in the first year.
- The soils were highly leached, making it important to reach adequate levels of Ca, Mg, P, and K over time.
- The first 30 cm of the topsoil was high in organic matter, which creates more negatively charged sites to which cations can bind, potentially lowering the amount of leaching. Therefore, it was important to build up even more organic matter in the soils by using a no-till or strip-till system of cultivation.
- The soils were prone to compaction, so care had to be taken not to compact the soil with traffic on the fields. The soils would need to be monitored for compaction every year.
- As the production of grain crops continues, the soil chemical balances should start stabilizing and crops should start producing higher yields over time.
- The split application of fertilizer, especially N and K, over the growing season was expected to have a positive effect on yield.
- The use of foliar feeding during the growing season should also have a positive effect on yields in the first year, when the soil does not have enough nutrients to produce very high yields.

Fertilizer Application in Precision Farming

Based on the soil analysis described above, we then derived georeferenced, PA-based recommendations for nutrient application, presented in Table 7.2, which allow for optimal use of fertilizer for maize cultivation in BL.

In general, Table 7.2 depicts a greater need for Ca, monoammonium phosphate (MAP) 33, and potassium chloride (KCl) 50 than for other nutrients.[38] As Table 7.2, panel A, shows, soil types determine the level and nature of required nutrients. Systematically, Fernwood requires the most attention across all nutrients and Cartref requires the least. It follows that any homogenous application is not only against recommendations but also likely to lead to inefficient farming.

The thickness of the white E horizon (Table 7.2, panel B) appears to have relatively little impact on the amount of recommended nutrients of all types. Harris and others (2010) pointed out that the water table depth in relation to the E horizon thickness affects the availability to crops of applied P as well as the potential for lateral transport of P through subsurface flow. In addition, when determining N fertilizer rates, it is important to keep in mind that poorly drained soils can lose N via denitrification. Thus, as recommended for BL (panel B), the thicker the white E horizon, the fewer

38 MAP 33 contains around 11 percent N and 22 percent P. It is widely used as a source of P and N, and has the highest P content of any common solid fertilizer (IPNI n.d.-b). KCl 50 is the most widely used K fertilizer due to its relatively low cost and inclusion of more K (50–52 percent) than most other sources (IPNI n.d.-a).

TABLE 7.2—FERTILIZER APPLICATION RECOMMENDATIONS

A. Average recommended fertilizer (kg/ha) by soil type						
Soil type	Calcium	MAP 33	Phosphate	Magnesium	Potassium	KCl 50
Cartref	88.1	48.9	20.6	17.3	10.9	40.0
Clovelly	926.2	490.5	236.8	184.9	109.9	491.8
Constantia	1,103.4	620.4	264.9	218.8	136.7	531.8
Fernwood	1,263.9	679.5	299.6	245.0	149.2	597.6
B. Average recommended fertilizer (kg/ha) by thickness of white E horizon						
Thickness (cm)	Calcium	MAP 33	Phosphate	Magnesium	Potassium	KCl 50
0	1,263.9	679.5	299.6	245.0	149.2	597.6
≥ 7	1,038.1	598.1	250.7	205.8	132.2	504.8
≥ 8 and ≤ 9	1,072.8	621.8	258.0	212.0	136.7	520.1
≥ 10	1,177.5	608.8	282.0	234.6	134.3	563.0
C. Average recommended fertilizer (kg/ha) by level of nitrogenous loss due to leaching						
Level of nitrogenous loss	Calcium	MAP 33	Phosphate	Magnesium	Potassium	KCl 50
Very high	1,260.6	686.5	302.4	249.0	151.1	602.5
High	1,086.4	609.2	257.8	211.0	133.9	520.1
Average	942.0	534.6	224.2	185.5	117.9	450.9
Low	926.2	490.5	236.8	184.9	109.9	491.8
D. Average recommended fertilizer (kg/ha) by frequency for top dressing						
Frequency	Calcium	MAP 33	Phosphate	Magnesium	Potassium	KCl 50
1 time	926.2	490.5	236.8	184.9	109.9	491.8
2 times	1,037.6	584.0	246.4	202.4	128.5	496.7
3 times	1,260.6	686.5	302.4	249.0	151.1	602.5
E. Average recommended fertilizer (kg/ha) by risk of waterlogging						
Waterlogging risk	Calcium	MAP 33	Phosphate	Magnesium	Potassium	KCl 50
Yes	1,217.7	654.6	290.1	238.2	144.0	579.3
No	1,122.5	636.9	275.7	224.5	140.5	557.7
Avg.	1,013.1	589.4	241.4	199.7	129.8	485.4

Source: Authors' calculations using data from Agri Xcellence.
Note: KCl = potassium chloride; MAP = monoammonium phosphate.

nutrients are required. Nevertheless, Ca is recommended at a higher amount than KCl 50, MAP 33, and the other nutrients.

Similarly, nitrate loss through leaching (Table 7.2, panel C) appears to have little relative impact on nutrient needs. Still, appropriate nutrient management can greatly reduce the risk of nitrate loss through leaching. In addition, highly leached soils (those whose loss is considered "high" or "very high") cannot retain enough Mg in the clay complex, and thus it is important to increase the soil organic matter and reach the appropriate fertilizer mix (with the proper proportions of Ca, Mg, K, and P) to satisfy the plants' needs for Mg. Thus, more nutrients should be applied to highly and very highly leached soils than to soils with average and low levels of leaching. Soils experiencing very high nitrate loss would need about 22–40 percent more of each nutrient in comparison to soils experiencing low nitrate loss (Table 7.2, panel C).

At the time of maize planting in BL, farmers applied diammonium phosphate (DAP), which contains 18 percent N and 46 percent phosphate, making it an excellent source of N and P, in addition to KCl 0-0-60, which contains 60 percent K fertilizer (as potassium oxide, or K2O, also known as potash, yielding 50 percent K). For top dressing (Table 7.2, panel D), N-supplying fertilizers (urea) and other nutrients (Ca, Mg, P, KCl 50, and MAP 33) were applied. In a very wet season, when heavy rain may leach away some of the fertilizer, top dressing should be split (one application at two to three weeks and the second before tasseling), for a total of three applications, consistent with the soil analysis report's recommendation to split the application of fertilizer, especially N and K, over the growing season. Thus, the amount of nutrients applied should be slightly higher in the second and third applications than in the first.

Maize is frequently subjected to waterlogging (Table 7.2, panel E), especially in poorly drained soils, where standing water can cause a rapid depletion of the oxygen required for plant growth and development (Geigenberger et al. 2000). In addition, waterlogging can leach out or change the availability of nutrients to the plant (Palapala and Nyamolo 2016). Thus, for BL, it was recommended that an average of 1,217.7kg/ha of Ca, 654.6 kg/ha of MAP 33, 290.1 kg/ha of phosphate, 238.2 kg/ha of Mg, 144.0 kg/ha of K, and 579.3 kg/ha of KCl 50 be applied when there is a risk of waterlogging (Table 7.2, panel E).

Table 7.3 displays descriptive statistics for all of the fertilizer recommendations. The mean and median values for each input are close to each other and the skew values are relatively low, indicating that the data are normally distributed.

TABLE 7.3—DESCRIPTIVE STATISTICS, FERTILIZER RECOMMENDATIONS, KG/HA

Statistic	Ca	MAP 33	K	Mg	P	KCl 50
Mean	665.91	373.28	158.94	131.73	82.07	318.10
Median	664.81	400.00	160.25	132.40	85.71	300.00
Mode	698.84	400.00	164.59	135.40	80.91	300.00
Min.	466.12	0.00	87.81	99.17	0.00	150.00
Max.	1,036.54	600.00	200.16	156.64	134.03	400.00

Source: Authors' calculations using data from Agri Xcellence.

There were 6,135 ha requiring Ca in the range of 500–1,000 kg/ha and 6,130 ha requiring Mg in the range of 90–150 kg/ha, suggesting that the entire land area required Ca and Mg. In addition, most of the land required more than 250 kg/ha of KCl 50 (that is, 56 percent of the land required between 250 and 300 kg/ha and 44 percent required more than 300 kg/ha—which is close to the mean value of 373 kg/ha). As for K, approximately 99 percent (6,112 ha) of the land required this nutrient in amounts greater than 120 kg/ha.

Fertilizer Application: National Recommendations in the Democratic Republic of the Congo

We use national recommendations for fertilizer as an example of non-CSA practices based on PA. Because BL is in the western part of the country, we use recommendations for the provinces of Kongo Central (formerly called Bas-Congo) and Kinshasa, and the former province of Bandundu, as opposed to nationwide recommendations.

In Kongo Central and Bandundu, maize is produced by smallholder farmers, cultivating 1 ha or less per household and using no external inputs. In Kinshasa Province, there are some large (100- to 1,000-ha) commercial, tractor-mechanized farms on the Batéké plateau, which usually use some chemical fertilizers (urea and N-P-K). In smallholder agriculture, yields are very low, less than 1,000 kg/ha (± 800 kg/ha) (USAID 2015b).

Farmers have only limited access to fertilizers because of their high cost. Maize always tends to be grown on the more fertile soils in the valley bottoms. Because no chemical fertilizers are used on maize or cassava, except on large commercial farms on the Batéké plateau near Kinshasa, and because organic fertilizers (manure and compost) are usually in very short supply, soil fertility is not restored after harvest. Furthermore, fallows tend to disappear completely due to population and marketing pressure. Thus, yields tend to decrease over time, and poor soil fertility becomes a major production constraint (USAID 2015b).

Overall, fertilizer application is based on national recommendations from the Ministry of Agriculture, which call for specific amounts for small, medium, and large farms. For example, the recommendation for large farms is that the first application be done following the formula NPK 17-17-17[39] (300 kg for N, P and K), in addition to 200 kg of urea. In Kongo Central Province, for example, the amount of fertilizer recommended for maize is 200 kg/ha, at a unit cost of US$1.60/kg.

These recommendations assume homogeneity across space and time, prescribing the same quantities of nutrients regardless of the soil and spatial heterogeneity. However, as the soil analysis performed in BL shows, there is wide variation in the soils' chemical and physical properties. Therefore, the optimal amount of fertilizer is specific to the region, soil type, and predicted rainfall. Thus the agricultural sector in the DRC would greatly benefit from precision farming practices, which facilitate the optimal use of fertilizers and other resources.

Benefits from Implementing Climate-Smart Agricultural Practices

Expected Long-Term Yield

Based on PA recommendations for nutrient application, the expected long-term maize yield is much higher than under national recommendations without PA—one more reason that the DRC agricultural sector would largely benefit from PA and CSA management practices in the medium and long run. As shown in Table 7.4, 49.1 percent of the land is expected to yield between 4 and 8 tons/ha, 30 percent to yield at least 9 tons/ha, and 20 percent to produce 2 to 3 tons/ha", compared with 0.8 tons/ha when PA is not applied.[40] Yield distribution is not uniform across the field (Table 7.4) due to the spatial heterogeneity of available soil nutrients.

TABLE 7.4—DISTRIBUTION OF EXPECTED LONG-TERM YIELD UNDER PRECISION AGRICULTURE PRACTICES

Yield (tons/ha)	Area (ha)	Area (% of total)
≤ 2	57.3	0.5
2–3	2,101.1	19.9
3–5	237.2	2.2
5–7	4,865.8	46.0
7–8	7.6	0.1
8–9	86.3	0.8
> 9	3,220.2	30.4
Total	10,575.5	100.0

Source: Authors' calculations using data from Agri Xcellence.

If provided with the information in Table 7.4, what would a smart farmer do? Because fertilizer cost per hectare is the same regardless of expected yield, a smart farmer would avoid planting in areas with at most 2 tons/ha of expected yield and maximize planting of areas with 5–7 tons/ha and more than 9 tons/ha. Such optimization thinking, which leads to smart farming, is possible only when knowledge is available to farmers.

39 Fertilizer grade refers to a legal guarantee of the content of available plant nutrients, expressed as a percentage by weight in the fertilizer. For example, the 12-32-16 grade of NPK complex fertilizers has 12 percent N, 32 percent P (in the form of P2O5), and 16 percent potash (K2O).

40 The average yield under national recommendations in the DRC is only 0.8 tons/ha (Ministry of Agriculture, DRC).

In addition, an analysis of first-year and long-term expected yields indicates that the total production from the entire parcel of land will be 50,360.6 tons of maize during the first year but will grow over the long term to 64,284.6 tons, an increase of 27.6 percent. These predictions are consistent with the BL progress report (Africom Commodities 2016), which predicted, based on the current condition of the crop, that a yield of 4–5 tons/ha can indeed be achieved.

Cultivation Method: Tillage versus No Tillage

In general, no-till agriculture is considered good for soil fertility, with benefits in terms of adaptive capacity and food security because it contributes to increased yields. Kassam and colleagues (2009) indicated that minimal soil disturbance through no tillage or reduced tillage ensures a favorable proportion of gases for root respiration, moderate organic matter oxidation, good porosity for water movement, and limited re-exposure to weed seeds and their germination—all of which may enhance crop growth and final grain yield.

In addition, research shows evidence of yield and soil improvements in humid tropical and temperate ecosystems where minimal and no-tillage practices are applied (Rasmussen 1999, Diaz-Zorita, Duarte, and Grove 2002; Bronick and Lal 2005). Consistent with previous research, Hine and Pretty (2008) suggested positive effects on maize yields compared with traditional tillage management.

The BL soil analysis revealed that the first 30 cm of the topsoil was high in organic carbon. Such organic matter creates negatively charged sites to which cations can bind, reducing the leaching of cations. Therefore, recommendations called for building more organic matter by using a no-till or strip-till system of cultivation, which can contribute toward improved water retention, rain use efficiency, soil improvement, and increased yields. In addition, farmers in the DRC practicing no tillage are likely to save on plowing costs, estimated at US$200–US$300 per hectare.

Optimal Soil and Crop Management

Research has shown that the greatest benefits of implementing improved cropland management practices under CSA are higher and more stable yields, increased system resilience, enhanced livelihoods, greater food security, and reduced uncertainty (Conant 2010; Woodfine 2009; Thomas 2008).

In BL, the application of inorganic fertilizer was based on the soil analysis with the objective of improving the proportion of nutrients retained in the soil while reducing both waste and GHGs. Given their low agricultural productivity, food insecurity, poverty, and additional constraints because of climate change, countries such as the DRC need to increase their food production. This process of agricultural intensification requires the use of inorganic fertilizer. Indeed, increases in fertilizer use have driven a rapid expansion in agricultural productivity in the post-World War II era (FAO 2015).

Optimal Soil Management: Cover Crops

As part of PA-driven soil management practices, BL farmers used cover crops, first planting them so that trial runs could be conducted. Thus, soil analysis as well as cover crop tests provided valuable insights into the best-suited applications of lime, humates, nutrients, and fertilizer in order to ensure the expected optimal yields (Africom Commodities 2016). The

BL experiment is in line with previous studies (Pretty 2000; Altieri 1999) showing that farmers benefited through increased yields of maize following the use of cover crops. In addition, mixing no-till farming and cover crop usage with herbicides has been found to reduce leaching and improve yields (FAO 2010).

The use of improved crop varieties in BL is also expected to increase average yields over time. Though the gains may vary across countries and crops, the International Centre for Tropical Agriculture (CIAT 2008) found a yield increase following the introduction of new bean varieties in some African countries. Thus, the use of improved crop varieties in BL is also expected to improve average yields.

Profitability: Fertilizer Costs

Table 7.5 compares first-year fertilizer costs between DRC farmers under precision farming, which requires location-specific fertilizer application, and those using homogenous fertilizer application as recommended by the DRC Ministry of Agriculture.

TABLE 7.5—FIRST-YEAR INPUT COSTS WITH AND WITHOUT PRECISION AGRICULTURE

Variables	PA	No PA
Average area planted (ha)	5,721.5	5,721.5
Application rate (kg/ha)	296.6	200.0
Fertilizer cost ($US/kg)	1.60	1.60
Fertilizer cost ($US/ha)	474.60	320.00
Total fertilizer cost ($US)	2,715,195.00	1,830,880.00

Source: Authors' calculations.

Note: "No PA" application rate is based on national recommendations of an average of 200 kg/ha of fertilizer for maize. "PA" application rate is a weighted average. PA = precision agriculture.

Agricultural practices involving efficient use and application of fertilizers (i.e., PA) lead to higher initial costs. We use an average unit fertilizer cost of $US1.60/kg and an area planted of 5,721.5 ha (the area of BL parcel 1), which leads to a total cost of $1,830,880 when fertilizers are applied per national recommendations, compared with $2,715,195 under PA. Therefore, precision farming, entailing an increase of 48 percent in fertilizer costs for the first year, does not allow immediate savings for farmers. However, this comparison paints an incomplete picture until we take into account the following factors:

- First, the need for fertilizer during the first year, following the soil analysis, will be higher than in subsequent years. The soil condition and nutrient balance are expected to improve over time, leading to lower fertilizer requirements in the future (Africom Commodities 2016).
- Second, the combined effect of inorganic fertilizer and organic fertilizer (compost and animal manure) use in the subsequent years in BL, as recommended by CSA practices, is likely to boost yields, leading to higher incomes that offset the fertilizer costs. Indeed, research has shown that maize yields increased by 100 percent in Kenya (Pretty et al. 2006), and maize and wheat yields increased by between 198 and 250 percent (Altieri 1999) following the adoption of organic fertilization. In addition, following PA recommendations is expected to improve soil conditions, reducing future fertilizer costs (as mentioned above) while having a positive effect on the environment.
- As pointed out above, the no-tillage practice offers an immediate savings on input costs (plowing).

- Some costs are not included in this analysis (cost of pesticides, operating expenses, transportation costs)[41] and could alter the results.

Table 7.6 shows a significant yield increase when PA practices are implemented. The total production with PA is 22,886 tons, representing an increase of a little more than 400 percent over conventional practices.

TABLE 7.6—MAIZE YIELD WITH AND WITHOUT PRECISION AGRICULTURE

Variables	PA	No PA
Hectares planted	5,721.50	5,721.50
Average yield (tons/ha)	4.00	0.78[a]
Total production (tons)	22,886.00	4,462.77

Source: Authors' calculations.
Note: [a]Average yield under no PA for maize in DRC between 2000 and 2014 from FAO (2013b). PA = precision agriculture.

As reported in Table 7.7, the level of income under PA is significantly higher than under the national recommendation (about four times as high). Given the higher yield that is expected to be sustained over time when PA practices are implemented, there is a very high potential for the yield to remain at approximately 4 tons/ha or more. Our findings also suggest a positive profit under PA, compared with negative profit under the national recommendations, indicating that although implementing PA may result in higher costs (if all costs are included), the expected increase in yield will more than offset the additional costs. In addition, a portion of the costs is expected to be lowered over time for reasons described above.

TABLE 7.7—INCOME WITH AND WITHOUT PRECISION AGRICULTURE

Variables	PA	No PA
Input costs (US$/ha)	474.56	320.00
Plowing (US$/ha)	0.00	250.00
Total planted area (ha)	5,721.50	5,721.50
Total input costs for 5,721.5 ha	2,715,195.04	1,830,880.00
Average yield (tons/ha)	4.00	380.00
Sales price ($US/ton)	380.00	4,462.77
Total production	22,886.00	1,695,852.60
Total revenue ($US)	8,696,680.00	265,477.60
Profit (including plowing costs)	8,696,680.00	

Source: Authors' calculations.
Note: For simplicity, we assume that all costs are the same except the ones whose application requires fine-tuned knowledge, such as fertilizer and cultivation methods. PA = precision agriculture.

Concluding Remarks and Policy Implications

Similar to that of most countries in SSA, the agricultural sector in the DRC has been characterized by low productivity. The effects of climate change constitute an additional challenge to food security; rising temperatures and increased frequency of extreme weather events (floods, droughts, and so on) have already started having negative effects on crop yields.

For these reasons, the DRC needs to revisit and improve on its current agricultural methods and management of natural resources to achieve food security while also preserving natural resources and the environment, and reducing the effects of climate change.

41 An estimate of these costs (which will further increase the input costs) is available for BL but not for farms under national recommendations, so no comparison is currently possible.

The government of the DRC recently initiated efforts to transform the agricultural sector; feed the growing population; and provide a basis for inclusive economic growth, food security, and poverty reduction. In 2014, it created the BL ASEZ, making investments in crop production, agroprocessing, and marketing following CSA practices induced by PA. PA methods help farmers optimize inputs for agricultural production in accordance with the capability of the land. Thus, some of the practices analyzed here fall into the category of conservation agriculture and PA, whose impacts on production have been extensively researched (FAO 2011; Umar et al. 2011). Specifically, the following practices were implemented: efficient and georeferenced application of inorganic fertilizer, use of selected seeds, use of cover crops, and minimal or no tillage.

This study aimed at examining the effects of PA-induced CSA practices on maize yields in BL by comparing input application with and without PA recommendations. In addition, it was an attempt to explicitly analyze the use of soil knowledge to guide optimal input use and cultivation methods to improve yields and farmers' income. The first step was an extensive soil analysis and data mapping of BL, which was crucial in that it provided a better understanding of the soil condition, texture, and nutrient deficiencies. Using the knowledge gained from the soil analysis, some recommendations were made to guide the timely application of nutrients in precise and targeted areas.

Overall, the findings suggest that climate-smart practices offer to countries such as the DRC a sustainable way to boost productivity through improved crop yields and increased input efficiencies. We compared the expected average long-term yield under PA with the average yield obtained under national recommendations (as formulated by the Ministry of Agriculture) and found that yield under PA was about four times higher than under national recommendations, indicating that farmers could largely benefit from increased crop yields under PA. Specifically, the average yield under national recommendations in the DRC is only 0.8 tons/ha, whereas the yield under PA was 4.0 tons/ha.

Under national recommendations, the average fertilizer application rate is 200 kg/ha, whereas under PA it is about 296 kg/ha. Though farmers may have to spend a little more at first on fertilizers under PA, the significantly large increase in crop yield more than offsets the cost of fertilizer. In addition, total fertilizer cost is expected to decrease over time because the CSA practices should enhance soil conditions and preserve the environment.

Moreover, market information suggests that the price of maize flour in the DRC decreased by 30 percent when BL began providing an additional maize supply for the country. Given that consumers allocate a high proportion of their income to food, a 30 percent reduction in the price of maize flour would make a significant and positive impact on consumers' budgets.

Consistent with previous studies, the use of cover crops, combined with mulching and no tillage, are expected to improve crop yield over time. Thus, the yield expected in the future could be even higher than that reported in this study. No-tillage practices are expected to cut farmers' costs as well, with plowing costs estimated at US$250 per hectare.

Overall, then, farmers' revenue under PA is significantly higher than that under the national recommendations. Though fertilizer costs are higher (due to a higher application rate in the first year), the savings on plowing and the increase in crop yield largely compensate for this cost, and yields are expected to increase over time.

It goes without saying that "blind farming," that is, farming without PA, is highly inefficient and exacerbates the challenges of addressing climate change. As in the case of the DRC, other African governments should promote PA as a way of optimizing the use of limited resources while mitigating the effects of climate change. For example, it should be mandatory to include results of soil analysis in farming loan and crop insurance applications. Similarly, under the National Agricultural Investment Plans, ministries of agriculture should require detailed soil analysis prior to every new land development for farming purposes. However, because of the high cost associated with PA technology, millions of smallholders, who make up more than 70 percent of the African agricultural production system, will likely be left out. Therefore, we propose that a special fund be set up to make PA accessible to these smallholders.

Smallholder farmers' access to PA is still very limited for two main reasons: affordability and understanding. Indeed, in the DRC, soil analysis costs US$74/ha—too expensive for smallholder farmers. The ideal would be the creation of a special-purpose funding vehicle as a platform for the corporate sector to work in partnership with the government, multilateral development banks, development organizations, donor agencies, foundations, nongovernmental and civil society organizations, small farmers, and local community organizations. With respect to understanding, it is important that national education and research systems be reorganized to upgrade smallholder farmers' skills to properly use PA tools. As the FAO stated, "this requires strategic interministerial planning involving the ministries of agriculture, education, and trade, along with representatives of tertiary and secondary institutes, farmer organizations, and agro-industry" (2015, 4).

Finally, to promote and expand the use of PA, given its benefits beyond targeted farmers, we propose that (1) PA practices be included as a requirement for every new agricultural development project and (2) soil analysis be made part of applications for agricultural loans and crop insurance.

CHAPTER 8

The Unholy Cross: Profitability and Adoption of Climate-Smart Agriculture Practices in Africa South of the Sahara

Ephraim Nkonya and Jawoo Koo[42]

42 We are grateful to the German Federal Ministry for Economic Cooperation and Development (BMZ) for providing funding for this study. We also acknowledge Edward Kato for providing analytical support.

Climate-smart agriculture (CSA) practices aim to achieve three closely related objectives—sustainably increase agricultural productivity, adapt to climate change, and mitigate greenhouse gas emissions. The CSA objectives directly contribute to achieving United Nations Sustainable Development Goals 1 (no poverty), 2 (zero hunger), 13 (climate action), and 15 (life on land). These factors underscore the importance of ensuring widespread uptake of CSA, which will significantly contribute to achieving overarching development objectives in Africa south of the Sahara (SSA), in particular, food security and poverty reduction.

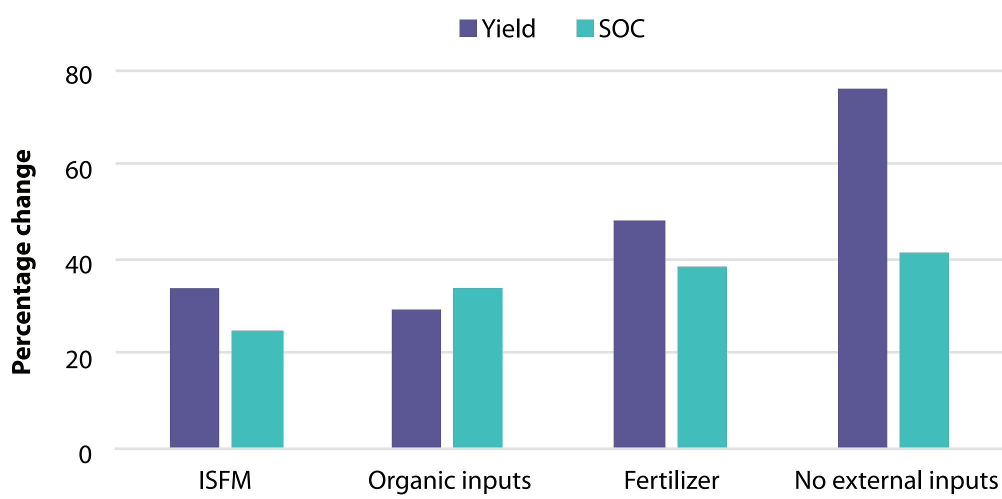
Scaling up the adoption of CSA requires that farmer incentives be taken into account—especially for practices that require significant investment in external and on-farm inputs. Smallholder farmers have particularly limited access to external inputs such as fertilizer, which leads to lower profitability (Chianu, Chianu, and Mairura 2012), lower CSA adoption, and land degradation. For example, over the past 56 years, intensity of fertilizer use—that is, the amount of nutrients used—in SSA has increased from 1 kg/ha of a nitrogen, phosphorus, and potassium blend in 1961 to only 13 kg/ha in 2014 (FAO 2015). The slow growth rate of inorganic fertilizer use has translated into low crop production, plunging the region into being a net food importer since 1980 (Rakotoarisoa, Iafrate, and Paschali 2011).

SSA countries have used different methods to increase fertilizer consumption and consequently food production. The most common method has been fertilizer subsidies, which have increased the rate of fertilizer use. For example, fertilizer use in Zambia increased by 12.5 percent due to subsidies (Druilhe and Barreiro-Hurlé 2012). Fertilizer subsidies have also been shown to increase yield by 12 percent for cotton in Burkina Faso, 41 percent for maize in Ghana, and 32 percent for maize in Nigeria (Druilhe and Barreiro-Hurlé 2012). However, such programs have crowded out private-sector development in input marketing. Across SSA, the cost of these subsidies has become a burden for governments' budgets, making them unsustainable.

This chapter examines the profitability and adoption rates of CSA practices in SSA. We particularly look at strategies that could be used to increase adoption of one particular CSA practice, integrated soil fertility management (ISFM). Other CSA practices include agroforestry, drought-tolerant crops and improved crop varieties, conservation agriculture, integrated crop-livestock management, improved water management, improved pasture and grazing land and water management, restoration of degraded lands, weather early warning systems, and risk insurance (World Bank 2011).

Our results on the adoption and profitability of CSA show an inverse relationship—that is, the adoption rate and profit are inversely related, a pattern that is puzzling and undesired—or, as we refer to it in this chapter, an unholy cross. We begin with a discussion of how ISFM achieves the three CSA objectives. The next section analyzes its profitability and adoption rate, compared with other land management practices, finding a profit-adoption pattern in SSA that is contrary to expectations—the higher the profit, the lower the adoption rate. This is followed by a discussion of the reasons behind this puzzling pattern and a reflection on the policy implications.

FIGURE 8.1—PERCENTAGE DECLINE IN YIELD AND SOIL ORGANIC CARBON, 1972–1993, KENYA LONG-TERM EXPERIMENT



Source: Authors' calculations from unpublished long-term experiment data, Kabete Agricultural Research Institute, Kenya.
Note: ISFM = integrated soil fertility management; SOC = soil organic carbon.

TABLE 8.1—MAIZE YIELD TREND, 1976–1993, KENYA LONG-TERM EXPERIMENT

Treatment[a]	Yield (tons/ha)				% yield increase[b]
	1976	1977–1981	1982–1986	1990–1993	
Control—no inputs	3.80	2.77	2.18	0.91	221
Organic inputs only	3.79	3.89	3.98	2.69	9
Fertilizer only	4.23	4.00	4.21	2.18	34
ISFM	4.43	4.72	4.98	2.92	n.a.

Source: Authors' calculations from unpublished long-term experiment data, Kabete Agricultural Research Institute, Kenya.
Note: a Organic inputs: 5 metric tons per hectare of manure; Fertilizer only: 60 KgN/ha-1 and 60 KgP2O5/ha-1; ISFM: 60 KgN/ha-1, 60 KgP2O5/ha-1, and 5 metric tons per hectare of manure. b Yield increase (percentage) when farmer switches to ISFM from another soil fertility management practice. ISFM = integrated soil fertility management; n.a. = not applicable.

Integrated Soil Fertility Management and Climate-Smart Agriculture Objectives

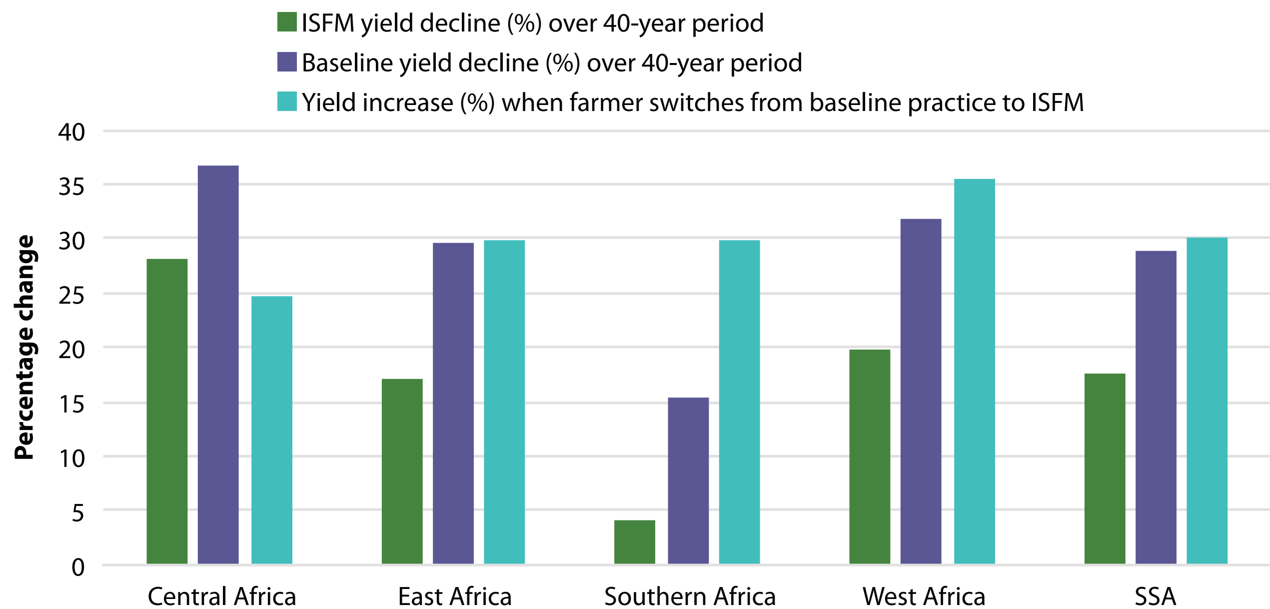
In an effort to better understand strategies for increasing the adoption of CSA, it is important to examine the objectives of CSA and the incentives for its adoption. To set the background for this analysis, this section illustrates the CSA objectives by using empirical evidence to show how ISFM, as an example of CSA, achieves these objectives.

Objective 1: Sustainably Increase Agricultural Productivity

Long-term soil fertility trials in Kenya have shown that the yield and soil organic carbon (SOC) of plots treated with ISFM, fertilizer only, and organic inputs decline over time (Figure 8.1 and Table 8.1). In the 21-year period reported (1972-1993), maize yield and SOC for the plots that did not receive any external inputs fell by almost 80 percent and 40 percent, respectively, whereas the yield on ISFM plots fell by only 34 percent (Figure 8.1). The percentage yield decline for the plots receiving inorganic fertilizer and those receiving organic inputs only were comparable to that of the ISFM plots. In fact, the average yield of plots under organic inputs was 23 percent higher than that of plots under fertilizer only. This result underscores the potential negative impacts of policies that promote fertilizer only. During the 1990–1993 period, findings suggest that yield increased threefold, from 0.9 tons/ha[43] to about 3.0 tons/ha (Table 8.1), when farmers switched from no external inputs to ISFM.

The decline in yield is largely due to continuous cropping, which depletes SOC and leads to deterioration of soil chemical and physical properties (Nandwa and Bekunda 1998). A subregional-level analysis using 40-year crop simulation modeling (Nkonya et al. 2017) shows comparable results—though smaller in impact, largely due to extensive aggregation (Figure 8.2). Yield on plots treated with ISFM fell by 18 percent, compared with about 30 percent for the baseline treatment, which is the average soil fertility management practice in SSA and differs across countries (Figure 8.2). If maize farmers in SSA adopt ISFM, food security will increase by at least 30 percent for the 50 percent of the SSA population who are maize consumers (CIMMYT 2016) (Table 8.2). This means that ISFM and other CSAs will improve food security, even though the improvement will happen at a declining rate if farmers practice continuous cropping.

FIGURE 8.2—YIELD CHANGE DUE TO LONG-TERM CONTINUOUS MAIZE CROPPING UNDER INTEGRATED SOIL FERTILITY MANAGEMENT AND OTHER LAND MANAGEMENT PRACTICES, 1980–2010



Source: Results of Decision Support System for Agrotechnology Transfer (DSSAT) crop simulation model from Nkonya et al. (2016) study.

Note: Baseline is average soil fertility management practice in SSA and differs across countries. ISFM = integrated soil fertility management; SSA = Africa south of the Sahara.

On-farm experiments in SSA have shown that a combination of CSA practices can sustainably increase agricultural productivity. Increased productivity can also be sustainable if farmers use a combination of other CSA practices that can help maintain and restore soil fertility. Such practices include fallowing, agroforestry, crop rotation, reduced tillage, cover crops, and balanced fertilizer application (Tilman et al. 2002). For example, a

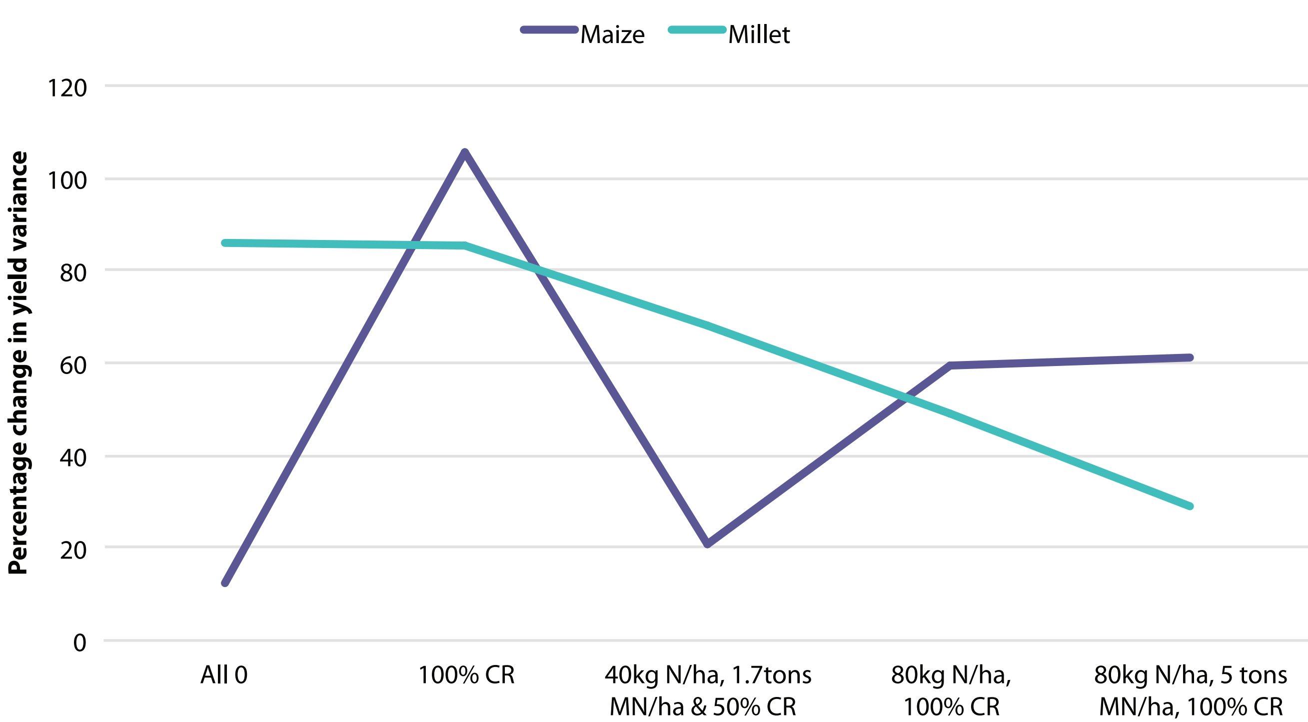
43 Throughout the chapter, *tons* refers to metric tons.

long-term (10-year) agroforestry experiment in Malawi showed that the yield of maize intercropped with Gliricidia started to increase in the third year and ultimately reached about 500 percent of its year-one yield (Akinnifesi et al. 2010). Gliricidia also improved SOC and other chemical and biophysical characteristics (Akinnifesi et al. 2010). In summary, the first CSA objective, of sustainably increasing agricultural productivity, can be achieved using a combination of practices that are affordable to smallholder farmers in SSA.

Objective 2: Increase Adaptation to Climate Change

ISFM practices reduce yield variability by improving the soil's water-holding capacity (Gentile et al. 2008; Lal 2011; Govaerts et al. 2009; Manna et al. 2005). To illustrate, Figure 8.3 offers results of a 30-year crop simulation, showing a declining yield variance for maize and millet as soil fertility management improves in Mali.[44] These results underscore the adaptation potential of ISFM and other CSA practices that enhance SOC.

FIGURE 8.3—IMPACT OF SOIL AND WATER MANAGEMENT ON MAIZE AND MILLET YIELD VARIANCE, 30-YEAR DSSAT SIMULATION RESULTS, MALI



Source: Results of DSSAT crop simulation model from Nkonya, Koo and Kato (2017).
Note: CR = crop residues; MN = manure; DSSAT = Decision Support System for Agrotechnology Transfer; tons = metric tons.

Objective 3: Mitigate Climate Change

As seen above, ISFM significantly increases SOC, simultaneously contributing to adaptation and mitigation of climate change. However, climate change mitigation may not be a criterion used by farmers to make investment decisions. Thus, there is a need to incentivize farmers to adopt ISFM in the form of payment for ecosystem services (PES). Determining the level of off-site climate mitigation benefits that accrue from ISFM would help policy makers design strategies for incentivizing adoption

44 Our own simulation results, not reported here, show there was an increase in yield variability due to climate change.

of ISFM and other CSA practices. We use crop simulation results from Rwanda to compute the value of the climate mitigation services provided by ISFM. A large proportion of Rwandan farmers (about 40 percent) use no external inputs (Nkonya et al. 2017), so that practice becomes our baseline. Farmers who adopt ISFM sequester more carbon (as CO_2 equivalent) than those using the baseline practice. The additional CO_2 equivalent sequestered is worth close to US$3,000/ha, which is about 200 percent of the profit these ISFM farmers get from their maize grain harvest (Table 8.2).

The discussion above shows that ISFM achieves all three major objectives of CSA, yet its adoption is the lowest among land management practices in SSA. Below we discuss the adoption pattern of ISFM in relation to its profitability.

Adoption of ISFM and Other Soil Fertility Management Practices

The adoption rates of ISFM and other soil fertility management practices differ significantly across crops. In Kenya, adoption of ISFM is highest for potatoes and beans, both of which are commercial crops (Figure 8.4). In Zambia, ISFM adoption is highest on maize plots and lowest on soybeans (Figure 8.5), an expected outcome, given that maize is Zambia's staple food crop, accounting

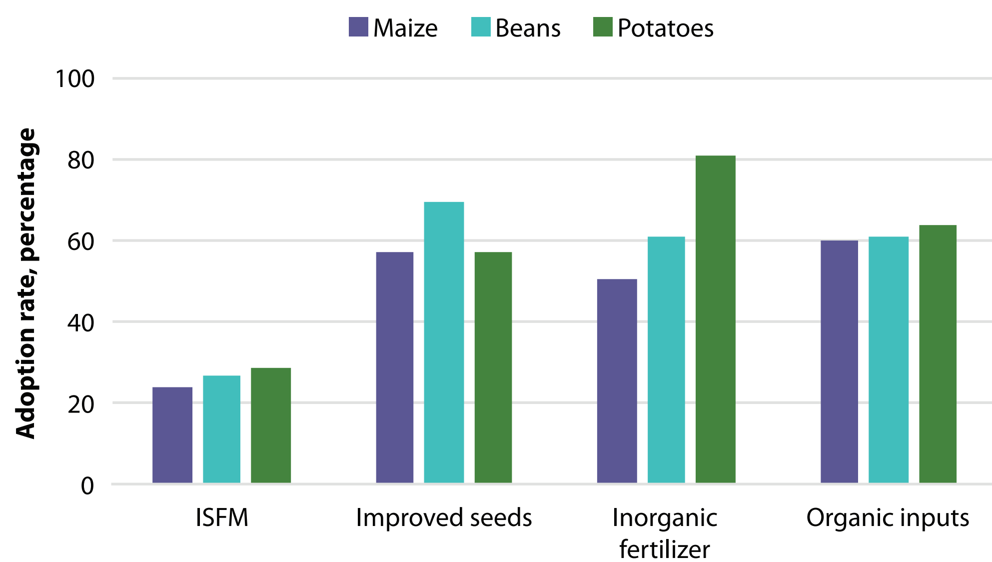
TABLE 8.2—VALUE OF OFF-FARM BENEFITS (CLIMATE MITIGATION) OF ADOPTING INTEGRATED SOIL FERTILITY MANAGEMENT ON MAIZE PLOTS

Statistic	Treatment			
	ISFM	Fertilizer	Organic	Baseline[b]
Yield (metric tons/ha)	3	2	2	1
Cost of production (US$/ha)	127	175	62	51
Profit (US$/ha)[a]	1,350	855	891	654
Value of CO_2 equivalent sequestered—net of value sequestered with no external inputs[c]				
• CO_2-equiv. sequestered (US$/ha)	2,701	584	1,095	n.a.
• As percentage of total profit	200	68	123	n.a.
• Off-farm benefit as % of total benefits	67	41	55	n.a.

Source: Computed from Nkonya et al. (2017).

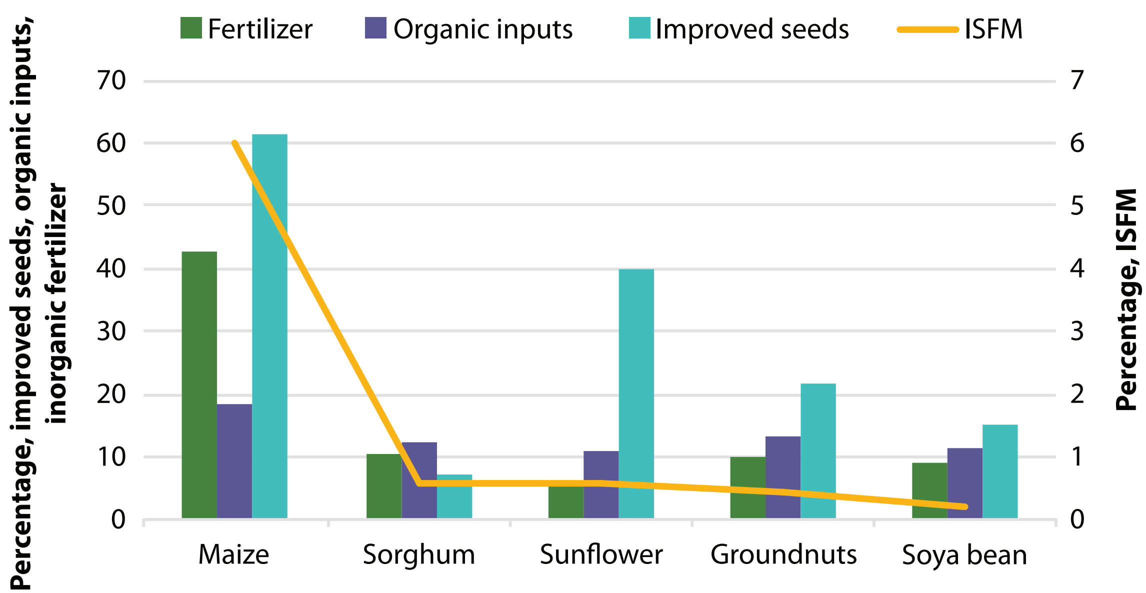
Note: [a] Price of maize per ton = US$475 (RATIN 2017). [b] Baseline is no external inputs. [c] Carbon price varies widely, from as low as <US$1 to as high as US$126 per ton of CO2 equivalent (World Bank 2017). n.a. = not applicable.

FIGURE 8.4—ADOPTION RATE OF IMPROVED SEEDS AND SOIL FERTILITY MANAGEMENT PRACTICES, KENYA, 2015



Source: Nkonya et al. (2017).

FIGURE 8.5—ADOPTION RATE OF INTEGRATED SOIL FERTILITY MANAGEMENT, ZAMBIA



Sources: Calculated from Rural Agricultural Livelihoods Survey (RALS) survey 2012 raw data.

for 49.4 percent of the country's caloric intake (FAO 2013). As is common in other countries, ISFM has the lowest adoption in Kenya and Zambia among the four technologies considered—improved seeds, inorganic fertilizer only, organic inputs only, and ISFM (Figures 8.4 and 8.5). Adoption of improved seeds is higher in both countries than elsewhere in SSA. For example, adoption of improved maize seeds is 33 percent in eastern Africa and 38 percent in southern Africa (Scoones and Thompson 2011), compared with 57 percent in Kenya. Adoption of inorganic fertilizer for potatoes is especially high in Kenya, where the tuber crop is grown for commercial purposes. Interestingly, Kenya has much higher inorganic fertilizer adoption than Zambia even though the latter gives a generous fertilizer subsidy, reflecting the effect of Kenya's strong input markets and the presence of agroforestry supported by local and international institutions.

The Unholy Cross?

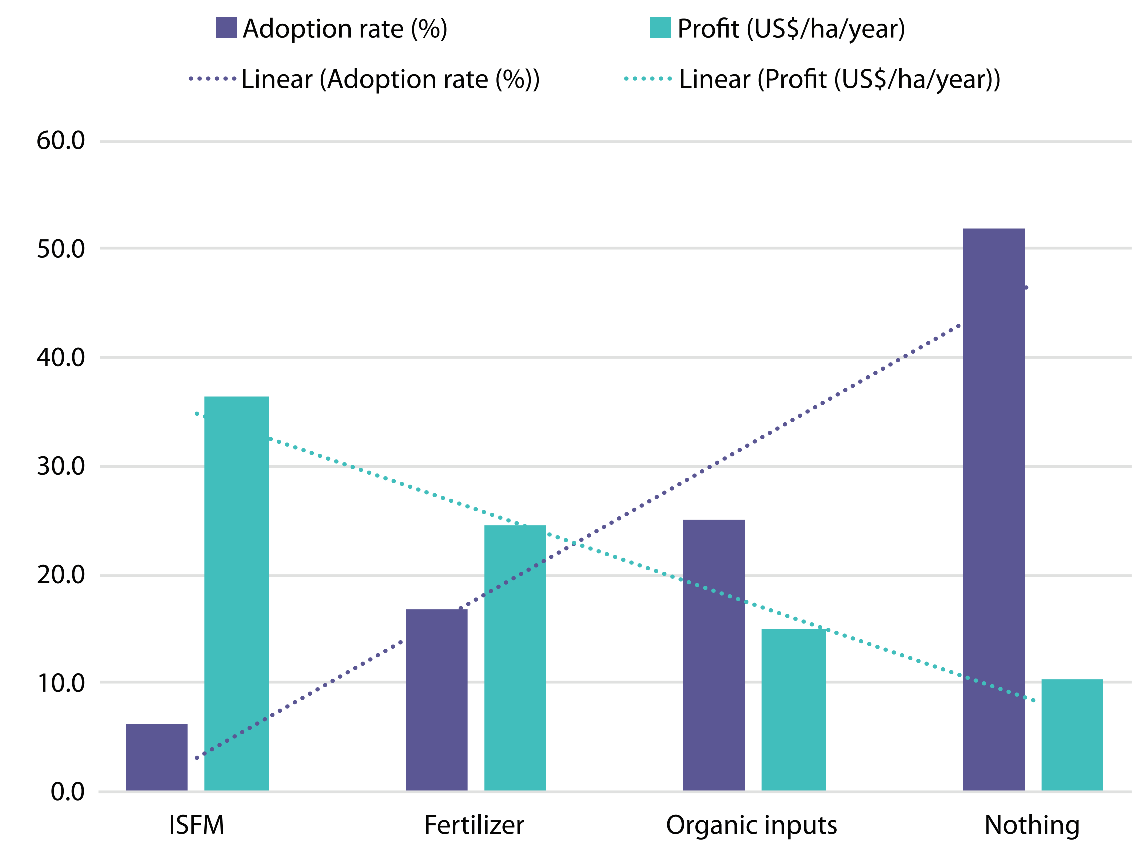
Our study to determine the profitability of fertilizer and other soil fertility management practices revealed puzzling results. According to economic theory, the higher the profit of a soil fertility management practice, the higher the adoption rate should be. However, our analysis of household survey data from seven SSA countries (Kenya, Malawi, Mali, Niger, Nigeria, Senegal, and Uganda) shows an inverse relationship between profitability and adoption of soil fertility management practices (Figure 8.6). ISFM has the highest profit but the lowest adoption rate. The majority of farmers (52 percent) apply no inputs at all, even though this practice has the lowest profit!

An important question is why we observe such puzzling farmer behavior. Below we discuss some possible reasons for the observed pattern based on our empirical studies and literature review.

Weak promotion of ISFM by extension agents: The first important question concerns the advisory services that farmers receive from extension service providers. Nkonya, Koo, and Kato (2017) asked extension agents in Nigeria and Uganda what types of extension messages they give to farmers.

Only one-third of the surveyed extension agents reported providing messages on organic soil fertility management practices—compared with about 70 percent who provided advisory services on inorganic fertilizer (Figure 8.7). In both countries, no extension agents reported promoting ISFM, suggesting weak capacity of extension agents to provide advisory services on ISFM. It is not surprising, then, that the adoption of ISFM in Nigeria and Uganda is only about 1 percent (Nkonya et al. 2016). The most common extension messages given were on improved varieties (about 90 percent of agents) and agrochemicals (about 80 percent). These are traditional messages that have been provided to farmers since the early 1960s to increase crop yield. The new paradigm of ISFM started in the late 1980s[45] (Bationo et al. 2007), so it is possible that many extension service providers have not received ISFM training. The majority of the extension agents interviewed were middle-aged, with an average age of 44 in both countries. Nkonya, Koo, and Kato (2017) conducted the extension agent study in 2012, so the agents' age suggests that they graduated from college in the 1980s or early 1990s, when ISFM was not yet widely known and the extension emphasis was on improved varieties and agrochemicals.

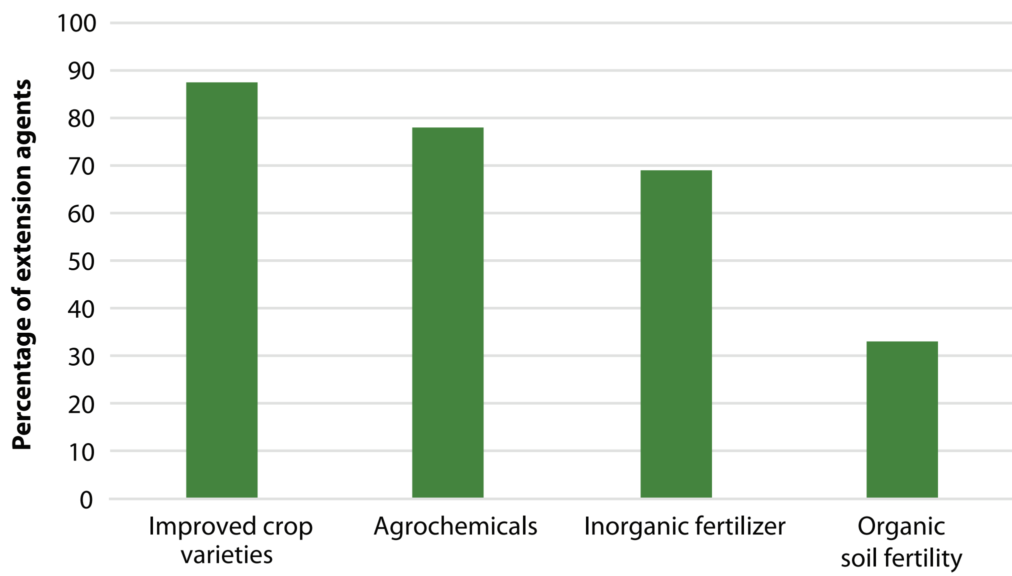
FIGURE 8.6—THE UNHOLY CROSS: INVERSE RELATIONSHIP BETWEEN PROFITABILITY AND ADOPTION OF SOIL FERTILITY MANAGEMENT PRACTICES, AFRICA SOUTH OF THE SAHARA



Source: Authors' calculations using raw household survey data from Kenya, Malawi, Mali, Niger, Nigeria, Senegal, and Uganda.

45 The first study documenting ISFM was published in 1987 (Kang et al. 1987).

FIGURE 8.7—TYPES OF MESSAGES GIVEN TO FARMERS BY EXTENSION AGENTS IN NIGERIA AND UGANDA



Source: Nkonya, Koo, and Kato (2017).

Labor intensiveness of ISFM involving biomass transfer: The majority of farmers who reported use of organic inputs applied manure. Our study has shown that labor accounts for 50 percent of the total cost of production for ISFM adopters who use manure or other organic inputs involving biomass transfer—that is, transportation of organic inputs from a source (such as the cattle pen) to crop plots.

The best strategy to address the high labor intensity of ISFM is to use agroforestry—that is, to incorporate trees on agricultural land. Studies have shown that planting leguminous trees on cropland can fix a large quantity of atmospheric nitrogen and carbon, both of which enhance soil fertility. For example, Sesbania sesban can fix up to 84 kg/ha of nitrogen (Akinnifesi et al. 2008), a level that supplies the recommended amount of nitrogen for maize, the leading consumer of fertilizer in SSA. Agroforestry labor is high only during planting, and no significant labor investment is required to maintain agroforestry trees.

High fertilizer cost: Fertilizer prices in SSA are much higher than in other countries; indeed, a kilogram of urea in SSA costs about US$1,[46] compared with US$0.65 in the United States (USDA 2016). The high fertilizer price in SSA is a result of high transportation costs, and it translates into high input transaction costs and lower profit for farmers. Most farmers also use unimproved varieties, whose yield response to fertilizer is low. All these factors translate to low fertilizer demand.

Off-farm and long-term nature of ISFM benefits: As seen above, a large share of the total benefits of adoption of ISFM is off-farm. Farmers are not likely to take into account off-farm climate mitigation services when making soil fertility improvement decisions. In addition, smallholder farmers also heavily discount investments in practices whose benefits are attainable only in the long run (Van Campenhout, D'Exelle, and Lecoutere 2015), a preference that further reduces the probability that they will adopt carbon-sequestering practices.

Profitability of no-input farming with no up-front investment: Though the "doing nothing" option has the lowest profitability, it is profitable, has no up-front investment costs, and is less risky than other practices.

46 This calculation is based on district-level fertilizer price data available from MIPAD (2017).

This could be the reason that the majority of farmers prefer this option. Meijer and others (2015) also observed that risk-averse smallholder farmers invest in low-cost management practices.

What Could Be Done to Undo the Unholy Cross?

A number of factors need to be considered to address the challenges discussed above.

Re-education Programs for Extension Agents

The capacity of extension agents to provide advisory services on ISFM, organic soil fertility, and other new paradigms for sustainable soil fertility management is low. There is a need to increase this capacity by providing short-term training and workshops to extension agents who are already in service. Such training could be provided by researchers, nongovernmental organizations, and other scientists with good knowledge of the new sustainable soil fertility management practices. This new knowledge must also be incorporated in agricultural college curricula to ensure that new graduates are equipped to promote new sustainable practices.

New Policies and Strategies that Do Not Treat Smallholder Farmers as Subsistence Farmers

For too long, government and even donor policies and strategies have treated smallholder farmers as subsistence farmers. Consequently, they have largely focused on provision of production-oriented rural services. For example, public extension agents affiliated with the ministries of agriculture largely provide production-related advisory services, whereas, in most countries, marketing advisory services are relegated to the ministries of industries and trade, where they do not receive much attention. Fertilizer can be profitable if it is applied to improved varieties that respond well to it. This means smallholder fertilizer users need to be treated the same as commercially oriented farmers and given appropriate advisory and other rural services. Smallholders face the same market forces that large-scale farmers do. For example, for them to adopt ISFM, they need to buy improved seeds and inorganic fertilizer—thus elevating their farming to market-oriented economic activity. At the same time, their higher output will require selling at remunerative prices. Hence, the provision of marketing advisory services should be incorporated into strategies to increase the capacity of extension services.

Storage Facilities and Other Market Value Chain Investments

As pointed out above, fertilizer is still quite expensive; therefore, its adoption will depend on farmers' perception of risk. This situation calls for the implementation of risk-coping mechanisms, including ISFM; improved seeds; storage facilities; processing equipment; and enhanced access to markets, crop insurance, and so on. For example, in the Democratic Republic of the Congo (DRC), farmers do not use fertilizer on maize because they often leave maize to dry in the field until a buyer shows up. With fertilizer, the maize husks are too heavy and tend to break the stalk, which may lead to loss of the harvest while waiting for a buyer. In this case, increased postharvest storage capacity could allow farmers to use fertilizer without the fear of crop loss. It could also enhance market participation, allowing farmers to delay sales, which could translate to higher prices.

Payment for Ecosystem Services

Given that a large share of the benefits of ISFM and other CSA practices are off-farm, subsidized programs could be used to incentivize farmers to adopt CSA practices. Subsidies could be given on the condition that a farmer adopt an easily verifiable land and water management practice that sequesters significant soil carbon. Promoted practices could include agroforestry, soil and water management structures, and others. The subsidies could be turned into PES to attract both national and international buyers. Needless to say, a strong market and verification strategies need to be developed to overcome a host of problems facing PES in developing countries, such as land tenure, legal knowledge of operating under contracts, and the like.

Concluding Remarks

CSA practices have both on-farm and off-farm benefits that far outweigh their investment costs. Yet their adoption rates are low in SSA. Increasing CSA adoption rates will require increasing the capacity of extension agents to provide the required advisory services. Additionally, CSA adoption requires significant farmer market participation to buy inputs and sell outputs. Unfortunately, current policies and investments remain focused on production, and efforts to improve the food value chain are limited. This situation will need to change to support widespread CSA adoption. To increase incentives for CSA adoption, it is important to design policies and strategies for PES because as much as two-thirds of the total benefit of ISMF is off-farm. Current subsidy programs can easily be turned into PES. Such a strategy will simultaneously serve food security and climate change adaptation and mitigation objectives.

CHAPTER 9

Gender-Sensitive, Climate-Smart Agriculture for Improved Nutrition in Africa South of the Sahara

Elizabeth Bryan, Sophie Theis, Jowel Choufani, Alessandro De Pinto, Ruth Meinzen-Dick, and Claudia Ringler[47]

[47] This chapter was prepared as part of the Gender, Climate Change, and Nutrition Integration Initiative (GCAN) funded by the Feed the Future Program of the US Agency for International Development (USAID) and linked to the CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS). The authors thank colleagues from USAID and partner organizations for feedback and input on earlier versions of this framework.

The effects of climate change are already being felt across the globe, particularly among smallholder producers in developing countries, whose livelihoods are strongly affected by climate conditions. Climate change will continue to threaten food production and security, particularly in Africa south of the Sahara, where dramatic increases in temperature (greater than the global average) and changing rainfall patterns are expected to result in declines in staple crop yields and farm profits (Kurukulasuriya 2006; Müller et al. 2011; Nelson et al. 2014; Niang et al. 2014; Seo and Mendelsohn 2008).

Efforts to increase coping and adaptive capacity have accelerated in recent years, resulting in adoption of adaptation strategies that include improved agricultural practices (using different crop and livestock practices and inputs), livelihood diversification strategies (for example, migration, off-farm work, and small enterprises) and risk mitigation strategies (such as improved food and water storage) (Bryan et al. 2009, 2013; Deressa et al. 2009; Kristjanson et al. 2012; Nhemachena and Hassan 2008). More recent efforts of governments and civil society organizations emphasize "climate-smart" practices and approaches that increase the productivity and profitability of agriculture, increase resilience to climate risks, and mitigate greenhouse gas (GHG) emissions (Lipper et al. 2014).[48]

Despite these efforts, there is consensus that current incremental approaches to adaptation are inadequate to address future climate challenges (Niang et al. 2014; Noble et al. 2014). Recognizing that poor smallholder producers face multiple stressors across a range of complex social and environmental contexts and that resources to respond to these stressors differ by gender and other factors, efforts to support producers' responses to climate change cannot take place in a vacuum.

Ensuring that responses to climate change are successful in making agricultural production, food systems, and livelihoods more resilient therefore requires careful consideration of all the factors influencing resilience in a given context. Such factors include environmental conditions, the institutional environment, and the policy context. When such factors are considered, responses to climate change also have the potential to accelerate gains toward other development objectives, such as health and nutrition improvements. At the global and regional levels, there is growing recognition of the importance and efficacy of addressing multiple development objectives simultaneously in an integrated fashion, as illustrated by the Sustainable Development Goals (SDGs). Therefore, combating and reducing the adverse impacts of climate change are key objectives of the SDGs; the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods, adopted by heads of state of the African Union; and many national-level agriculture and development strategies as laid out in nationally-determined contribution documents across the region.

48 Several organizations and donors, such as the Food and Agriculture Organization of the United Nations; the CGIAR Research Program on Climate Change, Agriculture and Food Security; the World Bank; and others have converged on a definition of climate-smart agriculture (CSA) that describes it as an approach with three objectives or pillars: (1) sustainably increasing agricultural productivity and incomes, (2) adapting and building resilience to climate change, and (3) reducing or removing GHG emissions, where possible and appropriate. The concept of CSA enables policy makers and practitioners to evaluate their agricultural strategies across these three pillars and to maximize gains across these objectives when possible. Given the risk that climate change poses to poor smallholder producers in developing countries, often the first two objectives are prioritized and mitigation is viewed as a co-benefit.

By identifying the synergies and trade-offs implicit in alternative actions, the research community can help identify policies, strategies, and technologies that can achieve multiple development goals while protecting against the negative impacts of climate change. Currently, no studies address the linkages among climate resilience, food security, nutrition, and women's empowerment. However, the literature has begun to connect several of these elements, linking agriculture to nutrition pathways (for example, Herforth and Harris 2014), gender and climate change (for example, Ringler et al. 2014), climate change and nutrition (Fanzo et al. 2017), and gender and nutrition (Meinzen-Dick et al. 2012). Based on a review of these bodies of literature, this chapter develops an integrated gender, climate change, and nutrition (GCAN) conceptual framework that can be used to guide integrated approaches to addressing multiple development challenges in the context of climate change by highlighting entry points for action, potential outcomes of various responses, and the trade-offs and synergies among outcomes.

Gender and Climate Change

Numerous studies have identified the salient factors influencing household-level responses to climate change, including access to rural services (such as extension and credit), access to information, demographic characteristics, agroecological conditions, social capital, and cognitive processes, among others (Bryan et al. 2009, 2013; Deressa et al. 2009; Di Falco and Bulte 2013; Nhemachena and Hassan 2008; Nielsen and Reenberg 2010; Juana, Kahaka, and Okurut 2013; Grothmann and Patt 2005). However, this research accounts for only the gender of the household head, showing that female-headed households are less likely to adapt to climate change (Bryan et al. 2013; Deressa et al. 2009; Nabikolo et al. 2012). This literature also pays little attention to the nutritional implications of various adaptation strategies and how gender intersects with the pathways from adaptation to nutritional outcomes.

The extensive literature on intrahousehold relations and resource allocation in the context of development demonstrates that men and women have different preferences and responsibilities, and that women are often at a disadvantage regarding access to and control over resources and decision-making authority (Doss 2001; Doss and Morris 2001; Peterman et al. 2011; Quisumbing 2003; Udry 1996). A growing number of studies are beginning to explore the reasons for gender differences in perceptions of climate change, adaptive capacity, and preferences for and adoption of climate-smart or risk management practices, not just between male and female household heads but between male and female decision makers within the same household (Bernier et al. 2015; Jost et al. 2015; Perez et al. 2014; Twyman et al. 2014). A recent review provided a conceptual framework for examining issues on gender and climate change, summarizing the evidence accumulated under the CGIAR Research Program on Climate Change, Agriculture and Food Security (Kristjanson et al. 2017). This section expands on that review by drawing on additional research on these issues.

The literature on gender and climate change suggests that the ways in which gender intersects with vulnerability and resilience to climate change are very context specific and nuanced, although some common themes emerge, as summarized in Box 9.1.

BOX 9.1—EXAMPLES OF KEY GENDER DIFFERENCES LIKELY TO AFFECT CLIMATE CHANGE ADAPTATION AT THE HOUSEHOLD LEVEL

Preferences for response options: Technology choices, investment choices (e.g., investments in productive inputs, children's health, education, diets)

Responsibilities: Livelihood strategies, labor roles, migration patterns

Resources: Information, assets, financial capital, natural resources, labor

Institutions: Organizational and group membership, market access, social norms

Source: Authors.

Perceiving climate change is an essential prerequisite for taking action and a factor in the types of response options that are chosen. In general, women tend to be less likely to perceive climate changes, and when they do perceive them, their perceptions often differ from those of men (Oloukoi et al., 2014; Twyman et al., 2014). For example, in Nigeria, these perception differences were related to gender-specific livelihood activities—men were concerned with climate change impacts on the yields of tuber and legume crops, and women perceived a reduction in the availability of fruits, seeds, and herbs from community woodlots (Oloukoi et al. 2014).

Information is also essential for adapting to climate change, but numerous studies show that women lack access to critical sources and types of information on climate change and appropriate responses (Bernier et al. 2015; Jost et al. 2015; Katungi, Edmeades, and Smale 2008; Lahai, Goldey, and Jones 1999; Tall et al. 2014). Given their different livelihood activities and roles in farming, men and women also have different preferences for information (Jost et al. 2015; Tall et al. 2014). For example, a study from Senegal found that women preferred to receive forecasts of dry spells and information on the cessation of the rainfall season, given that they plant after the men's fields have been planted (Tall et al. 2014). Information seems to be a critical barrier to women's adoption of climate-smart practices—a study from Kenya found that, though women's awareness of climate-smart practices was lower than men's, women who were aware of improved practices were at least as likely as men to adopt them (Bernier et al. 2015).

Although productive assets and financial capital are important for adaptation, there is ample evidence of a gender resource gap in agriculture: women tend to have fewer or lower-value assets, less access to capital and labor, fewer agricultural inputs, and less access to other productive resources, such as land (Deere and Doss 2006; Doss and Morris 2001; Peterman, Behrman, and Quisumbing 2014; Perez et al. 2014; Peterman et al. 2011). These gender disparities limit countries' capacity to adapt to climate change and to achieve several other development goals (Quisumbing 2003).

The literature also suggests that formal and informal institutions, such as local organizations, markets, and social and cultural norms, influence how climate risks are experienced, how resources for adaptation are distributed, and how men and women respond to climate change (Adger 2003; Adger et al. 2009; Agrawal and Perrin 2008; Agrawal 2010). Institutions can promote cooperation and group-based approaches to adaptation or they may hinder the adoption of particular adaptation strategies (Di Falco and Bulte 2013; Rodima-Taylor 2012). Given that institutions are defined within a local context, the ways in which men and women participate in and are influenced by them vary. In general, women face institutional barriers to adaptation due to social norms governing the division of labor (such as women's heavy domestic workload and inability to engage in certain livelihood activities) and women's ability to participate in group activities, move freely, and use particular technologies or practices (Djoudi and Brockhaus 2011; Jost et al. 2015; Katungi, Edmeades, and Smale 2008; Naab and Koranteng 2012; Nielsen and Reenberg 2010). For example, it is often considered culturally inappropriate for women to engage in agroforestry (Kiptot and Franzel 2012) or certain types of irrigation (Njuki et al. 2014).

The literature also highlights gender differences in preferences for adaptation strategies that vary widely across different contexts, often related to traditional labor roles (Bernier et al. 2015; Djoudi and Brockhaus 2011; Jost et al. 2015; Naab and Koranteng 2012; Twyman et al. 2014). For instance, women in Ghana preferred to invest in infrastructure for improving water access during times of drought due to their responsibility for domestic water collection (Codjoe, Atidoh, and Burkett 2012). Men and women also do not necessarily share the same preferences regarding investment in children's health and education or dietary choices (Gillespie, Harris, and Kadiyala 2012; Quisumbing and Maluccio 2003). Responses to climate change can lead to shifts in traditional gender roles. For example, women in Mali became engaged in charcoal production using local forest resources due to male out-migration as a result of climate change (Djoudi and Brockhaus 2011).

Although there are no empirical studies on the differential long-term impacts of climate change on men and women, there are several studies on the impact of climate shocks on gender-differentiated asset dynamics, food security, and nutrition. The literature on shocks and poverty traps (for example, Barrett and Constas 2014; Carter et al. 2007; Carter and Barrett 2006; and Dercon 2004) shows that the ways in which shocks differentially affect men's and women's assets depend on the type of shock and the local context. Quisumbing, Kumar, and Behrman (2011) found that the asset holdings of women in Uganda were more severely affected by shocks than those of women in Bangladesh, given Ugandan women's larger role in agricultural production. In Zimbabwe, drought appeared to have a negative impact on the body mass index of women but not of men (Hoddinott 2006). Similarly, a qualitative study from Mali found that food shortages resulting from environmental change affected women more than men (Djoudi and Brockhaus 2011).

New research highlights the fact that technologies and practices adopted at the household level do not benefit all members of the household equally (Theis et al. 2017). Some practices, such as conservation agriculture, may have a negative impact on women due to increased labor requirements (Beuchelt and Badstue 2013; Nelson and Stathers 2009). Climate change responses can affect women both positively and negatively, suggesting that there are important trade-offs across outcomes that must be considered. For example, male out-migration as an adaptive response to climate change may increase women's decision making authority while at the same time increasing their labor burden (Djoudi and Brockhaus 2011; Nelson and Stathers 2009).

Agriculture-to-Nutrition Pathways and the Role of Women

There is increasing interest in leveraging the agricultural sector to complement nutrition-specific interventions and mitigate risks. Researchers and practitioners have identified a set of pathways through which agriculture is hypothesized to affect nutrition (Haddad 2000; Kadiyala et al. 2014; Gillespie, Harris, and Kadiyala 2012; Herforth and Harris 2014; SPRING 2014).

These pathways trace how the rural poor's diverse engagement in agricultural livelihoods can affect their ability to care for infants and young children, allocate income for nutrition- and health-enhancing goods and services, produce healthy and diverse foods, and so on. Key agriculture-nutrition linkages include how production outcomes influence food prices, expenditures, and diet choices; how crop choices influence the consumption decisions of producer households; how nutrient losses can be minimized through processing and preparation; and how agriculture indirectly affects nutrition through income changes, time allocation, and changes in the health environment (Haddad 2000). Because agriculture is at once a source of income and food as well as the main energy expenditure for the majority of the world's rural poor, agricultural work can have both positive and negative impacts on nutrition.

Women's empowerment is thought to interact with the agriculture-to-nutrition pathways in several ways (Meinzen-Dick et al. 2012). First, women's work in agriculture may increase their bargaining power within a household. Given evidence that suggests women are more likely to spend earnings on nutrition-enhancing purchases (Gillespie, Harris, and Kadiyala 2012; Smith et al. 2003), an increase in women's bargaining power could bring about greater allocation of resources for nutrition. However, as Malapit and Quisumbing (2015) pointed out, without nutrition knowledge, women will not necessarily bargain for better nutrition. In addition, greater bargaining power can benefit nutrition by enabling women to negotiate for access to various health services for themselves and their children.

On the other hand, women's work in agriculture may decrease time available for other activities important for nutrition and, without substitutes for this work, nutrition may suffer (see Komatsu, Malapit, and Theis 2015 for a review of the literature). The impact of women's time displacement from domestic work to agriculture depends on the age of their children, the availability and quality of substitutes for domestic work, the importance of income, and the quantity of food produced relative to care work (Glick 2002). Moreover, the quality of care work may be more important than the quantity (for example, feeding infants appropriate complementary foods at the right time may be more important than overall time spent preparing food and feeding). Finally, women's energy expenditure on physically demanding agricultural tasks, especially while pregnant, can have detrimental impacts on maternal and child nutrition and health (Owens et al. 2015; Rao et al. 2003). Although women's empowerment influences agriculture-to-nutrition pathways, agricultural interventions also directly influence aspects of women's empowerment, including their control over assets, participation in decision making, control over income, and workload (Johnson et al. 2016; Malapit et al. 2014), depending on the degree of gender sensitivity of the implementation approach (van den Bold, Quisumbing, and Gillespie 2013).

The agriculture-to-nutrition framework neglects additional interactions that relate to how farmers respond to climate risks. First, though the framework captures variations in the quantity and quality of food produced, it does not detail the dynamic ways in which farmers manage risk and respond to failures in agricultural production, and the implications of these actions for nutrition and health outcomes. Rural households are constantly balancing consumption and investment decisions, which are influenced by risk aversion, availability of alternative livelihoods, storage capabilities, access to markets, financial services, and social protection options, among other factors. Distress sales of assets, such as livestock, in response to shocks can smooth short-term consumption but reduce resilience to future shocks, as well as shift the bargaining power of household members whose assets were sold or lost. Although the agriculture-to-nutrition framework works well in a "normal" year without shocks, it needs modification to capture the nutrition implications of households' complex responses to risk.

Second, the agriculture-to-nutrition literature does not unpack the many factors that influence agricultural decisions and investments, such as access to information (extension and climate information services), access to technology and credit, and tenure security. These factors, implicit in the enabling environment, are important to articulate when looking at how and why farmers choose to shift production in response to climate change. Gender differences in the factors that affect agricultural decisions mean that women face different incentives and constraints than men, resulting in different production choices.

Third, natural resources and the institutions that govern them play a larger role in nutrition than indicated in the agriculture-to-nutrition pathways literature. Collectively managed natural resources can be important for nutrition through the direct harvesting of forest products, fish, fodder, and fuel resources; through provision and maintenance of water resources for irrigation, drinking, and hygiene; and through ecosystem services that benefit agricultural production, such as erosion control and pollination. Climate change directly affects natural resources, such as water availability, while increasing households' reliance on natural resource extraction. Subsequent environmental degradation (for example, deforestation or excessive groundwater extraction) may exacerbate the severity of future climate shocks and stresses, with clear implications for food and nutrition security as well as the health and care environment.

Climate Change and Nutrition

Undernutrition is commonly framed as a consequence of climate change (Phalkey et al. 2015; Myers et al. 2017; Fanzo et al. 2017). By some projections, medium-high climate change is expected to result in an additional 4.8 million undernourished children by 2050 (IFPRI 2017). Of the people at risk for hunger, 97 percent will live in developing countries, with the highest number in Africa south of the Sahara (2.4 million) (IFPRI 2017). Climate change affects food availability and prices, impacting overall calorie consumption as well as consumption of healthful foods, such as vegetables, fruits, and animal-source foods. Springmann and colleagues (2016a) estimated that by 2050, climate change would result in 529,000 deaths due to decreased food intake and decreased vegetable and fruit consumption.

Although the effects of climate change on nutrition and health deserve immediate attention, it is also important to recognize the role nutrition plays in determining individuals', communities', and nations' capacities to respond to climate change. Evidence shows that better child nutrition is associated with higher cognitive and educational performance in middle childhood and greater productivity in adulthood due to increased physical capacity for manual labor (Victora et al. 2008; Haas et al. 1995; Rivera et al. 1995). Therefore, considering the current nutritional status of individuals and larger communities can be helpful for understanding the extent to which these communities are vulnerable to climate shocks and their physical ability to respond.

An underappreciated relationship in the climate change–nutrition literature is the full set of linkages between diet choice and environmental outcomes. It is important to consider the trade-offs and implications of consumption choices and resulting production system changes for future climate change and other environmental outcomes. For example, animal-source food production systems and practices may negatively affect the environment by increasing GHG emissions and contaminating surface and groundwater (Vetter et al. 2017; Ranganathan et al. 2016). Although there may be opportunities for shifting to more plant-based protein sources in developed countries for enhanced environmental outcomes,[49] animal-source foods are a rich source of protein and micronutrients needed for growth and development that are often lacking in the diets of the poor in developing countries (Murphy and Allen 2003). Therefore, climate mitigation policies may also affect diet choice, health, and malnutrition (Springmann et al. 2016b).

The nutritional context also determines which climate change response strategies may be most effective at addressing the most pressing nutritional challenges. It is helpful to think of the bidirectional relationship between climate change and nutrition using a food systems approach focused on food value chains as a way to leverage agriculture to improve nutrition, particularly value chains for micronutrient-rich foods (Ruel, Alderman, and the Maternal and Child Nutrition Study Group 2013). Value chain approaches go beyond farm-level production to include the way foods are produced, processed, distributed, and marketed. Climate change and shocks may affect these activities, and response strategies at various stages of the value chain also have implications for food, nutrition, and environmental security (Fanzo et al. 2017).

Fanzo et al. (2017) identified focal areas for interventions to reduce nutrition risks under climate change along the food value chain and discussed ways in which actors can strengthen adaptation-mitigation synergies at different spatial and time scales. Beginning with inputs, increased access to diverse seed varieties and local livestock breeds that are resilient to heat, drought, pests, and disease, along with improved soil quality and water access, have the potential to increase dietary diversity and ensure increased production in the face of climate shocks and stressors. Mitigation and adaptation strategies, such as mixed crop and livestock systems or improved livestock feeding practices, are also needed to minimize the impacts of production on climate change.

Moving along the value chain, food storage and processing is key to ensuring that food is safe, its nutritional content is preserved, and food waste is reduced. One example is the increased risk of aflatoxin production in crops under climate change and its detrimental effects on both health (Kensler et al. 2011) and child growth (Khlangwiset, Shephard, and Wu 2011; PACA 2014).

[49] For example, Harwatt and others (2017) suggested that shifting to more consumption of beans instead of beef in the United States would contribute to GHG mitigation.

Climate change is expected to affect other components of the value chain, including distribution, marketing, and retail, for example by reducing market access for smallholder farmers, thus affecting availability of and access to foods and, in turn, nutrition outcomes. Climate-proofed infrastructure and transportation can reduce these adverse impacts, protect nutritional value, and reduce food waste through improved connections between farmers and markets (Fanzo et al. 2017).

At the end of the value chain, actors must consider the different dimensions of food consumption and utilization. Ensuring dietary diversity and food security throughout the value chain secures the supply side of nutrition, but the complex relationships between health, nutrition, and the environment require actors to go a step further. For example, infectious disease is affected by climate and can, in turn, increase nutrient demands and requirements while reducing nutrient absorption, ultimately affecting nutritional status. Climate shocks potentially prevent access to local health services, which could also have negative impacts on health and nutrition status. Patz and colleagues (2003) reviewed a wide range of climate change–infectious disease linkages. Burke, Gong, and Jones (2015) provided a useful example of climate-disease linkages by showing that droughts can substantially increase HIV/AIDS infection rates.

It is evident that the relationship between climate change and nutrition is complex and intertwined with other dimensions of well-being. In a vicious cycle, communities without adequate means of risk mitigation and adaptation are forced to make short-term decisions on food consumption; livelihoods; land, water and energy use; and transportation that endanger their nutrition security in the long term and impair effective climate change mitigation, potentially worsening planetary health (Fanzo et al. 2017).

Discussion

The literature reviewed above shows that although considerable work has been done to explore the connections between gender and climate change, agriculture and nutrition, and nutrition and climate change, many research gaps remain. The literature on gender and climate change highlights many ways that the adaptive capacity, preferences and needs for responding to climate change, and decision-making authority of men and women may differ. Though some research is beginning to explore the implications of climate change and alternative responses for better well-being outcomes of men and women, much more is needed in this area to generate actionable evidence. More research is also needed to develop effective approaches to engaging women in actions that increase resilience to climate change. The challenge is that the barriers to women's participation and the approaches designed to reach women must vary across different sociocultural environments. Similarly, the literature on agriculture for nutrition and health does not articulate production risk due to climate change; the role of decision-making processes in determining nutritional outcomes; and the interactions between agriculture, nutrition, and the environment, particularly the management of natural resources. The nutrition literature has only recently begun to consider the risks due to climate change and the implications of value chains on environmental outcomes, including GHG emissions.

Although recent research has highlighted the concept of resilience as an important factor to consider in development programming and has begun to develop indicators for its measurement (Barrett and Constas 2014; Béné, Frankenberger, and Nelson 2015; Constas et al. 2014; Frankenberger et al. 2014), the extent to which issues related to gender and nutrition are addressed remains minimal in the resilience literature. For example, few resilience frameworks incorporate preferences and decision-making processes, which are fundamental for understanding gender-differentiated aspects and impacts. No comprehensive studies or tools integrate all these concepts, even though governments, NGOs, donors, and other stakeholders that aim to achieve multiple development objectives increasingly emphasize addressing issues of gender and social inclusion, nutrition, and climate resilience in an integrated fashion. The challenges of designing, monitoring, and evaluating such integrated programs are widely acknowledged (Cole et al. 2016).

This article, therefore, develops a GCAN conceptual framework that draws on the existing literature to provide stakeholders from different disciplines and backgrounds with a common point of reference for understanding these complex issues and interlinkages. The framework can be used to identify research and evidence gaps, identify possible trade-offs and synergies among different objectives, and highlight entry points for programs and projects that aim to increase resilience and influence outcomes, such as nutrition or women's empowerment. Given that gender, nutrition, and climate challenges vary across local contexts, the framework is not intended to be prescriptive but rather to provide a means for examining the key issues across the intersection of these issues.

This work draws primarily from elements of four existing frameworks: the (Frankenberger et al. (2014) resilience framework; a framework on gender and climate change (Behrman, Bryan, and Goh 2014, cited in Kristjanson et al. 2017); the *Global Nutrition Report's* climate change and nutrition framework (IFPRI 2015); and the Strengthening Partnerships, Results, and Innovations in Nutrition Globally (SPRING) agriculture-for-nutrition framework (Herforth and Harris 2014). The appendix presents visual representations of these frameworks. We selected these four frameworks because they integrate multiple elements of interest or are widely known and used in the development community, or both.

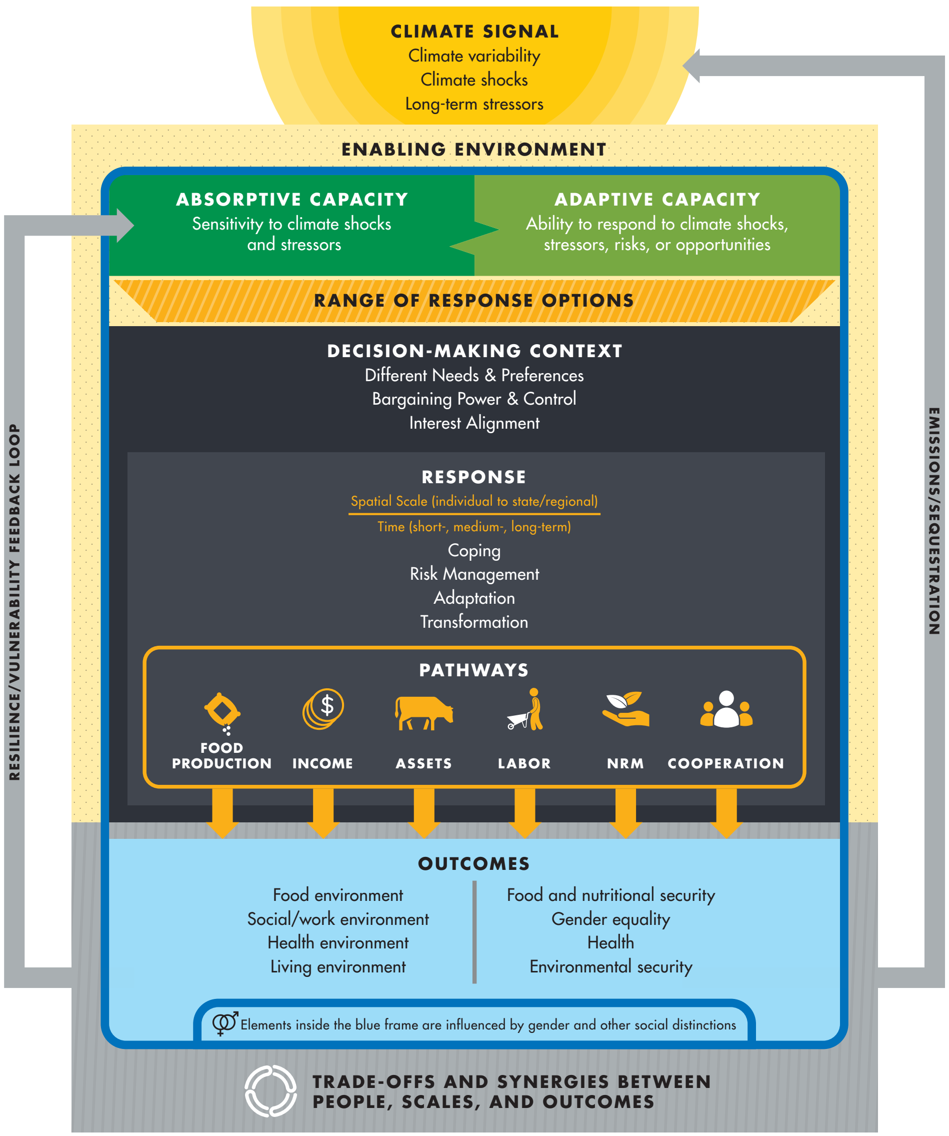
Framework for Integrating Gender, Climate Change, and Nutrition

Resilience is a dynamic, path-dependent concept. People's current state and their ability to respond to shocks and stressors will influence their well-being in the immediate future and their capacity to meet future challenges. In the GCAN framework (Figure 9.1), resilience depends on several key elements including the initial state of absorptive and adaptive capacity when a given climate shock or stress is experienced; the portfolio of available options; the actions taken in response to the climate signal; and the outcomes of those responses, which influence the context in which future climate shocks and stressors are experienced.

Although this framework focuses on climate shocks and stressors, it could also be adapted to assess other sources of livelihood risk, such as food price shocks, political instability, and conflict. It can also be adapted to illustrate the intersection of climate, gender, and nutrition issues within a given local context, development program, or set of response options (for example, on-farm climate-smart practices or technologies).

Numerous underlying factors determine the key elements of the GCAN framework. The framework shown in Figure 9.1 does not attempt to define or list all these factors, which can be categorized in different ways and vary depending on the scale or context of analysis. Rather, to further explore the key elements of this general framework, Figures 9.2 and 9.3 adapt it to

FIGURE 9.1—INTEGRATED FRAMEWORK FOR CLIMATE RESILIENCE, GENDER, AND NUTRITION, GENERAL



Source: Authors.
Note: NRM = natural resource management.

show the key variables one might examine at the household and policy levels, respectively. The specific details provided in the household and policy versions of the GCAN framework are not an exhaustive set of factors or characteristics that influence resilience at that level but merely serve to illustrate the key elements of the framework. This section describes the key elements of the overarching framework (Figure 9.1) in more detail, drawing on specific examples from the more detailed household- and policy-level GCAN frameworks (Figures 9.2 and 9.3, respectively).

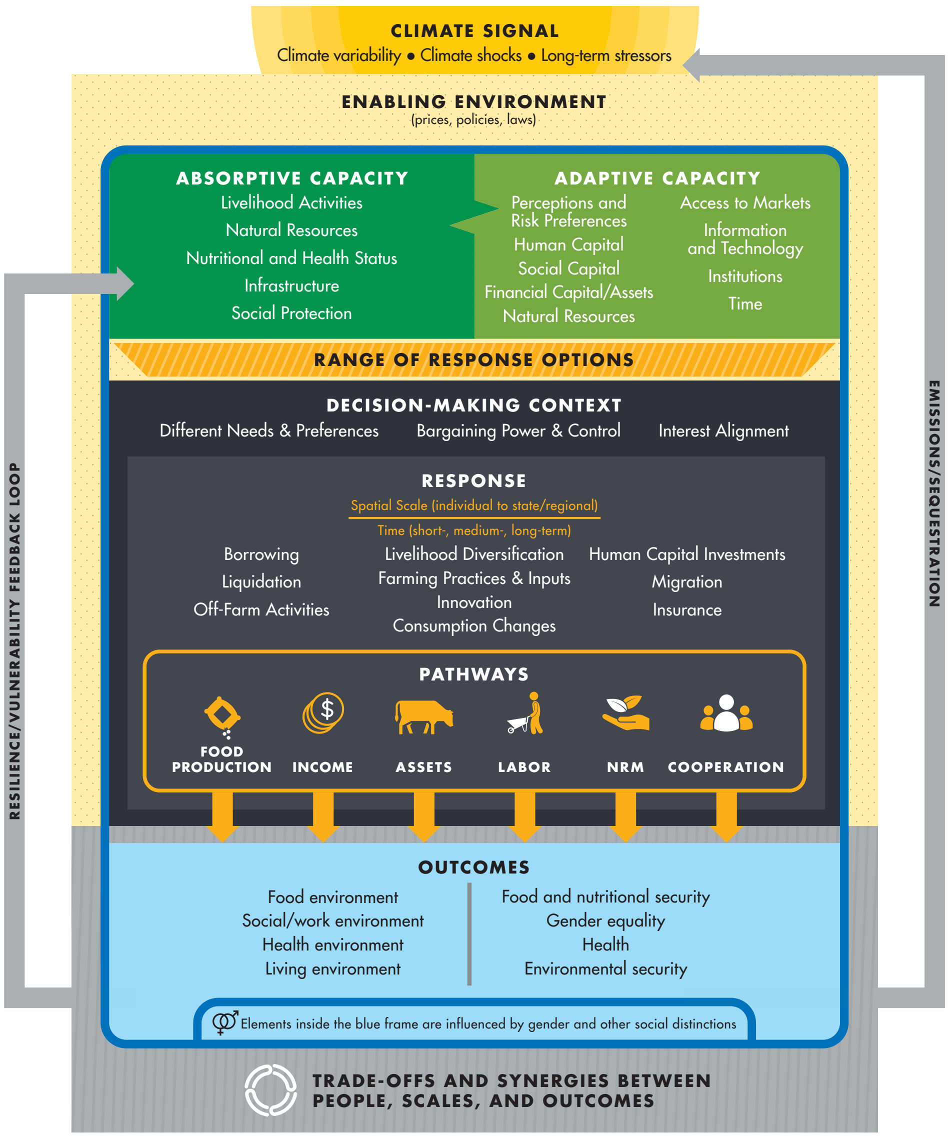
The Climate Signal

The climate signal represents the source of uncertainty, volatility, shocks, and longer-term changes. These shocks or stressors can be characterized in many ways, such as by the scale and magnitude of the event or change (Smithers and Smit 1997). Long-term climate changes involve shifts in average temperature and rainfall conditions, as well as in the frequency of extreme weather events, such as droughts, floods, and storms. This framework not only focuses on long-term climate changes but also illustrates how normal patterns of climate variability and extreme weather events influence resilience.

The Enabling Environment

The effects of climate change occur within a particular context or enabling environment, which influences the ability of individuals and groups—across a broad scale—to absorb and respond to the impact of the changes they experience. Policies, laws, and

FIGURE 9.2— INTEGRATED FRAMEWORK FOR GENDER, CLIMATE CHANGE, AND NUTRITION, HOUSEHOLD LEVEL



Source: Authors.
Note: NRM = natural resource management.

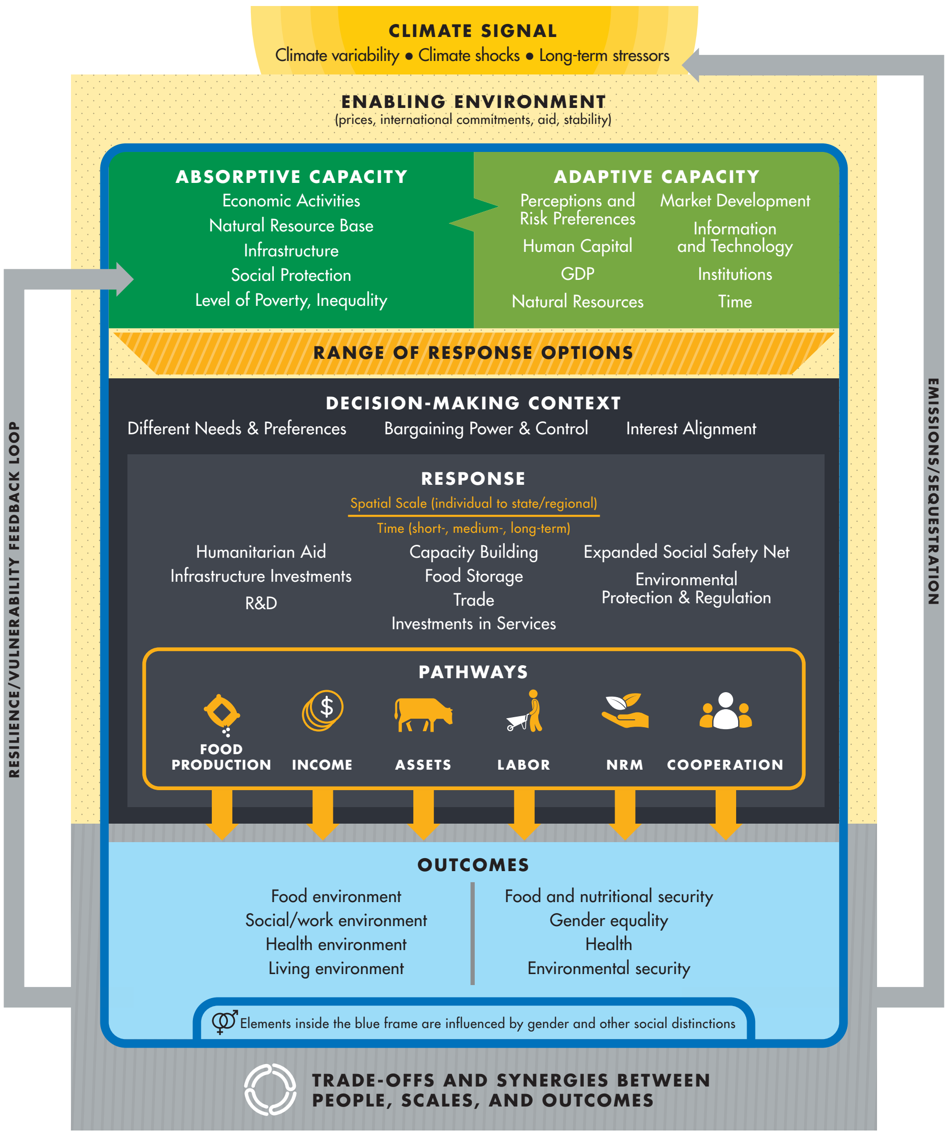
other institutions all influence individual, household, and group responses to climate shocks and stressors (Figure 9.2). At higher levels, such factors as international commitments, international aid flows, and the degree of political stability influence the resilience of nations and regions to climate shocks and stresses (Figure 9.3).

Absorptive and Adaptive Capacity

Drawing on the resilience literature, which sometimes refers to three capacities for resilience—absorptive, adaptive, and transformative (Béné, Frankenberger, and Nelson 2015; Frankenberger et al. 2014)—the GCAN framework includes elements for absorptive and adaptive capacity. Here, absorptive capacity is defined as the sensitivity of individuals, groups, communities, countries, or regions to shocks and stressors—that is, factors that determine the extent to which different actors are directly affected by climate shocks and stressors, and the extent of the changes they need to make to preserve or improve their well-being. For example, a smallholder farmer with a diversified livelihood that includes farm and nonfarm income sources may not experience as great a loss of income upon delayed onset of rains as a neighboring farmer whose livelihood is dependent on a single rainfed crop.

The health and nutritional status of individuals at the time of a climatic shock also affects their absorptive capacity—for example, whether or not they can withstand an increased risk of infectious disease. Because health status affects both the productivity of households and the time burden associated with

FIGURE 9.3— INTEGRATED FRAMEWORK FOR GENDER, CLIMATE CHANGE, AND NUTRITION, POLICY LEVEL



Source: Authors.
Note: GDP = gross domestic product; NRM = natural resource management; R&D = research and development.

providing care to the sick, health status is important to absorptive capacity. Other factors, such as infrastructure and the strength of the social safety net, also influence absorptive capacity at the household level (Figure 9.2). Absorptive capacity at the country level is influenced by such factors as the structure of the economy, the natural resource base, the level of poverty or inequality, and relations with other countries in the region (Figure 9.3).

Adaptive capacity is defined as the ability of different actors or groups of actors to respond to climate shocks, stressors, risks, or opportunities. This ability depends on a variety of factors that interact in different ways based on social demographics, such as gender and age. At the individual or household levels, these factors include the capacity of individuals to perceive and understand climate risks, their access to financial capital and assets, their human and social capital, their access to information and technology, and their time constraints (Figure 9.2). At the state or policy level, factors influencing adaptive capacity include the perceptions and risk preferences of policy makers, gross domestic product, information systems and the availability of technology, health systems, and access to markets (Figure 9.3).

High absorptive capacity reduces the urgency of adaptation. To a certain extent, absorptive capacity can offset adaptive capacity. Conversely, low absorptive capacity necessitates higher adaptive capacity to respond to shocks and stressors. However, many of the factors that drive absorptive and adaptive capacity are positively correlated, so people with high absorptive capacity often also have a high adaptive capacity and vice versa.

Absorptive and adaptive capacity interact with the enabling environment to determine the range of response options available to decision makers from the individual to the state level. As mentioned in the literature review, important gender differences, such as women's lack of access to information, often limit the range of response options available to them. Women's low adaptive capacity relative to men's limits their potential contribution to increasing resilience at the household, community, and national scales, and poses the risk that adaptation will occur in ways that do not reflect women's needs and priorities.

Response Options

Different actors—including individuals, households, groups, communities, and policy makers—respond differently to the climatic challenges they have experienced or anticipate. Drawing on the literature on climate change adaptation and resilience, in the GCAN framework, responses can take several forms, from actions directed toward coping with the immediate impacts of a climate shock or stress, to adaptive or transformative approaches that protect or improve livelihoods and well-being outcomes over the longer run. Coping responses generally refer to strategies that utilize available resources, skills, and opportunities to address, manage, and overcome adverse climate stresses and shocks in the short to medium term. Risk management strategies involve plans, actions, or policies that aim to reduce the likelihood or impact of future negative events (or both). Adaptation involves adjustments to actual or expected climate stimuli in order to avoid harm or exploit potential benefits to return to, maintain, or achieve a desired state. Transformative responses aim to change the fundamental attributes of a system or context to improve well-being outcomes, and include actions such as those that address underlying social vulnerabilities.

The GCAN framework shows that responses to climate shocks and stressors take place across different spatial scales, from individual actions to state or regional responses. These actions can also be characterized by the time scale at which they occur. Some actions can be implemented in the short term, such as an individual farmer's or farm household's decision to plant a new crop variety, whereas others take time to implement, such as switching from annual crops to tree crops, or developing new crop varieties.

Decision-Making Context

The actions households take in response to climate challenges often depend on internal negotiations between different actors who advocate for their own needs, preferences, and priorities that may overlap but often diverge. The ability of different actors to influence the outcomes of these decision-making processes depends on their own bargaining power and control over resources.

The extent to which the chosen responses reflect the needs and priorities of different individuals also depends on the degree to which the interests of different actors involved in the decision-making process align. For example, a husband and wife who tend to agree on a course of action are both likely to be satisfied with the decision. On the other hand, disagreement among decision makers is likely to result in one or more individuals' being dissatisfied with decisions that are made, as well as skewing of benefits toward individuals with more decision-making power. Divergent preferences around responses to climate shocks and stressors may be seen in decisions to migrate and in the prioritization of uses of limited resources, such as water and land.

Pathways to Change

Drawing on the agriculture-to-nutrition literature, the GCAN framework shows that actions taken in response to climate shocks and stressors potentially influence well-being outcomes through six possible pathways: (1) food production, (2) income, (3) asset dynamics, (4) labor, (5) natural resources, and (6) cooperation.

Changes in farming practices, crops, or inputs have implications for food production at the farm level. In the absence of fully functioning markets, as is the case in many developing countries, these changes in food production have dramatic impacts on the food environment. Similarly, changes in income or assets (or both) as a result of responses to climate shocks and stressors influence nutrition and health outcomes—differently depending on who controls the income or asset. Livestock assets, in particular, may directly influence nutritional and health status—potentially positively by increasing access to animal-source foods, or negatively by worsening the water, sanitation, and hygiene environment via exposure to disease and fecal matter.

Many responses to climate challenges also have implications for labor allocation, which in turn influences outcomes such as care practices (that is, the amount of time people—often women—spend caring for children or the elderly) and leisure time, an indicator often linked with well-being and empowerment. In addition, practices that affect the management and use of natural resources also have implications for outcomes, such as the WASH environmental and health status. Another key pathway pertains to the degree to which coordination or cooperation exists at the household, community, or broader scales. At the household scale, such coordination would indicate greater cooperation among household members for

BOX 9.2—THE FOOD, SOCIAL/WORK, HEALTH, AND LIVING ENVIRONMENTS

The food environment includes food availability, quality, and access. Food availability entails temporal stability through production and storage, both of which are directly affected by climate shocks. Quality refers to both the nutritional value of diets and the safety of food. Access to food necessitates adequate market access and affordability. Price increases, ruptures in market access, production failures, and shifts in production diversity are ways in which the food environment can be affected by environmental shocks and stressors.

The social/work environment refers to shifts in time use as well as access to and control over assets as people alter their livelihood strategies in response to climate change. Such shifts affect the intrahousehold bargaining power and empowerment status of men and women, with implications also for intergenerational gender equality. An increased time burden for men, women, and children may intensify human energy expenditure and carry possible opportunity costs in terms of alternative livelihood activities, access to services, investment in human and social capital, and in some cases greater physical risk. Shifts in time use may also affect care practices and the ability to raise healthy children and care for the elderly.

The health environment entails health stresses and health care. Transmission of viral, bacterial, and parasitic diseases is projected to increase with climate change. Gender-based violence is also a health risk associated with climate shocks, stressors, and responses. Health care service delivery may be disrupted by climate shocks that reduce access to health facilities.

The living environment refers to changes in water security (reliable, safe, affordable, and physically accessible water services for human use and consumption), physical infrastructure for access to services (such as education and health), sanitation and hygiene, disaster risk reduction (such as flood infrastructure and cyclone shelters), and the natural resource base as a result of climate shocks and stressors and the responses to them. Changes in the living environment also have implications for greenhouse gas emissions.

Source: Adapted from IFPRI (2015).

common interests. At the community scale, it refers to cooperation around shared resources and social capital, which can greatly facilitate access to information, learning, social insurance, resources, and labor (Bernier and Meinzen-Dick 2014). At higher scales, cooperation could refer to coordination among regional states to ensure a stable food supply through trade or cross-boundary water management.

Well-Being Outcomes

The GCAN framework focuses on food and nutritional security, environmental security, gender equality, and health as four final outcomes that are affected by the interactions between climate shocks and stresses and by the various responses to these challenges at different scales.

Four interrelated “environments” that mediate these outcomes are highlighted in the blue area of Figures 9.1–9.3: the food environment, the social/work environment, the health environment, and the living environment (Box 9.2).

Linkages, Trade-Offs, and Synergies between People, Outcomes, and Time Scales

Importantly, considerable linkages, trade-offs, and synergies arise across these “environments” or development outcomes, temporal scales, and different groups of people. For example, poor water quality in the living environment increases vulnerability to other health stresses; people may cope by seeking different water sources, which increases their time burden and potentially their security risk. Practices that improve food availability and access in the food environment, such as increasing the use of chemical fertilizers or pesticides, may have negative implications for the health and living environment, such as water quality and GHG emissions.

In terms of temporal trade-offs, responses that may yield benefits in the short term, such as selling assets to meet consumptive demands, may improve nutritional status in the short term but have negative implications for long-term availability of and access to food. Intergenerational trade-offs also exist. For example, when women’s workloads increase to secure livelihoods in the face of climate change, there can be negative implications for the health status of pregnant women and their infants (Owens et al. 2015).

Moreover, there are differences in terms of how the costs and benefits of the chosen response options are distributed. For example, responses to climate change and shocks may intensify or alleviate inequalities between men and women and require us to examine who bears the brunt of shifts in time burden, human energy expenditure, control over assets and income, and subsequent bargaining power and empowerment.

The GCAN framework shows that outcomes at any given point in time influence future absorptive and adaptive capacity as well as future potential response options. Similarly, actions taken in response to existing climate conditions have implications for the trajectory of future climate changes by influencing GHG emissions and carbon sequestration. These feedback loops illustrate the dynamic nature of resilience or vulnerability to climate conditions and change, highlighting the fact that outcomes, such as nutrition and health status, are never static.

The flow of the elements of this framework, from top to bottom and back up again, can follow several possible scenarios. For example, actors may be able to increase their resilience to climate shocks and stressors due to high initial absorptive and adaptive capacity, which enables them to make changes that improve their well-being outcomes and, in turn, increase their future absorptive and adaptive capacity. Alternatively, vulnerability to climate shocks and stressors may increase, given low absorptive and adaptive capacity and limited response options, which causes well-being to deteriorate. Adapting the framework to explore a specific shock or stress in the context of a particular community, program, or country can yield valuable insights into the potential consequences of that shock; how different people or groups may be affected; how they may respond; and what policies, programs, or actions might be implemented to improve well-being outcomes in both the short and the long term.

Conclusions

Development programming is moving toward more integrated, systems-based approaches that address multiple, interlinked development challenges simultaneously. However, these approaches require coordination across different disciplines and areas of expertise. A conceptual framework can help identify key elements and connections between disciplines and provide a common ground for different disciplines to see how they affect each other and what synergies they may find in complex challenges. In particular, it highlights possible unintended consequences of interventions, hidden factors that influence specific development outcomes, and relationships and trade-offs between processes and outcomes.

The GCAN framework provides guidance on key areas to consider, including (1) the importance of gender-differentiated capacities to respond to climate change, needs and preferences for response options, and outcomes of different practices and approaches; (2) the food system and nutritional status as factors influencing capacities to respond to shocks and stressors; (3) the linkages between various well-being outcomes, such as how environmental impacts and women's empowerment affect nutrition and health outcomes; and (4) the importance of multiple pathways through which climate change responses influence nutrition, health, gender equality, and other development outcomes.

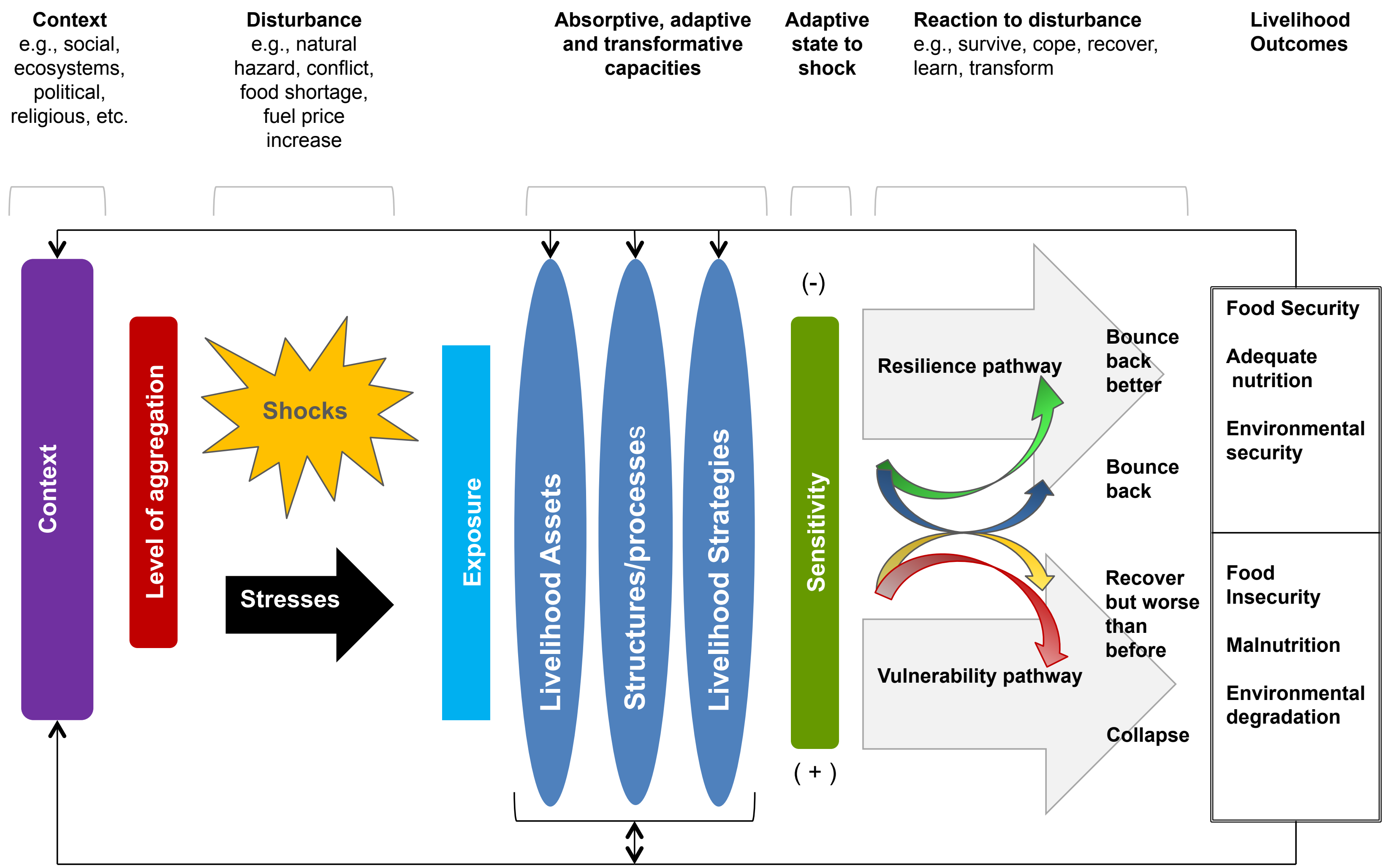
A suitable framework also clarifies the types of information that must be collected to adequately understand the system. The present framework draws on available evidence but also identifies numerous gaps that require further study. Specifically, there is little evidence on which approaches are effective to improve the nutrition and women's empowerment outcomes of agricultural interventions while also ensuring that these approaches increase resilience to climate shocks and stressors. Moreover, although resilience and climate-smart interventions are starting to be promoted more widely, few studies evaluate the differential impacts of interventions on well-being outcomes for men and women and the implications of these interventions for nutrition and health. By highlighting often-overlooked differences in men and women's preferences and ability to actualize those preferences, the framework shows that future research requires a fundamentally inclusive, participatory approach that seeks to identify distinct priorities and concerns by social group and develops solutions with marginalized groups and local actors (for example, Cole et al. 2016; Douthwaite and Hoffecker 2017; Kirstjanson et al. 2017).

More research is also needed on the trade-offs and synergies across different development outcomes, such as agricultural productivity, livelihood resilience, and ecosystem resilience / environmental outcomes. Such research would be able to identify any potential multiplier effects of development interventions that effectively integrate gender and nutrition considerations (for example, development outcomes when women are empowered to be more involved in increasing resilience).

The GCAN framework was designed with the aim of identifying entry points for cross-sectoral actions that can achieve positive impacts across multiple outcomes. Therefore, it can also be used to guide the needs assessments, design, and monitoring and evaluation of agricultural programs and other development interventions to ensure that their climate risk, gender, and nutrition implications are considered. This framework enables program implementers and policy makers to think of the systems and institutions across different scales that affect each other, and how to properly measure and monitor the interactions between them. It also provides a guide for identifying opportunities and obstacles related to the program and outcomes of interest and for tracing the impact pathways from interventions to outcomes. Participatory tools and guides will be developed based on this framework to further support the design, implementation, and assessment of integrated programs that improve the livelihoods and well-being of vulnerable populations.

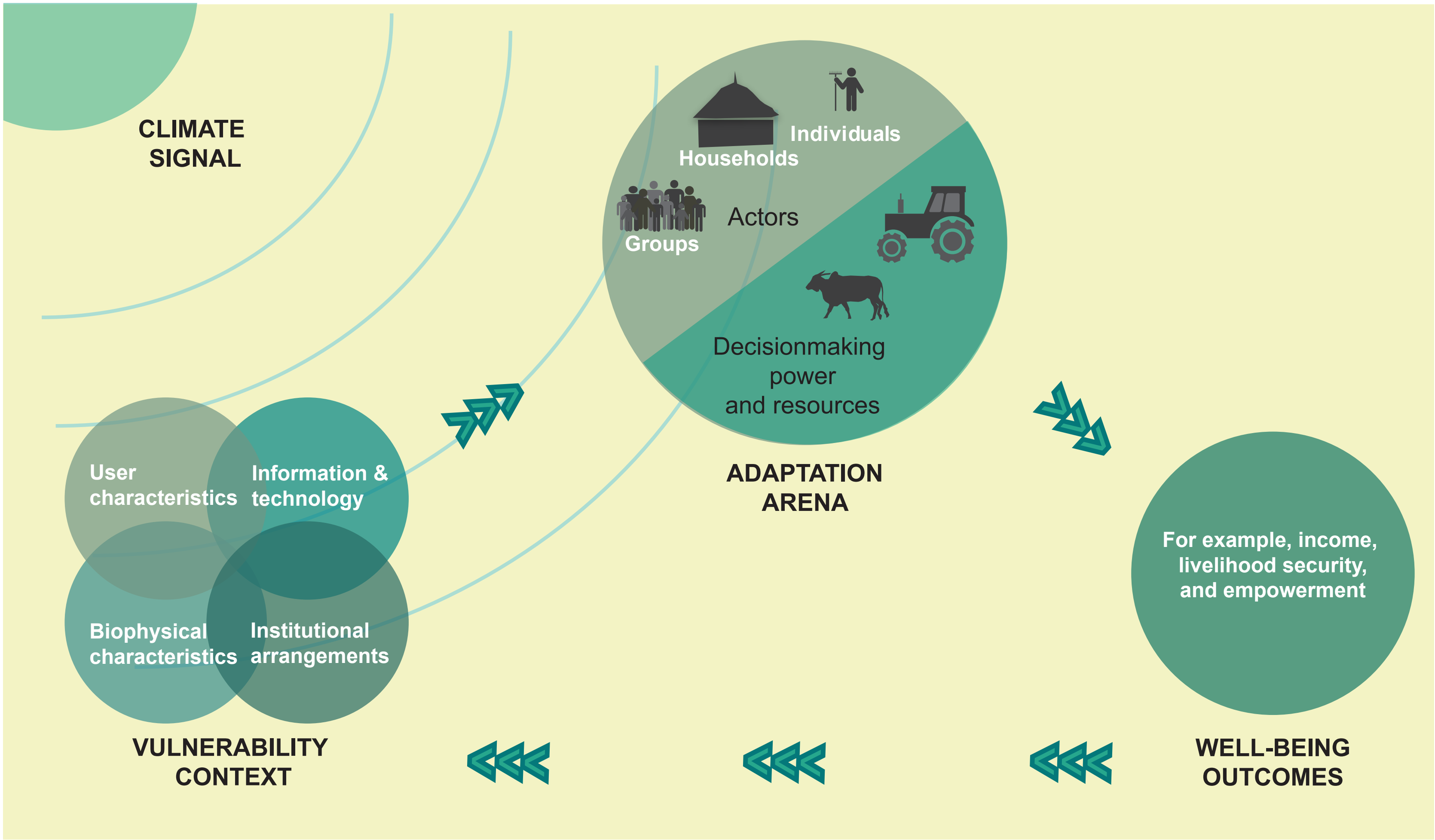
Appendix

FIGURE 9A.1—RESILIENCE ASSESSMENT FRAMEWORK



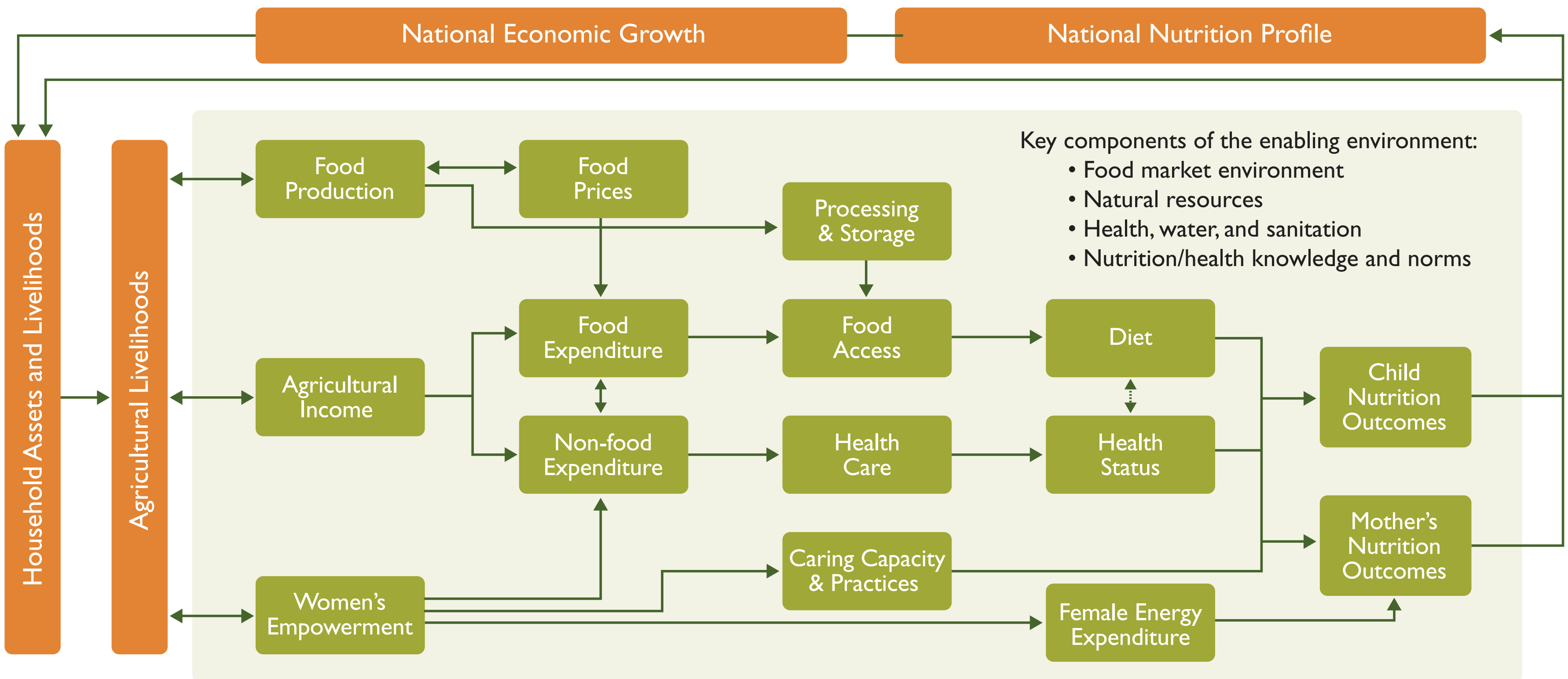
Source: Reprinted with permission from Frankenberger et al. 2014

FIGURE 9A.2—FRAMEWORK ON GENDER, AGRICULTURAL DEVELOPMENT, AND CLIMATE CHANGE



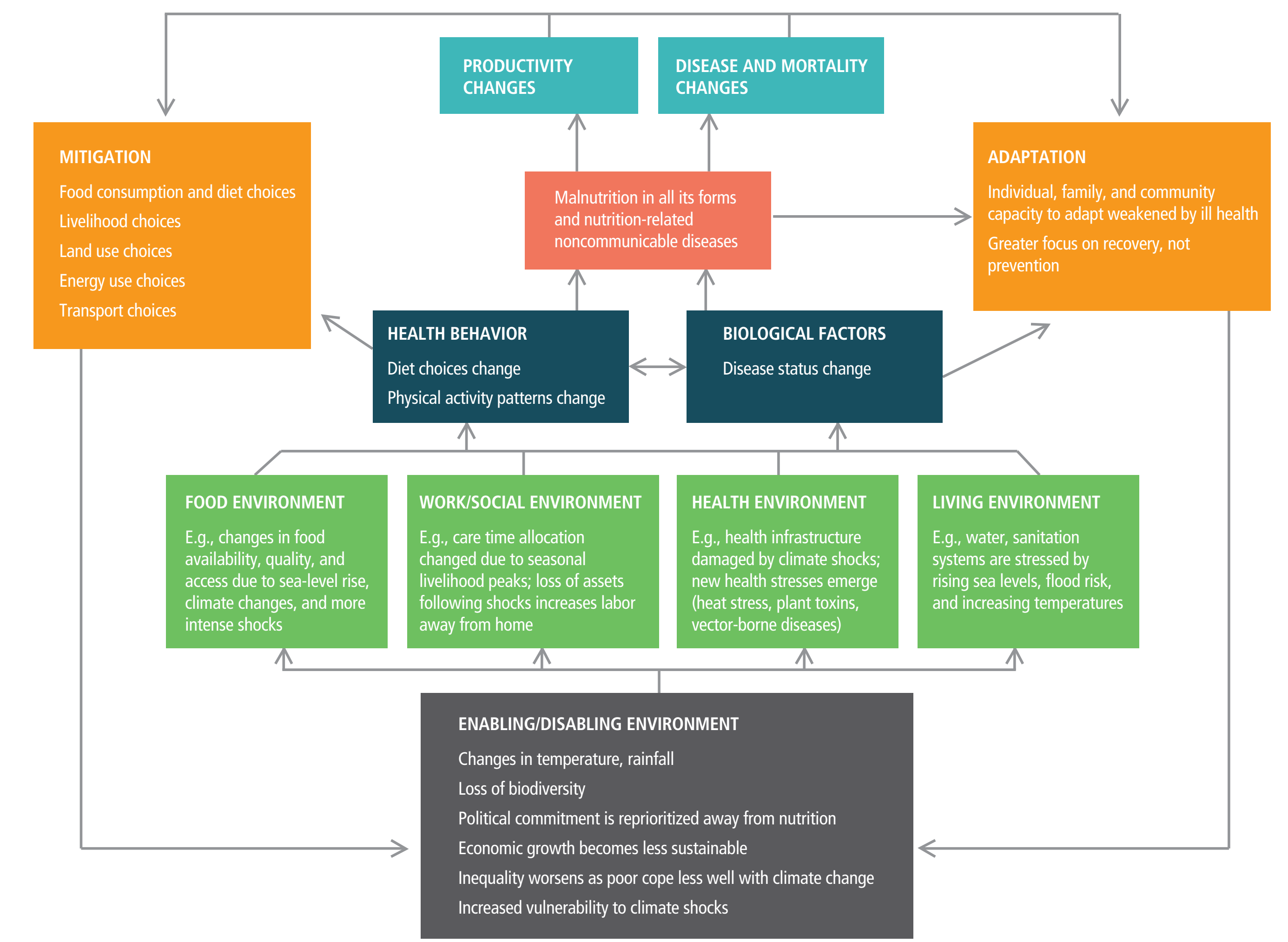
Source: Behrman, Bryan, and Goh (2014), cited in Kristjanson et al. 2017.

FIGURE 9A.3—AGRICULTURE-TO-NUTRITION PATHWAYS



Source: Reprinted with permission from Herforth and Harris (2014).
Note: Women's empowerment pathway is highlighted in blue.

FIGURE 9A.4—CONCEPTUAL LINKS BETWEEN CLIMATE CHANGE AND NUTRITION



Source: IFPRI (2015).

CHAPTER 10

A Strategic Approach and Business Model for Scaling Up Ecosystem-Based Adaptation for Sustainable Development in Africa

Richard Munang and Robert Mgendi

Ecosystem-based adaptation (EbA) is a known strategy for building climate resilience and enhancing the ecosystems that underpin the productivity of key socioeconomic sectors in Africa. EbA for agriculture is an approach used to build climate-resilient food systems; it encompasses climate-smart agriculture (CSA) and a broad range of other techniques. In light of mounting climate impacts and escalating degradation of ecosystems, the urgent need to scale up such climate-resilient approaches as EbA and CSA and safeguard future food systems cannot be overstated. And effective scaling-up calls for a break from classical approaches that view EbA and CSA as a silo climate resilience technique, and a move toward embracing a new paradigm that portrays them as part of an integrated composite solution to maximizing the productivity of agriculture and food systems in Africa for accelerated socioeconomic transformation. This transformation is critical to achieving the goals of the Malabo Declaration and the Sustainable Development Goals (SDGs). Recognizing ecosystems' catalytic place in Africa's socioeconomic transformation and realization of these goals can provide impetus for market-based incentives to expand EbA and such resilience approaches as CSA. Actualizing this integrated approach will require inclusive partnerships among complementary actors to bridge the requisite policy and nonpolicy gaps and foster practical means to achieve this integration. UN Environment is already fostering these inclusive, mutual, multistakeholder partnerships at the policy and operational levels by facilitating a country-driven policy and implementation framework through the Ecosystem Based Adaptation for Food Security Assembly (EBAFOSA).

Background and Context of Ecosystem-Based Adaptation

Ecosystem-based adaptation implies building or boosting the resilience of ecosystems to climate change impacts (by sustainably managing, conserving, or restoring them) so they can continue providing the ecosystem goods and services, such as hydrologic regulation, biodiversity, and healthy soils, that human communities need to adapt to climate change (UNCCD 2017). EBA purposefully uses "green infrastructure" and ecosystem services to increase human societies' resilience to climate change, reducing their vulnerability to its effects. EbA comprises measures to conserve, restore, or sustainably manage ecosystems and natural resources, such as CSA, and it complements or even substitutes for conventional adaptation approaches that involve "hard," or "gray," infrastructure measures. In addition, EbA is often cheaper than gray hard-and-fast engineering approaches. For example, in Viet Nam it has been proven that planting and maintaining mangrove forests to act as breakwaters and protect the coast is significantly cheaper, costing approximately US$1.1 million for 12,000 ha, than mechanical repair of wave-induced dike erosion, which can cost up to US$7.3 million annually (Olivier et al. 2012). Similarly, in New York City, two schemes were evaluated to manage storm-water flows. One, green-infrastructure-based, emphasized stream-buffer restoration, green roofs, and bio-swales (landscape elements designed to remove silt and pollution from surface runoff water). The other was a gray infrastructure plan involving tunnels and storm drains. The green infrastructure option presented a cost savings of over US$1.5 billion (Talberth and Hanson 2012). Decision makers in Idaho and North Carolina found similar cost savings through green infrastructure.

To enable communities to adapt to climate change, EbA has been applied to a range of ecosystems that communities depend on for livelihoods—mountains, coasts, agricultural landscapes, and so on. Examples of practical EbA interventions include the following (Reid et al. 2017):

- Restoration of coastal ecosystems such as coral reefs, mangrove forests, dune systems, and salt marshes to dissipate the energy of powerful tropical storms. This EbA intervention responds to coastal climate change impacts, especially sea-level rise, and is applied in place of, or in complementarity with building sea walls, a gray approach.
- Wetland and floodplain management to prevent floods and maintain water flow and quality in the face of changing rainfall patterns in place of building dikes/levees/ embankments, which is the gray approach.
- Conservation and restoration of forests and other natural vegetation to stabilize slopes, prevent landslides, and regulate water flow. Cumulatively, these strategies also improve the groundwater recharge rate and prevent flash flooding.
- Establishment of healthy and diverse agroforestry systems and CSA practices to cope with increasingly variable climatic conditions by improving soil structure, preventing erosion, enhancing groundwater recharging, and so on.

Ecosystem-Based Adaptation for Food Security: A Strategic Thrust

In Africa, agriculture is the most inclusive economic sector, providing livelihood opportunities for the majority of people on the continent, including vulnerable women. The sector employs on average 64 percent of labor in Africa (Calestos 2011), and women produce a significant 47 percent of Africa's food (Kanu, Salami, and Numasawa 2014). It is thus the most promising sector for enhancing the economic participation of the majority of people in Africa.

In addition, Africa holds a comparative advantage in agricultural resources to leverage toward building a competitive agriculture sector. Maximizing productivity can potentially accelerate socioeconomic transformation. For instance, the continent has 65 percent of the world's arable land (UNESCO 2017) and 10 percent of its renewable internal freshwater resources (Pietersen et al. 2006). With growth in Africa's middle class, currently estimated at 300 million people (Mubila and Aissa 2011), the continent's food market is projected to grow to US$150 billion by 2030. If harnessed, the entire agriculture and agribusiness sector is projected to grow to be worth an estimated US$1 trillion by 2030 (World Bank 2013), thus enhancing agriculture's contribution to Africa's gross domestic product.

Agriculture has been documented to be at least two to four times more effective at reducing poverty than any other sector (Calestos 2011) and to have the potential to catalyze achievement of all of the Sustainable Development Goals (SDGs) and many of the Malabo Declaration goals (Marks 2016a, 2016b). Agricultural growth also stimulates productivity in other sectors, such as processing and transportation, whose value chains link with the agricultural value chain, resulting in economywide impacts.

Furthermore, in Africa, a 10 percent increase in crop yields translates to approximately a 7 percent reduction in poverty. Neither the manufacturing nor the services sector can achieve an equivalent impact (Imhoff 2015). This capacity, coupled with the agricultural sector's inclusivity, indicates its unique potential to enhance inclusive economic growth for substantial poverty reduction and achievement of multiple SDGs.

Regardless of this potential, however, Africa's current socioeconomic development challenges mean that the continent is far from achieving inclusive growth. Poverty is high, with more than 40 percent of the population living on less than US$1.90 daily (United Nations 2016). Youth unemployment is another stressor, with young people ages 15–25 representing more than 60 percent of the continent's population (AfDB et al. 2013), 60 percent of them unemployed (Agbor, Taiwo, and Smith 2012) and more than 70 percent living on less than US$2.00 per day (Montpellier Panel 2014b). Related to poverty is low labor productivity, with Africa's productivity 20 times lower than that of developed regions (United Nations 2016). Low productivity, in turn, implies minimal value addition and growth of industry. Food and nutritional insecurity is also high, with more than 50 percent of the adult population in Africa south of the Sahara (SSA) facing moderate or severe food insecurity (United Nations 2016).

In light of the potential inherent in agriculture, maximizing its productivity stands out as strategic in orchestrating the much-needed turnaround. This vital truth has been acknowledged in pivotal policy declarations and development blueprints, led at the continent level by the African Union (AU) and at the global level through the SDGs. Among these are the Maputo (African Union 2003) and Malabo (African Union Commission 2014) declarations and the related Vision 2025 for Africa's agriculture, as well as a commitment by the AU heads of state and government to end hunger, halve poverty in Africa by 2025, and reduce postharvest losses by 50 percent. In addition, the Comprehensive Africa Agriculture Development Programme (CAADP) implementation strategy recognizes EbA approaches as key strategies, among others, to enhance agroproductivity in Africa (African Union and NEPAD n.d.). Further, the AU Agenda 2063 recognizes agriculture as the means to achieve inclusive, sustainable development on the continent (African Union Commission 2015). It also underscores the need for gender parity and enhancing women's agroproductivity through access to financing, for instance calling for dedication of 30 percent of agricultural financing to women. Agenda 2063 also underscores the need to achieve more than 50 percent clean energy, which will be vital in modernizing and transforming Africa's agriculture in a sustainable way.

An overriding theme implied in these blueprints is the need to modernize and optimize Africa's agriculture while at the same time ensuring that the productivity of the ecosystems that underpin agricultural productivity are safeguarded for future generations. At the global level, the 2030 Agenda for Sustainable Development and the SDGs align with these noble continental aims. Specifically, SDG 1 aims for poverty eradication. SDG 2 aims to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture, with targets to be achieved by 2030. SDG 13 calls for action to combat climate change. SDG 15 calls for sustainable management and restoration of ecosystems. SDG 5 aims to empower women in areas including agriculture, where they produce up to 80 percent of the food. These goals overlap considerably with the Malabo Declaration goals, which include commitments to end hunger and halve poverty by 2025, to supporting agriculture-led growth, and enhancing resilience of livelihoods and production systems to climate variability and related risks.

These development blueprints and policy declarations provide the first principles and theoretical solutions for transforming Africa's agriculture. Their implementation constitutes an impactful practical solution.

Eliminating Inefficiencies to Realize the Potential of Agriculture: The Place of Ecosystem-Based Adaptation

In spite of the promise of the blueprints and declarations mentioned above, the African agricultural sector is vulnerable to ecosystem degradation, climate change, and postharvest losses, among other inefficiencies. As an example of the first vulnerability, ecosystem degradation, SSA's food loss due to agroecosystem degradation is estimated to be as high as the equivalent of 6.6 million tons[50] of grain annually, enough to meet the annual caloric needs of approximately 31 million people (Munang et al. 2015). Land and ecosystem degradation in SSA is estimated to cost US$68 billion annually (Montpellier Panel 2014a). It is noteworthy that healthy ecosystems are the foundation of long-term productivity, underpinning food production through ecosystem goods and services such as water, soils, and pollinators. For instance, pollination by bees is an ecosystem service necessary for 75 percent of all crops used as human food (Bradbear 2009). Increasing the quantity and variety of pollinating insects can increase crop yields by more than 20 percent (INRA 2016).

In relation to the second vulnerability, climate change, the 2015 technical report on Africa's adaptation gap (Schaeffer et al. 2015) observes that for a global warming scenario of less than 2.0°C, the agriculture sector will be hit by yield declines of up to 40 percent, resulting in a 25–90 percent increase in the incidence of undernourishment, not to mention economic losses. Based on *The Emissions Gap Report 2015*, produced by UN Environment, the globe is on track for a warming of around 3.0°C to 3.5°C by 2100, with a confidence level greater than 66 percent (UNEP 2015), implying that impacts could be worse. Adapting to climate change is therefore an imperative to safeguard Africa's future food security. The costs are expected to be no less than US$50 billion annually by 2050, and the pace of international support does not reflect this continental urgency.

As for postharvest losses, low value addition (World Economic Forum 2015) means that Africa's average annual cereal grain losses are high, estimated at US$4 billion annually (Nomathemba et al. 2010), or enough grain to feed an extra 48 million people for a year (FAO n.d.; Formo et al. 2014). Postharvest losses in SSA average 30 percent of total production (World Economic Forum 2015). In 2010, the Food and Agriculture Organization of the United Nations (FAO) estimated Africa's cumulative postharvest losses of cereals, roots and tubers, fruits and vegetables, meat, milk, and fish to be about 100 million tons with a total value of US$48 billion (FAO 2010). In light of Africa's US$35 billion food import bill in 2011, recovering these losses would essentially eliminate the need for imports without increased production and inject an extra US$35 billion to capitalize other sectors of the continent's economy.

The Africa Competitiveness Report 2015 noted that the continent's below-par performance in agriculture undermines poverty reduction and inclusive growth (World Economic Forum 2015). There is therefore an urgent imperative to optimize the productivity of Africa's agriculture by eliminating these inefficiencies.

Cumulatively, prioritizing efforts to maximize the productivity of Africa's agriculture will have a ripple effect of improving the livelihoods of the majority of people on the continent, including vulnerable women, thereby accelerating achievement of multiple goals, including SDGs 1, 2, 5,

50 *Tons* refer to metric tons throughout the chapter.

and 10. But this cannot happen without eliminating prevailing inefficiencies along the entire agricultural value chain.

Ecosystem-Based Adaptation for Food Security: Positioning EbA and CSA Strategically

Rather than being viewed as a silo climate adaptation technique not directly connected with socioeconomic priorities, EbA, including CSA, must be strategically positioned as a key element in a composite solution to eliminate the leading inefficiencies along Africa's agricultural value chains in order to accelerate socioeconomic transformation and achieve the SDGs and Malabo Declaration goals. EbA's compatibility with the approaches of smallholder farmers (UNCCD 2017), who produce up to 80 percent of the food in SSA (FAO n.d.), coupled with its ability to increase yields by up to 128 percent (De Schutter 2011) under the changing climate and to safeguard long-term production (Munang and Andrews 2014), makes it pertinent to such integration as part of a potential composite solution. Such strategic positioning of EbA as part of a broad solution to address a leading socioeconomic challenge in Africa has potential to create incentive for scaling up this approach.

Policies integrating EbA for on-farm production will contribute to climate adaptation, addressed in SDG 13 and Malabo Commitment VI, given that EbA is a climate adaptation technique. EbA will also boost food security through yield increases of up to 128 percent as well as healthier food with more immune-boosting compounds (Kirsten and Jens 2001), hence contributing to SDG 2 (Targets 2.3 and 2.4) while also enhancing farmer incomes to combat poverty (SDG 1 Targets 1.5 and 1b). It will also enhance the capacity of ecosystems to continue providing ecosystem goods and services that enable communities to adapt to climate change (SDG 13 Targets 13.2 and 13.3; SDG 15 Targets 15.1, 15.2, 15.3, and 15.5; and Article 7 of the Paris Agreement on climate change). In addition, some EbA techniques that should be prioritized, such as agroforestry or farmer-managed natural regeneration, will enhance carbon sinks, contributing to SDG 13 and Paris Agreement Articles 4, 5, and 7. For example, based on inference, Rohit, Brent, and John (2006) calculated that a single large-scale forest regeneration project of 25,000 ha can ensure that a country sequesters up to 15.6 million tons of CO_2. The clean energy value addition of EbA production will not only create further incentive for application of EbA but also minimize emissions sources (SDG 13; Paris Agreement Article 4). For example, solar-powered irrigation can sequester more than 1 million tons of CO_2 equivalent by 2030 (REEEP 2015). Value addition will also eliminate postharvest losses, leading to the recovery of both food and finances, while creating additional higher-order jobs along the entire agricultural value chain. This paradigm can potentially create up to 17 million jobs (Bafana 2014) along the value chain and catalyze an agricultural sector worth US$1 trillion by 2030 (World Bank 2013), without adding to aggregate greenhouse gas emissions and pollution, thereby minimizing health risks (SDG 3). EbA will also contribute directly to SDG 1 (combating poverty) and SDG 2 (enhancing food security), and catalyze SDG 7 (affordable and clean energy). It will also catalyze SDG 8 by enhancing high-quality jobs and structural transformation as well as contributing to macroeconomic expansion through increased agricultural GDP.

Positioning EbA and CSA techniques as part of a composite solution to eliminate inefficiencies along Africa's agricultural value chains and to work toward realizing the Malabo Declaration goals and SDGs stands out as potentially catalytic to scaling up of EbA. This is the strategic trajectory that the continent is actualizing through multistakeholder, mutual, and complementary partnerships being fostered under the Ecosystem-based Adaptation for Food Security Assembly (EBAFOSA) policy action framework facilitated by the UN Environment, discussed below.

Moving from Talk to Action: The Ecosystem-Based Adaptation for Food Security Assembly Business Model for Scaling Up EbA and Allied Climate Resilience Techniques

EBAFOSA's strategy for scaling up EbA is to position it as part of a menu in an integrated solution to climate-proof and maximize the productivity of Africa's agricultural value chains. Such a solution would aim to ensure that the socioeconomic benefits of food security, jobs, and income and macroeconomic growth are created alongside climate resilience and enhanced ecosystems, hence catalyzing the achievement of multiple SDGs—as opposed to considering EbA as a stand-alone climate adaptation strategy implemented only as a climate obligation and not connected to any direct socioeconomic action. Positioning EbA in this way is the foundation of EBAFOSA's EbA business model, aimed at incentivizing business-driven actions to scale up EbA.

The model covers two components:

Integrating EbA, including allied resilience techniques of CSA, as a key component to sustainably industrialize Africa's agriculture. This component involves amalgamating on-farm EbA and CSA actions with various forms of clean energy–powered value addition; information-and-communications-technology (ICT)–enabled market and supply chain linkages, especially market prices, input suppliers, advisory services, financial intermediation, and the like, for efficient access to support services; and official standardization to enhance the marketability of products—all in a continuum toward establishing clean energy–powered agro-industrialization. This approach places EbA and CSA among the ingredients required to industrialize Africa's agriculture, contributing not only to food security but also to the creation of additional income and business opportunities along the entire agricultural value chain and the intervening value chains.

This paradigm is implemented under the EBAFOSA policy action framework by ensuring that actors practicing EbA are linked with these complementary actors through mutual partnerships. For example, in Turkana County, Kenya, EBAFOSA Kenya is convening stakeholders from the county government, the private sector (financiers; providers of ICT, irrigation, and other technologies; and advisory service providers), and faith-based organizations in a complementary partnership toward developing a 100-acre solar-powered irrigation enterprise. The crops targeted are amaranth and sorghum, grown using nature-based approaches. These are high-value, climate-resilient crops known to improve soil structure and enhance water retention, making them well suited to EbA's goal of enhancing ecosystems. The enterprise is linked to markets and supply chains, including advisory extension services and financial intermediation through ICT. Cumulatively, this enterprise is incentivizing the application of EbA to ensure food, income, and livelihood security in order to meet SDGs 1 and 2. It is also building biophysical resilience through incentivizing scaled-up use of EbA and clean energy (SDG 13; Paris Agreement Articles 7 and 4), as well as enhancing ecosystems' productivity and resilience (SDG 15).

In the Democratic Republic of the Congo (DRC), a group of young university graduates who are EBAFOSA DRC members have channeled their skills, networks, and capital to optimize the cassava value chain. These young people are using clean energy to process cassava, an indigenous, climate-resilient crop, into flour, and then packaging and standardizing the flour for sale on high-value markets. Through this integration, the youth generate up to US$4,000[51], [52] in weekly income, translating to US$16,000 monthly and US$196,000 annually. In addition, they are incentivizing the production of climate-resilient cassava (an EbA approach that fulfills Paris Agreement Article 7 as well as SDG 13) and clean energy value addition (Paris Agreement Article 4; SDG 13), while creating incomes and jobs, and enhancing food security (SDGs 1 and 2). Through EBAFOSA, these youth are set to train youth groups across the 40 EBAFOSA countries in Africa on their business model, thus expanding their business aims while contributing toward building the capacity of more youth across Africa to replicate this model of clean energy–powered value addition through EbA.

Integrating EbA and CSA techniques as a component to remove risk from agricultural value chain financing. Studies show that a leading constraint on the development of private financing for agriculture is its perceived high risk (World Bank 2015). Climate change–induced crop failure is a key contributory factor to this risk given the up to 40 percent yield reductions under climate change as projected in the 2nd Africa Adaptation Gap Report. For example, private-sector lending to the catalytic agriculture sectors remains underdeveloped due to perceived high risk. This constraint can be remedied through risk-sharing facilities that cover key climate-related risk factors (driven by climate change–induced crop failure) and financial risk (driven by repayment defaults). By leveraging the climate risk–reducing properties of EbA, EBAFOSA aims to integrate EbA into these climate risk–sharing facilities in order to reduce some of the risk of climate change–induced crop failure, with the end goal of lowering the risk and cost of agricultural value chain financing, thereby attracting more private financing.

Makueni County, Kenya, is the first county in Africa to legislate creation of a climate change fund to domestically finance resilience-building efforts. Through EBAFOSA, stakeholders are working with the county government to leverage this fund for additional private-sector resources, as opposed to using the whole fund as a social program to finance climate-resilience actions. The fund is setting aside 50 percent of its portfolio to securitize up to 10 times its value in private banks. These securitized monies will be loaned to entrepreneurs engaged in actions that optimize the agricultural value chain using EbA and clean energy. Thus, the fund will indirectly finance the scaling up of EbA-driven agriculture (relevant to SDGs 2, 3, 13, and 15) and clean-energy agricultural value addition to create multiple low-carbon, higher-order income and job opportunities (SDGs 1, 7, 8, and 13). In Makueni County, then, EbA is integrated into a solution to mitigate the risk of agricultural value chain financing through a risk-sharing facility that covers both climate risk (through climate risk–mitigating EbA approaches) and financial risk (through cash deposits that cover repayment defaults).

51 https://www.afdb.org/fileadmin/uploads/afdb/Documents/Events/ayaf2017/Statements/2017_04_25_Statement_by_AfDB_President_AYAF.pdf

52 http://www.iita.org/news-item/iita-trustees-field-visits-tour-kalambo-station-facility/

Innovative Volunteerism: The EBAFOSA Modus Operandi

To achieve all of the goals mentioned above, EBAFOSA, established in 40 countries, has become an inclusive, country-driven policy action framework that convenes multiple stakeholders in a country—individual and institutional, state and nonstate—drawn from complementary sectors. These actors volunteer their physical and nonphysical resources, such as professional skills, networks, partnerships, ongoing and planned initiatives, time, products, and services. They thus build mutual partnerships that address their respective business and organizational objectives (such as expanding market share and operationalizing policies) while remaining geared toward realizing the larger, shared EBAFOSA strategic objective: bridging relevant policy gaps (by harmonizing policies across multiple relevant line ministries) and operational gaps (such as financing, technical expertise, and technology) toward establishing EbA-based agro-industrial zones powered by clean energy to accelerate the achievement of multiple SDGs. These zones integrate EbA as a crucial component of agro-industrialization in operationalizing their business model.

These voluntary mutual partnerships among complementary actors at both policy and operational levels, aimed at bridging the gaps, constitute the EBAFOSA modus operandi, called *innovative volunteerism*. This process uses voluntary actions to build partnerships that address the immediate business and organizational objectives of the partners but also align with achieving the larger EBAFOSA strategic objectives.

Examples of Innovative Volunteerism in Practice

Innovative volunteerism is not blind optimism. It is already on the move, demonstrating that the strength of this paradigm can be channeled through voluntary, state-driven partnerships. The spirit of innovative volunteerism is mobilizing youth groups through EBAFOSA in countries like Nigeria.

Innovative volunteerism at the policy level. EBAFOSA is convening policy makers from ministries of transportation, agriculture, the environment, lands, energy, and industrialization, among others, across countries in Africa to form interministerial policy task forces. Driven by the objective of maximizing the impact of their policies, ministerial staff are volunteering their professional skills, networks, and time to work together to harmonize their relevant line ministry policies to ensure that they support the amalgamation of EbA-driven agriculture with clean energy–powered value addition and links to markets and commercial supply chains. Already EBAFOSA Cameroon, Côte d'Ivoire, Gambia, Ghana, Nigeria, Sierra Leone, and Tanzania have formed these task forces. In Tanzania, the FAO supported the first seating of the task force. Though a recent development, this is an innovative solution that has mobilized cross-cutting support. Countries around the globe should likewise contextualize this harmonization as critical to accelerate achievement of the SDGs.

Innovative volunteerism at the operational level. EBAFOSA Kenya provides a test case of work at the operational level. An enterprise resource planning system for agribusiness management called EdenSys, developed by an EBAFOSA Kenya stakeholder, is currently integrating the entire EbA-driven agriculture and clean energy value addition value chain in the country and set to expand across the 40 EBAFOSA countries. By collaborating with clean energy actors, banks (including microfinancers), extension and advisory service providers, and farmers' groups on the EBAFOSA platform, the EdenSys application, accessible by phone and computer, has mapped and archived the intervening services needed to optimize the entire agricultural value chain. The application allows enterprises along the EbA- and clean energy–based agricultural value chains to post their financial records online and, based on their balance sheets, apply for loans by phone or computer. The application is enhancing market access for all of these intervening actors while also contributing to broader EBAFOSA aims by bridging financial inclusion and access gaps to indirectly finance scaled-up use of EbA (addressing SDGs 2, 3, 13, and 15) and clean energy (SDGs 7 and 13), as well as enhancing food security and incomes, and creating jobs, including high-quality off-farm jobs in agroprocessing, ICT, and clean energy (SDGs 1, 2, and 8).

In Nigeria, through the EBAFOSA framework, premised on the spirit of innovative volunteerism, mobilized youth groups have volunteered their skills and partnered with farmer cooperatives to develop EbA farming and expand the reach of EbA actions in Nigeria. The farms are being linked to markets and other commercial value chains to increase their earnings. More than 1,000 youth are currently engaged in these partnerships.

Through EBAFOSA Malawi, stakeholders have engaged with the Malawi Bureau of Standards to develop quality standards for sesame, a high-value and drought-resistant crop. This partnership is enhancing the marketability of sesame, increasing earnings from this crop, and incentivizing its wide-scale growth. Cumulatively, these effects are combating poverty and food insecurity.

These pockets of success are a clarion call and an encouragement for us to build on them and create full-scale solutions. Harnessing the spirit of innovative volunteerism, Africa can achieve a market-driven scaling-up of EbA to attain the SDGs, ensuring that truly no one is left behind.

Conclusion

To effectively scale up EbA and allied climate resilience techniques such as CSA, there is an urgent need to break away from a silo perspective that views EbA as only a climate resilience strategy. Rather, EbA and CSA must be positioned as part of a solution for achieving Africa's leading socioeconomic priorities and driving realization of the SDGs and Malabo Declaration goals, which the region urgently needs to attain. This positioning of EbA and CSA, as part of a composite solution to maximize the productivity of the region's agricultural value chains, provides the gateway to generate market-based incentives to scale up both EbA and CSA.

To actualize this trajectory in a practical sense, the region needs to bridge gaps at the policy and operational levels. To do so, inclusive, country-driven mutual partnerships among multiple but complementary actors—institutional and individual, state and nonstate—at both policy and operational levels are a prerequisite. And EBAFOSA provides a ready policy action framework whereby these partnerships are being forged on a continental scale.

CHAPTER 11

Tracking Key CAADP Indicators and Implementation Processes

Tsitsi Makombe, Wondwosen Tefera, Greenwell Matchaya,
and Samuel Benin

The Comprehensive Africa Agriculture Development Programme (CAADP) is Africa's policy framework for transforming the agriculture sector and achieving broad-based economic growth, poverty reduction, and food and nutrition security. It was officially ratified by African Union (AU) heads of state and government in the 2003 Maputo Declaration on *Agriculture and Food Security* with two main targets: achieving a 6 percent annual agricultural growth rate at the national level and allocating 10 percent of national budgets to the agriculture sector. In 2014, AU heads of state and government reaffirmed their commitment to CAADP by adopting the Malabo Declaration on *Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods* in which they made seven broad commitments including upholding the CAADP principles and targets, ending hunger and halving poverty by 2025, tripling intra-African agricultural trade, and enhancing mutual accountability for results by conducting a continental Biennial Review (BR) using the CAADP Results Framework (RF).

The Regional Strategic Analysis and Knowledge Support System (ReSAKSS) was established in 2006 to provide data and knowledge products to facilitate CAADP benchmarking, review, dialogue, and mutual learning processes. It is facilitated by the International Food Policy Research Institute (IFPRI) in partnership with Africa-based CGIAR centers, the African Union Commission (AUC), the NEPAD Planning and Coordinating Agency (NPCA), and leading regional economic communities (RECs). ReSAKSS led the development of the first CAADP Monitoring and Evaluation (M&E) Framework (Benin, Johnson, and Omilola 2010) and has been helping to track progress on core CAADP indicators since 2008 through its website (www.resakss.org) and flagship Annual Trends and Outlook Reports (ATORs).

The new CAADP RF for 2015–2025 outlines 40 indicators for tracking and reporting on progress in implementing the Malabo Declaration across three levels (AUC and NPCA, 2015). Level 1 includes the high-level outcomes and impacts to which agriculture contributes, including wealth creation; food and nutrition security; economic opportunities, poverty alleviation, and shared prosperity; and resilience and sustainability. Level 2 includes the outputs from interventions intended to transform the agriculture sector and achieve inclusive growth: improved agricultural production and productivity; increased intra-African regional trade and functional markets; expanded local agro-industry and value-chain development, inclusive of women and youth; increased resilience of livelihoods and improved management of risks in agriculture; and improved management of natural resources for sustainable agriculture. Level 3 includes inputs and processes required to strengthen systemic capacity to deliver CAADP results and create an enabling environment in which agricultural transformation can take place: effective and inclusive policy processes; effective and accountable institutions, including assessing implementation of policies and commitments; strengthened capacity for evidence-based planning, implementation, and review; improved multisectoral coordination, partnerships, and mutual accountability in sectors related to agriculture; increased public and private investments in agriculture; and increased capacity to generate, analyze, and use data, information, knowledge, and innovations.

ReSAKSS is expanding its database to track the indicators in the new CAADP RF and continue to support CAADP implementation processes, including promoting mutual accountability through agriculture joint sector review (JSR) assessments, providing technical support to the CAADP BR process, and leading efforts to establish country-level strategic analysis and knowledge support systems (SAKSS) that provide data and analysis in support of CAADP.

This chapter discusses progress on 29 of the 40 indicators in the new CAADP RF. These 29 indicators are the ones for which cross-country data have been assembled so far—details of the indicators and aggregate statistics are available in the data tables in Annexes 1 to 3 of this report. The remaining indicators will be added in subsequent ATORs and on the ReSAKSS website as data become available. ReSAKSS will also continue to present data for 13 indicators that were reported on previously and which remain of interest to stakeholders both in this report and on the ReSAKSS website. Details of the indicators and aggregate statistics are available in the data tables in Annex 5 of this report.

Progress in CAADP Implementation Processes

The first decade of CAADP (2003–2013) was largely characterized by an implementation process that provided countries and regions with a clear set of steps to embark on through the CAADP Round Table process, which included signing a CAADP Compact, developing national or regional agriculture investment plans (NAIPs or RAIPs), and holding a CAADP business meeting. With CAADP now in its second decade, countries and regions are following somewhat similar steps as they develop second generation or new NAIPs/RAIPs and prepare for the first CAADP BR scheduled for January 2018. The following section describes country and regional progress in completing the CAADP process as well as progress by ReSAKSS in supporting the process through its support for NAIP formulation, JSR assessments, and the CAADP BR.

As of August 2017, 42 of 55 AU member states had signed CAADP compacts and 33 had developed, reviewed, and validated related NAIPs. The NAIPs provide detailed implementation plans for achieving CAADP/Malabo goals and targets. Following the signing of the compact and the development of a NAIP, countries hold a business meeting to discuss financing modalities for the plan. By August 2017, 28 countries had held business meetings (Table L3(a)). To help countries finance the gaps in their NAIPs and achieve their targeted outcomes, the Global Agriculture and Food Security Program (GAFSP) was created in 2010. To date, 17 countries in Africa have been approved for GAFSP funding totaling US$611.5 million (Table L3(a)).

Beginning in 2016, the AU and NPCA and relevant RECs have organized Malabo domestication events in various countries to launch the NAIP formulation process and ensure its alignment with Malabo commitments. Among the outputs of the event is a roadmap outlining the country's NAIP development process. To date, domestication events have been held in eight countries (Table L3(a)). Technical support from ReSAKSS and IFPRI leads to the production of a Malabo Status Assessment and Profile that evaluates the current situation in a country, and a Malabo Goals and Milestones Report that analyzes requirements for achieving Malabo targets. By August 2017, Malabo Status Assessments and Profiles had been completed for 13 countries and Malabo Goals and Milestone Reports had been completed for 4 countries (Table L3(a)).

The Malabo Declaration calls for strengthening national and regional institutional capacities for knowledge and data generation and management that support evidence-based planning, implementation, and M&E. Agricultural JSRs are one way of operationalizing mutual accountability. JSRs provide an inclusive, evidence-based platform for multiple stakeholders to jointly review progress; hold each other accountable for actions, results, and commitments; and, based on gaps identified, agree on future implementation actions. To strengthen mutual accountability, ReSAKSS, at the request of AUC and NPCA and in collaboration with Africa Lead, has to date initiated agricultural JSR assessments in 30 countries. These assessments are aimed at evaluating the institutional and policy landscape as well as the quality of current agricultural review processes, and identifying areas that need strengthening in order to help countries develop JSR processes that are regular, comprehensive, and inclusive. Out of 30 country-level JSR assessments that have been initiated, 7 were completed in 2014 and 11 were completed between 2015 and 2016, bringing the total number of countries with completed assessments to 18 (Table L3(a)). At the regional level, in June 2016 the Economic Community of West African States (ECOWAS) was the first REC to hold a regional JSR. The experiences and lessons learned during the JSR assessments are being used to strengthen JSR processes and to support AUC and NPCA in preparing for the inaugural CAADP BR report that will be presented at the AU summit in January 2018.

Starting in 2016, ReSAKSS, under the leadership of AUC and NPCA, has been supporting the CAADP BR process by providing technical support to countries in data collection, analysis, and reporting. Before the BR process was rolled out to all countries, the AUC and NPCA organized six regional training workshops where country representatives were trained on BR tools and guidelines. As of August 2017, 52 of the 55 AU member states had launched the BR process and were at varying stages of completing their country reports and data templates that will be used to produce an inaugural continental BR report and scorecard for the January 2018 summit. A total of 31 countries had their BR reports drafted, validated, and submitted to the respective REC. The BR process is proving to be a useful tool for rallying agriculture sector stakeholders and enhancing mutual accountability. A second round of the BR is scheduled for 2020, with the preparation process expected to start in 2018.

Progress in CAADP Indicators

Of the 40 CAADP RF indicators, 34 are quantitative while 6 are qualitative and largely deal with strengthening country-level capacities to deliver on the CAADP agenda. The following section assesses Africa's performance on 29 of the 40 indicators for which data are readily available, that is 23 quantitative and all 6 qualitative indicators. The progress is organized using the three levels of the CAADP RF: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development; Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth; and Level 3—Strengthening Systemic Capacity to Deliver Results.

Unlike the qualitative indicators that are presented primarily at the country level, progress in the quantitative indicators is presented at the aggregate level in six different breakdowns: (1) for Africa as a whole; (2) by AU's five geographic regions (central, eastern, northern, southern, and western); (3) by four economic categories (countries with less favorable agricultural conditions, countries with more favorable agricultural conditions, mineral-rich countries, and middle-income countries); (4) by the eight regional economic communities (CEN-SAD, COMESA, EAC, ECCAS, ECOWAS, IGAD, SADC, and UMA)[53]; (5) by the period during which countries signed the CAADP compact (CC1, CC2, CC3, and CC0)[54]; and (6) by the level or stage of CAADP implementation reached by the end of 2016 (CL0, CL1, CL2, CL3 and CL4).[55] Annex 4 lists the countries in each CAADP category. Progress is also reported over different sub-periods, where achievement in post-CAADP sub-periods (that is, annual average levels in 2003–2008 and 2008–2016) are compared with achievement in the pre-CAADP or base sub-period of 1995–2003. The discussion here is mainly confined to trends for Africa as a whole and for countries categorized by year in which they signed a CAADP compact and by stage of CAADP implementation reached.

CAADP RF Level 1 Indicators: Agriculture's Contribution to Economic Growth and Inclusive Development

Wealth Creation

In the aftermath of the global commodity and financial crises in 2007 and 2008, Africa has experienced slower economic growth, breaking from the strong growth the continent had experienced since the early 2000s. Recently, and especially in 2016, the slowdown in growth has been attributed to lower commodity prices and a less-supportive global environment (IMF 2016). To illustrate, although *per capita gross domestic product* (GDP) for Africa as a whole grew at an annual average rate of 3.9 percent in 2003–2008, it fell to 0.6 percent in 2008–2016 (Table L1.1.1). A similar trend is also observed across most classifications: geographic regions, economic classifications, RECs, and CAADP groups. The group of countries with more favorable agriculture conditions seems to have fared well in 2008–2016 with the highest annual average growth rate of 3.5 percent, perhaps because they are less dependent on oil and mineral resources, which faced declining prices. On average, the groups of countries that have been implementing CAADP the longest (especially CC1 countries) or are most advanced in implementing CAADP (CL4) achieved higher GDP per capita growth in 2003–2008 compared to the groups of non-CAADP countries (CC0 or CL0). Despite the slower rate of economic growth, Africa as a whole and

53 CEN-SAD = Community of Sahel-Saharan States; COMESA = Common Market for Eastern and Southern Africa; EAC = East African Community; ECCAS = Economic Community of Central African States; ECOWAS = Economic Community of West African States; IGAD = Intergovernmental Authority for Development; SADC = Southern African Development Community; UMA = Arab Maghreb Union.

54 CC1 = group of countries that signed the compact in 2007–2009; CC2 = group of countries that signed the compact in 2010–2012; CC3 = group of countries that signed the compact in 2013-2015; CC0 = group of countries that have not yet signed a CAADP compact.

55 CL0 =group of countries that have not started the CAADP process or are pre-compact; CL1 =group of countries that have signed a CAADP compact; CL2 = group of countries that have signed a compact and formulated a NAIP; CL3 = group of countries that have signed a compact, formulated a NAIP, and secured one external funding source; CL4 = group of countries that have signed a compact, formulated a NAIP, and secured more than one external funding source.

all classifications have experienced sustained increases in GDP per capita. For example, Africa's GDP per capita increased from an annual average of US$1,437 in 1995–2003 to US$1,691 in 2003–2008 and US$1,883 in 2008–2016. Since 2003–2008, southern and northern Africa and middle-income countries experienced the highest GDP per capita (above US$3,000), while mineral-rich countries have had the lowest GDP per capita (US$431).

Since 2003, *household consumption expenditures per capita* have grown steadily for Africa as a whole and across all classifications (Table L1.1.2). Moreover, many of the classifications either maintained or registered improved growth rates in 2008–2016 compared to 2003–2008. And consistent with the GDP per capita growth pattern, Africa's household consumption expenditure per capita increased from US$1,014 in 1995–2003 to US$1,127 in 2003–2008, reaching US$1,296 in 2008–2016. The groups of countries engaged in CAADP, and especially those that signed a CAADP compact earlier (CC1) and those that have gone through most of the CAADP stages (CL4), registered higher growth in household consumption expenditure during the CAADP era (2003–2008 and 2008–2016), thereby reducing the expenditure-per-capita gap between them and the groups of non-CAADP countries or those that have not yet embarked on the process (CC0 and CL0).

Food and Nutrition Security

Rates of hunger and malnutrition (undernourishment and child underweight, stunting, and wasting) have been declining over the last 20 years but remain high across all classifications. For example, the proportion of people that are *undernourished* in Africa as a whole decreased from 24.9 percent in 1995–2003 to 20.8 percent in 2003–2008 and further down to 17.6 percent in 2008–2015 (Table L1.2.1). Despite the declining trend for Africa as a whole, rates of undernourishment remained rather high, above 30 percent, in eastern Africa and mineral-rich countries during 2008–2015. The groups of countries involved in the CAADP process, especially those that signed CAADP compacts earlier (CC1) and are most advanced in implementing the process (CL4), have seen faster declines in the rate of undernourishment than the groups of countries that are not part of the process (CC0 and CL0). Although the rate of decline has been slower in the groups of countries that have not engaged in the CAADP process, which include South Africa and most northern Africa countries, the levels of undernourishment are much lower in these groups.

As part of the Malabo commitment to ending hunger, African leaders resolved to improve the nutritional status of children, namely by reducing stunting to 10 percent and underweight to 5 percent by 2025. The *prevalence of underweight children* under five years of age has consistently declined across all classifications. For Africa as a whole, prevalence decreased from an annual average level of 24.6 percent in 1995–2003 to 22.4 percent in 2003–2008 and further down to 19.8 percent in 2008–2016 (Table L1.2.2A). Although northern Africa countries together had the lowest prevalence of underweight children in 1995–2003, they also had the fastest rates of decline, bringing down the prevalence from 8.2 percent in 2003 to 4.6 percent in 2016, thus meeting the Malabo underweight goal as a group. Fast declines in the rate of underweight children were also observed in southern Africa, which brought down the prevalence from 16.9 percent in 2003 to 10 percent in 2016. In addition, the group of countries engaged in the CAADP process experienced faster declines in the prevalence of underweight children than those that are not engaged in the CAADP process.

The *prevalence of child stunting* remains stubbornly high in Africa as a whole, at 33.7 percent in 2016. The prevalence rate has also remined high across most classifications, at above 35 percent, despite sustained declines. The prevalence of stunting in Africa as a whole fell slowly from 41.8 percent in 1995–2003 to 39.2 percent in 2003–2008 and to 35.3 percent in 2008–2016 (Table L1.2.2B). The rate of decline in child stunting slowed during the first segment of the CAADP period (2003–2008) across all classifications but increased during 2008–2016. Northern Africa countries which make up the majority of the groups of countries that have not yet joined the CAADP process (CC0 and CL0) began with the lowest rates of child stunting, which fell to about 20 percent during 2008–2016. With stunting levels still above 35 percent for most classifications, there is need to accelerate the rate of decline in order to achieve the Malabo target of bringing down stunting to 10 percent by 2025.

Although levels of *child wasting* in Africa are relatively lower than other measures of malnutrition, the rate of decline has been slow across all classifications. For Africa as a whole, the prevalence of child wasting averaged 10.6 percent in 1995–2003, declining marginally to 9.9 percent in 2003–2008 and further down to 9.1 percent in 2008–2016 (Table L1.2.2C). Although child wasting levels are relatively lower than child stunting and underweight levels, they have consistently increased in northern Africa and in the group of countries that have not yet joined the CAADP process (CC0 and CL0). This trend indicates that the higher levels of GDP per capita and household consumption per capita observed in northern Africa have not led to lower child wasting.

Despite good progress in reducing malnutrition, the rates of decline have been slow and not on track to achieve the Malabo goals of reducing stunting to 10 percent and underweight to 5 percent by 2025 for Africa as a whole. Concerted and urgent effort is needed to speed up the reduction of malnutrition including by making agriculture programs nutrition sensitive.

Africa's *dependence on cereal imports* has gradually increased over time, reaching an annual average level of 31.8 percent in 2008–2010 (Table L1.2.3). This means that about 32 percent of Africa's cereal food supply in 2008–2010 was imported from elsewhere. The increasing trend is consistent across most classifications even though the level of dependency is quite different among the classifications. Central and northern Africa regions had the highest cereal import dependency ratio at 73.5 percent and 50.7 percent, respectively, in 2008–2010. Southern Africa is the only region that reduced its cereal import dependency ratio in 2008–2010, by an average of -9.9 percent per year. As may be expected, countries with more favorable agricultural conditions had the lowest cereal import dependency ratio, even though their dependency has steadily increased over time from 12.2 percent in 1995–2003 to 15.7 percent in 2003–2008 and further to 17.3 percent in 2008–2010. This indicates that due to the amenable agricultural conditions, much of the available domestic food supply of cereals has been produced in the countries themselves. The groups of countries that joined CAADP earlier (CC1) and those that have progressed the furthest in the CAADP process (CL3 and CL4) are among those with lowest cereal import dependency ratios.

Employment

Tables L1.3.1A and L1.3.1B show *employment rates* as the number of employed people as a percentage of the labor force (15–64 years, Table L1.3.1A) and as a percentage of the working-age population (+15 years, Table L1.3.1B). Naturally, the employment rate relative to the labor force is much higher. On average, the employment rate for Africa as a whole and other classifications has increased marginally or remained fairly constant over time. For Africa as a whole, the rate is moderate when considering the working-age population; it increased marginally from 58.5 percent in 1995–2003 to 59.0 percent in 2003–2008 and to 59.8 percent in 2008–2016 (Table L1.3.1B). The employment rates are relatively higher in groups of countries that have signed CAADP compacts or are further along in the CAADP process than in groups of countries that are not part of the process (CC0 and CL0). Given the presence of high levels of undernourishment discussed earlier (and poverty discussed in the next section), the moderate employment rates, with employment concentrated in the agricultural sector, indicate that many of the working-age population or labor force may be considered poor, that is working poor. Moreover, underemployment and poor quality jobs continue to present significant challenges for Africa.

Poverty

The incidence and depth of poverty have been on a declining trend, but rates are still relatively high. In Africa as a whole, the *proportion of population that lives below US$1.90 a day*, measured by the poverty headcount ratio, declined marginally from 49.5 percent in 1995–2003 to 45.6 percent in 2003–2008 and to 42.2 percent in 2008–2016 (Table L1.3.4). The reduction in poverty headcount was also consistent across all classifications. Northern Africa, despite having the lowest poverty rate, experienced the fastest poverty reduction during the CAADP era, reducing its poverty rate from 3.8 percent in 2003–2008 to 2.1 percent in 2008–2016. Although southern Africa has one of the highest levels of GDP per capita and household consumption expenditure per capita (Tables L1.1.1 and L1.1.2), the incidence of poverty in the region remains high at 39.3 percent in 2008–2016. This suggests the need to exert more effort to achieve inclusive growth and the Malabo target of halving poverty by 2025.

The depth of poverty—or the poverty gap—measures the extent to which individuals fall below the poverty line, which has implications for the resources needed help them move out of extreme poverty. For Africa as whole, the depth of poverty, measured by *poverty gap index at US$1.90 a day*, fell from 25 percent in 1995–2003 to 20.9 in 2003–2008 and down to 17.1 percent in 2008–2016 (Table L1.3.3). On average, during the CAADP era, the rate of decline was faster in 2008–2016 compared to the 2003–2008, despite the recent slowdown in GDP per capita growth discussed earlier. In more recent years, 2008–2016, the poverty gap index was highest in central Africa (28.9 percent) and mineral-rich countries (32.1 percent) and was lowest in northern Africa (0.4 percent). Also, the poverty gap index declined fastest in northern Africa countries at 16.7 percent per year in 2008–2016. Groups of countries that have progressed furthest in the CAADP process (CL3 and CL4) registered a lower poverty gap index than those that have signed a compact only (CL1) or have gone further and developed a NAIP (CL2).

In Africa as a whole, *income inequality* measured by the Gini index, has been a declining slowly. As Table L1.3.5 shows, the Gini index for Africa as a whole declined marginally from 43.8 in 1995–2003 to 43.1 in 2003–2008 and to 42.6 in 2008–2016. However, while income inequality has fallen across most classifications, more recently (2008–2016) it has increased marginally in central Africa and in the groups of countries that signed a CAADP compact earlier (CC1) and those that have not embarked on the CAADP process (CC0 and CL0).

CAADP RF Level 2 Indicators: Agricultural Transformation and Sustained Inclusive Agricultural Growth

Agricultural Production and Productivity

Over the past two decades, *agriculture value added* in Africa as a whole almost doubled, increasing from an annual average of US$7.2 billion per country in 1995–2003 to US$13.2 billion in 2008–2016 (Table L2.1.1). The value added also increased across all classifications. For Africa as a whole, agriculture value-added grew at an annual rate of 4.7 percent in 2008–2016, slightly up from 4.2 percent in 2003–2008, but lower than the CAADP target of 6 percent. However, several classifications including northern Africa, countries with more favorable agricultural conditions, and the group of countries that signed a compact in 2010–2012 (CC2) surpassed the 6 percent target in 2008–2016. In addition, groups of countries engaged in the CAADP process achieved stronger agricultural growth rates than those that are not (CC0 and CL0).

The *agricultural production index* (API) for Africa as a whole and all other classifications has increased steadily over the past 20 years. Table L2.1.2 shows that the API for Africa as a whole increased from 80.9 in 1995–2003 to 100.6 in 2003–2008 and further to 119.6 in 2008–2014. The rate of increase in the API has been higher in the CAADP era than the pre-CAADP period across all classifications and also higher for the group of countries that are furthest in the CAADP implementation process than in the groups of non-CAADP countries.

Over the past 20 years too, *labor and land productivity*, which play a key role in driving agricultural growth, have been increasing in Africa as a whole and across most classifications. For example, the rate of growth in labor productivity, measured by agriculture value added per agricultural worker, rose steadily for Africa as whole from 1.4 percent per year in 1995–2003 to 1.7 percent in 2003–2008 and to 2.7 percent per year in 2008–2016 (Table L2.1.3). Across several classifications, labor productivity grew faster in the CAADP era, reversing the negative growth experienced during the pre-CAADP period (1995–2003). In 2008–2016, labor productivity grew most rapidly in eastern and northern Africa, countries with more favorable agricultural conditions, middle-income countries, EAC, IGAD, and UMA regions, and in the groups of countries that joined the CAADP process later (CC3) and those that have not progressed much in the CAADP process (CL1). Higher levels of labor productivity in the groups of non-CAADP countries (CC0 and CL0) are likely due to the higher levels of mechanization in that group.

Land productivity, measured by agriculture value added per hectare of arable land, grew faster than labor productivity, with the rate of growth increasing from 3.1 percent per year in 1995–2003 to 5.4 percent per year in 2008–2016 for Africa as a whole (Table L2.1.4). Land productivity also performed much better across all classifications during the CAADP era and especially in 2008–2016. Also in 2008–2016, the greatest growth was observed in eastern Africa, countries that have more favorable agricultural conditions, middle-income countries, CEN-SAD, COMESA, EAC, IGAD, UMA, and in the groups of countries that joined the CAADP process later (CC3) and those have not progressed far in the CAADP process (CL1). In addition, groups of countries that joined CAADP earlier and are furthest along in the process attained higher levels of land productivity than the groups of non-CAADP countries.

Yield trends for the top five agricultural commodities (cassava, yams, maize, meat, and cow milk)[56] show varied performance over the past 20 years. For Africa as a whole, both *cassava and yam yields*, measured in metric tons per hectare (ton/ha), grew faster during 2003–2008 but experienced negative growth during the later CAADP period, 2008–2014 (Tables L2.1.5A and L2.1.5B). *Maize yield* stayed at 1.7 ton/ ha in both 1995–2003 and 2003–2008 but grew to 2.0 ton/ha in 2008–2014 (Table L2.1.5C). *Meat and milk yields*, measured as kilograms per head, have both experienced an increasing trend with meat yield increasing faster during 2003–2008 and milk yield during 2008–2014 (Tables L2.1.5D and L2.1.5E). Meat and milk yields are much higher in the groups of non-CAADP countries due to the high level of mechanization in that group of countries.

56 These were the commodities with the largest shares in total value of production for Africa as a whole.

Intra-African Regional Trade and Market Performance

Tripling intra-African agricultural trade is one of the seven commitments of the Malabo Declaration. *Intra-African agricultural exports* have been increasing, and have more than doubled for Africa as a whole, increasing from US$0.6 billion in 1995–2003 to US$1.6 billion in 2008–2016 (Table L2.2.1A). Growth was particularly remarkable in southern Africa where it more than doubled and in northern Africa where it grew six-fold during the same period. The group of countries that are further along in the CAADP process (CL3 and CL4) and those countries that joined the process earlier (CC1 and CC2) witnessed consistent increases in intra-African agricultural exports compared to those that have not advanced in the process (CL1 and CL2) or those that signed compacts later (CC3). The groups of non-CAADP countries experienced a decline in their exports in 2003–2008, followed by a rapid increase in 2008–2016.

Intra-African agricultural imports (Table L2.2.1B) increased steadily over the two decades for Africa as a whole and most classifications. Africa's intra-African agricultural imports more than doubled between 1995–2003 and 2008–2016, growing from US$252 million to US$514 million, respectively. The group of countries that are further along in the CAADP process especially (CL3) experienced faster growth in intra-African agricultural imports than those that have not advanced very far (CL1 and CL2). The groups of non-CAADP countries together also experienced rapid growth in imports, particularly in 2008–2016.

For Africa as a whole, the *domestic food price volatility index*, which measures the variation (volatility) in domestic food prices over time, rose during 2003–2008 as a result of the 2007 global food price crisis. Following the crisis, food price volatility has been decreasing, declining by an average of 11 percent per year in 2008–2016, compared to the average increase of 3.7 percent per year in 2003–2008 (Table L2.2.2). Although food price volatility was higher in the groups of countries that joined CAADP earlier and are further along in the CAADP process, these groups also had faster rates of decline in volatility during 2008–2012. Raising agricultural productivity levels to ensure adequate domestic supply can help insulate African countries from volatile global food prices.

Resilience of Livelihoods and Management of Risks

The existence of food reserves and programs and early warning systems is a key level 2 indicator for increased resilience of livelihoods and improved management of risks in the agriculture sector. As of August 2017, 38 countries had food reserves, local purchase for relief programs, early warning systems, and food feeding programs (Table L3(b)).

CAADP RF Level 3 Indicators: Strengthening Systemic Capacity to Deliver Results

Capacities for Policy Design and Implementation

The 2016 ATOR also presents an additional set of qualitative indicators for tracking progress in implementation of actions aimed at strengthening systemic capacity for agriculture and food security policy planning and implementation. These indicators are presented in Table L3(b). As of August 2017, 15 countries had formulated new or revised NAIPs through an inclusive and participatory process. Twenty-one countries had inclusive, institutionalized mechanisms for mutual accountability and peer review (mainly JSRs). Twenty-eight countries were implementing evidence-informed policies with relatively adequate human resources in place. Twenty-two countries had functional multisectoral and multistakeholder coordination bodies—mainly agricultural sector working groups. Sixteen countries had successfully undertaken agriculture-related public-private partnerships (PPPs) aimed at boosting specific agricultural value chains. In addition, SAKSS platforms help meet country-specific data, analytical, and capacity needs, and to date, ReSAKSS has helped to establish these platforms in a total of 14 countries.

Public Agriculture Expenditure

Through the Malabo Declaration, African leaders committed to enhance both public and private investment finance for agriculture and uphold their commitment to allocate at least 10 percent of public expenditure to agriculture. Over the past 20 years, for Africa as a whole, *public agriculture expenditures* have increased steadily, growing from US$0.7 billion per country per year in 1995–2003 to US$1.1 billion in 2008–2016 (Table L3.5.1). Public agriculture expenditures grew strongly in both 1995–2003 and 2003–2008, by 11.5 and 11 percent, respectively. However, following the global food-price and financial crises, which reduced fiscal revenues, growth in expenditures decelerated at about 4.8 percent per year on average in 2008–2016, and expenditures fell to US$0.9 billion per country as of 2016. The declining trend in public agricultural expenditure was also observed in eastern, southern, and western Africa; only central and northern Africa experienced increased expenditures during 2008–2016. Declines in public agriculture expenditures were also witnessed in the groups of CAADP countries (CC1, CC3, CL1, CL4).

Although public agriculture expenditures have increased remarkably over time, for Africa as a whole, the *share of agriculture expenditure in total public expenditure* has fallen short of the CAADP target of 10 percent budget share. The share grew from an annual average of 3.2 percent in 1995–2003 to 3.5 percent in 2003–2008 and declined to 3.0 percent in 2008–2016 (Table L3.5.2). Although a handful of countries met the CAADP budget target, none of the classifications managed to achieve the CAADP budget target in 2008–2016. The groups of countries that joined the CAADP process early (CC1 and CC2) and those that are further along in the implementation process (CL2, CL3, and CL4) had relatively higher shares of public expenditures, at more than 4 percent during 2008–2016.

In Africa as a whole, *public agricultural expenditure as a share of agriculture* GDP averaged 6.2 percent per year in 2003–2008 and declined to 5.5 percent in 2008–2016 (Table L3.5.3). Northern and southern Africa regions, mineral-rich countries, SADC, UMA, and the groups of non-CAADP countries had higher shares, above 10 percent in 2008–2016, indicating they invest more in agriculture relative to the size of the sector. More needs to be done to raise public agriculture investments in order to increase agricultural productivity growth and deepen the progress toward achieving Malabo targets for poverty, hunger, and nutrition by 2025.

CHAPTER 12

Concluding Remarks

Rising temperatures, changes in rainfall patterns, and increased frequency of extreme weather events are expected to slow progress toward increased productivity of crop and livestock systems and improved food security, particularly in Africa south of the Sahara. These manifestations of climate change are already having serious impacts on crop yields, especially for African farmers who rely on rainfall. An integrated framework to address this multifaceted threat is urgently needed. Climate-smart agriculture (CSA), with its multi-pronged approach, offers an opportunity to address the challenges of meeting future food security demands under a changing climate.

Findings from this report provide a clear sense of the potential positive effects that CSA practices can have on productivity and on the number of people at risk of hunger, through a reduction in agricultural commodity prices. In addition, adoption of CSA practices has the potential to reduce soil degradation by increasing soil organic carbon content, or at least reducing soil organic carbon losses. Overall, these findings suggest that CSA practices can contribute to increasing resilience to climate change. The reduction of greenhouse gas (GHG) emissions is compatible with increasing productivity, but achieving significant abatement levels will depend on the feasibility of enforcing emission intensity reductions on the ground and also on the impact of CSA adoption on other carbon-rich environments such as forests. More research is needed to develop reliable and inexpensive methods to verify emission reductions and monitor land use change as well as on the trade-offs and synergies across different development outcomes.

African countries have committed themselves to achieving the aspirations of the Malabo Declaration, including ending hunger by 2025 and building resilience of vulnerable livelihoods and production systems to climate variability and shocks. They have committed to scaling up investments for resilience-building initiatives and to mainstreaming resilience and risk management into their policies, strategies, and investment plans. CSA is an important approach for meeting Malabo goals, with potential for increasing agricultural productivity and meeting food security objectives while enhancing resilience. However, the effectiveness of CSA will largely depend on its widespread adoption and implementation. This will require key innovations and policy actions, including:

- **CSA-related training programs for extension agents:** A defining characteristic of CSA practices is their location-specificity, meaning that practices and technologies must be tailored to local conditions. The capacity of extension agents to provide advisory services on integrated soil fertility management (ISFM), organic soil fertility, and other new paradigms for sustainable soil fertility management practices is low. This capacity should be increased through short-term training and workshops for extension agents who are already in service.
- **Policies and strategies that treat smallholder farmers as entrepreneurs:** CSA does not by itself solve some of the long-standing problems that have limited the progress and development of agricultural producers. For too long, governments and even donors have treated smallholder farmers as subsistence farmers, and their policies and strategies have largely focused on provision of production-related rural services, rather than market potential. Public extension agents affiliated with the ministries of agriculture largely provide production-related advisory services; but marketing advisory services in most countries are relegated to the ministry of industries and trade, where they receive little attention. Smallholders have the potential to

generate profits and care for their land. They will benefit from being treated as commercially-oriented farmers if they are provided with appropriate advisory and information services to fully connect them with successful value chains.

- **Storage facilities and other market value-chain investments:** Increased farm and nonfarm investments along agricultural value chains can create incentives for farmers to adopt CSA practices. These include the implementation of risk-coping mechanisms, namely ISFM, improved seeds, storage, processing equipment, and enhanced access to markets, crop insurance, and other mechanisms.
- **Payment for ecosystem services (PES):** A significant share of the benefits generated by CSA practices materializes off-farm and sometimes, as in the case of the reduction of GHG emissions, even at the global level. Programs such as PES should be used to reward farmers who adopt CSA practices. By internalizing positive externalities, PES would help farmers defray initial investments and take on additional risks associated with CSA practices.
- **Agriculture risk management including formal insurance mechanisms:** Farmers need a more sophisticated toolkit to cope with risks induced by changing climate conditions. Furthermore, farmers should be able to take advantage of the upside risk of investments without the danger of catastrophic consequences. Comprehensive risk management strategies, including several insurance pilot programs, show the potential positive impact of innovative approaches and of insurance mechanisms. However, additional work to understand the effectiveness and the potential for substantially scaling up these mechanisms is needed. Such efforts can go a long way in helping the continent meet the Malabo Declaration commitment to enhancing resilience of farming livelihoods.
- **Improved adoption of CSA practices:** While adoption of CSA has the potential to increase agricultural productivity and trade and thus to mitigate climate-induced risks, it may be hindered by several factors, including the level of investment costs, limited access to CSA technologies and knowledge of how to implement the technologies, imperfect markets, and institutional barriers. And in some contexts, there are significant trade-offs between meeting shorter-term food security objectives and the longer-term objective of building resilience. Policies that allow for more public-private partnerships are needed to facilitate the required investments and the adoption of CSA practices and technologies. It is also critical for governments to improve vital institutions that facilitate access to CSA technologies.
- **Full inclusion of the interlinkages across gender, climate change, agriculture, and nutrition when designing CSA policies and programs:** The gender, climate change, and nutrition (GCAN) framework outlined in the report can be used to identify gender differences as they relate to capacities to address climate variability and shocks, preferences for climate change response options, and the effect of climate change responses on nutrition, health, and gender equality as well as other development outcomes. Thus, the GCAN framework can be used to categorize entry points for multisectoral actions that can achieve positive impacts across numerous outcomes. It can also be used to guide the design, implementation, and monitoring and evaluation of agricultural policies and programs to ensure that they account for the climate risk, gender, and nutrition implications.

Overall, the implementation of CSA practices for smallholder farmers is still limited for two main reasons: financial viability and understanding. To address the financial viability issue, we propose the creation of a special-purpose funding vehicle as a platform for the corporate sector to work in partnership with governments, multilateral development banks, development organizations, donor agencies, foundations, nongovernmental and civil society organizations, small farmers, and local community organizations. In addition to creating a platform for sustainable development, such a funding approach would not have the market-distorting effects associated with pure government subsidy programs. With respect to improving understanding, national education and research systems should be re-organized to upgrade smallholder farmers' skills to properly use CSA practices. This will require multisectoral and interministerial approaches involving all key stakeholders—including farmers' organizations and agro-industries—in planning, implementation, and monitoring and evaluation of CSA practices. Finally, the ongoing appraisal and formulation of new national agricultural programs and investment plans provides a good opportunity to incorporate CSA into these plans.

ANNEXES

Core CAADP M&E and Supplementary Indicators

Annexes:
Core CAADP M&E and Supplementary Indicators

This section presents data and trends across three levels of the CAADP Results Framework as well as supplementary data and trends.[57]

The data are presented at the aggregate level for the entire continent (Africa); the five geographic regions of the African Union (central, eastern, northern, southern, and western); eight Regional Economic Communities (CEN-SAD, COMESA, EAC, ECCAS, ECOWAS, IGAD, SADC, and UMA);[58] four economic categories that are classified according to agricultural production potential, alternative nonagricultural sources of growth, and income level; and nine CAADP groups representing either the period during which countries signed a CAADP compact or the level of CAADP implementation reached by countries by the end of 2015. Data for individual countries and regional groupings is available at www.resakss.org.

Technical Notes to Annex Tables

1. To control for year-to-year fluctuations, point estimates are avoided. Therefore, the values under the column "2003" are averages over the years 2002 to 2004 and the values under the column "2016" are averages over the years 2015 to 2016

2. Annual average level and annual average change for 2003–2016 include data from 2003 up to the most recent year that is measured and available.

3. Annual average level is the simple average over the years shown, inclusive of the years shown.

4. Annual average change for all indicators is annual average percent change, the beginning to the end years shown by fitting an exponential growth function to the data points (that is, "LOGEST" function in Excel).

5. For indicators for which there are only a few measured data points over the years specified in the range (such as poverty, which is measured once every three to five years or so), a straight-line method was used to obtain missing values for the individual years between any two measured data points. Otherwise, estimated annual average change based on the measured values is used to obtain missing values either preceding or following the measured data point. In cases where the missing values could not be interpolated, the data is reported as missing and excluded from the calculations for that time period. Any weights used for these indicators are adjusted to account for the missing data in the series of the indicator.

57 Future Annual Trends and Outlook Reports (ATORs) will report on more of the CAADP Results Framework indicators as more data becomes available.

58 CEN-SAD = Community of Sahel-Saharan States; COMESA = Common Market for Eastern and Southern Africa; EAC = East African Community; ECCAS = Economic Community of Central African States; ECOWAS = Economic Community of West African States; IGAD = Intergovernmental Authority for Development; SADC = Southern African Development Community; UMA = Arab Maghreb Union.

6. Values for Africa, the regional aggregations (central, eastern, northern, southern, and western), economic aggregations (less favorable agriculture conditions, more favorable agriculture conditions, mineral-rich countries, and middle-income countries), Regional Economic Communities (CEN-SAD, COMESA, EAC, ECCAS, ECOWAS, IGAD, SADC, and UMA), and CAADP groups—Compact 2007–2009 (CC1), Compact 2010–2012 (CC2), Compact 2013–2015 (CC3), Compact not yet (CC0), Level 0 (CL0), Level 1 (CL1), Level 2 (CL2), Level 3 (CL3), and Level 4 (CL4)—are calculated by weighted summation.[59] The weights vary by indicator and are based on each country's proportion in the total value of the indicator used for the weighting measured at the respective aggregate level. Each country i's weight in region j (wij) is then multiplied by the country's data point (xi) and then summed up for the relevant countries in the region to obtain the regional value (yj) according to: $y_j = \Sigma_i w_{ij} x_i$.

The trend data are organized as follows:

Annex 1
Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development

Annex 2
Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth

Annex 3
Level 3— Strengthening Systemic Capacity to Deliver Results

Annex 4
Country Classification by Period When CAADP Compact Was Signed and Level of CAADP Implementation

Annex 5
Supplementary Data Tables

59 CC1 = group of countries that signed the compact in 2007–2009; CC2 = group of countries that signed the compact in 2010–2012; CC3 = group of countries that signed the compact in 20132015; CC0 = group of countries that have not yet signed a CAADP compact.

CL0 =group of countries that have not started the CAADP process or are pre-compact; CL1 =group of countries that have signed a CAADP compact; CL2 = group of countries that have signed a compact and formulated a NAIP; CL3 = group of countries that have signed a compact, formulated a NAIP, and secured one external funding source; CL4 = group of countries that have signed a compact, formulated a NAIP, and secured more than one external funding source.

ANNEX 1a: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.1.1

TABLE L1.1.1—GDP PER CAPITA (constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	1,437	1.1	1,533	1,691	3.9	1,883	0.6	1,924
Central	731	0.1	763	823	2.6	899	0.9	919
Eastern	558	1.5	594	662	5.1	811	1.7	869
Northern	2,534	2.4	2,787	3,053	3.6	3,285	-0.3	3,321
Southern	2,939	0.7	3,038	3,320	4.1	3,657	0.4	3,675
Western	1,021	1.1	1,154	1,347	5.3	1,658	2.2	1,755
Less favorable agriculture conditions	456	1.2	493	538	2.8	600	1.5	627
More favorable agriculture conditions	458	0.4	462	491	3.0	604	3.5	676
Mineral-rich countries	412	-1.6	402	431	3.1	521	2.6	559
Middle-income countries	2,278	1.6	2,481	2,768	4.2	3,085	0.5	3,141
CEN-SAD	1,353	1.5	1,485	1,674	4.5	1,894	0.5	1,934
COMESA	958	0.9	989	1,074	3.8	1,145	-0.8	1,142
EAC	548	0.9	576	625	3.4	752	2.9	826
ECCAS	892	0.3	919	1,078	7.0	1,307	1.0	1,343
ECOWAS	1,021	1.1	1,154	1,347	5.3	1,658	2.2	1,755
IGAD	559	1.4	594	668	5.7	828	1.5	881
SADC	1,821	0.4	1,859	2,012	3.6	2,192	0.4	2,208
UMA	3,134	2.4	3,488	3,846	3.4	3,967	-0.7	3,973
CAADP Compact 2007-09 (CC1)	811	1.2	930	1,107	6.1	1,410	2.6	1,508
CAADP Compact 2010-12 (CC2)	578	0.1	586	623	2.7	728	2.6	795
CAADP Compact 2013-15 (CC3)	1,363	1.4	1,424	1,626	6.2	1,934	0.8	1,980
CAADP Compact not yet (CC0)	3,314	1.9	3,600	3,911	3.1	4,110	-0.1	4,130
CAADP Level 0 (CL0)	3,314	1.9	3,600	3,911	3.1	4,110	-0.1	4,130
CAADP Level 1 (CL1)	1,435	1.3	1,494	1,730	6.8	2,080	0.7	2,118
CAADP Level 2 (CL2)	520	-0.9	513	533	1.6	583	1.9	626
CAADP Level 3 (CL3)	477	1.6	510	545	3.0	649	1.9	682
CAADP Level 4 (CL4)	800	0.9	892	1,038	5.4	1,303	2.7	1,409

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

ANNEX 1b: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.1.2

TABLE L1.1.2—HOUSEHOLD CONSUMPTION EXPENDITURE PER CAPITA (constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	1,014	0.6	1,066	1,127	2.4	1,296	2.4	1,432
Central	453	-1.1	448	461	1.7	524	2.8	597
Eastern	560	0.1	558	597	2.9	723	2.8	804
Northern	1,546	0.4	1,568	1,596	1.9	1,920	2.8	2,114
Southern	1,891	1.1	2,004	2,130	2.8	2,347	1.2	2,476
Western	757	1.5	883	988	3.3	1,178	3.6	1,368
Less favorable agriculture conditions	373	0.3	392	394	1.4	428	1.8	462
More favorable agriculture conditions	431	0.5	434	448	1.7	512	2.4	552
Mineral-rich countries	275	-1.7	263	283	2.9	308	1.7	327
Middle-income countries	1,441	0.9	1,540	1,644	2.6	1,925	2.7	2,153
CEN-SAD	962	1.0	1,040	1,122	3.0	1,331	3.1	1,499
COMESA	833	-0.1	820	845	2.3	967	2.1	1,045
EAC	430	0.5	434	454	2.4	558	3.4	623
ECCAS	463	2.0	528	551	3.5	758	4.4	945
ECOWAS	757	1.5	883	988	3.3	1,178	3.6	1,368
IGAD	653	0.3	651	697	2.8	835	2.8	936
SADC	1,158	0.6	1,198	1,264	2.5	1,381	1.1	1,451
UMA	1,672	-0.8	1,656	1,608	0.0	1,792	2.7	1,998
CAADP Compact 2007–09 (CC1)	763	1.6	911	1,029	3.4	1,247	3.9	1,464
CAADP Compact 2010–12 (CC2)	429	-0.1	425	443	2.0	504	2.2	547
CAADP Compact 2013–15 (CC3)	789	1.6	856	902	3.6	1,198	4.0	1,449
CAADP Compact not yet (CC0)	2,032	0.6	2,091	2,181	2.1	2,432	1.7	2,573
CAADP Level 0 (CL0)	2,032	0.6	2,091	2,181	2.1	2,432	1.7	2,573
CAADP Level 1 (CL1)	811	1.4	878	930	4.1	1,265	4.2	1,552
CAADP Level 2 (CL2)	397	-0.7	388	401	1.5	427	1.2	448
CAADP Level 3 (CL3)	323	1.0	341	364	2.5	409	1.8	436
CAADP Level 4 (CL4)	702	1.4	804	892	3.1	1,075	3.7	1,249

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

ANNEX 1c: *Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.1*

TABLE L1.2.1—PREVALENCE OF UNDERNOURISHMENT (% of population)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2015)	Annual avg. change (2008–2015)	2015
Africa	24.9	-2.1	22.7	20.8	-3.6	17.6	-2.1	16.6
Central	37.1	-4.0	31.5	29.2	-3.1	23.9	-2.6	22.5
Eastern	44.2	-2.2	40.1	36.8	-3.6	31.3	-2.2	29.4
Northern	6.2	-0.8	5.9	5.6	-1.7	5.1	-1.0	5.0
Southern	28.4	-2.1	26.3	24.8	-2.4	21.0	-2.6	19.5
Western	17.4	-2.8	15.4	13.3	-6.3	10.4	-2.0	9.9
Less favorable agriculture conditions	31.9	-4.8	25.8	24.1	-2.8	19.4	-3.5	17.4
More favorable agriculture conditions	41.3	-2.2	37.8	34.8	-3.5	29.3	-2.4	27.3
Mineral-rich countries	36.3	2.0	38.9	38.3	-1.0	34.6	-1.5	33.5
Middle-income countries	12.9	-3.0	11.3	9.9	-5.5	8.0	-1.7	7.7
CEN-SAD	16.1	-2.0	15.0	13.4	-4.9	11.1	-1.8	10.6
COMESA	33.6	-2.2	30.7	28.6	-2.9	24.7	-2.1	23.4
EAC	34.9	0.0	34.1	31.7	-3.1	28.4	-1.6	27.0
ECCAS	44.6	-4.1	36.7	32.6	-4.6	24.0	-4.3	21.3
ECOWAS	17.4	-2.8	15.4	13.3	-6.3	10.4	-2.0	9.9
IGAD	47.1	-3.3	40.8	36.9	-4.0	30.5	-2.8	28.1
SADC	30.4	-0.8	29.6	28.0	-2.5	24.7	-1.7	23.5
UMA	7.4	-1.2	6.8	6.3	-2.9	5.3	-2.0	5.0
CAADP Compact 2007–09 (CC1)	27.6	-4.3	22.9	20.4	-4.9	16.0	-2.9	14.8
CAADP Compact 2010–12 (CC2)	34.8	-0.2	34.4	32.1	-2.9	28.2	-1.9	26.8
CAADP Compact 2013–15 (CC3)	39.7	-2.6	35.5	31.9	-4.7	24.9	-2.9	23.0
CAADP Compact not yet (CC0)	6.4	-0.9	6.1	5.9	-1.1	5.6	-0.5	5.6
CAADP Level 0 (CL0)	6.4	-0.9	6.1	5.9	-1.1	5.6	-0.5	5.6
CAADP Level 1 (CL1)	41.0	-2.3	37.4	34.2	-3.9	28.0	-2.3	26.3
CAADP Level 2 (CL2)	31.2	-2.8	27.0	23.5	-6.2	16.5	-3.3	15.4
CAADP Level 3 (CL3)	28.5	-1.0	26.8	25.3	-1.6	22.8	-2.0	21.6
CAADP Level 4 (CL4)	31.0	-2.8	27.6	25.0	-4.4	20.5	-2.5	19.1

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

ANNEX 1d: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.2A

TABLE L1.2.2A—PREVALENCE OF UNDERWEIGHT, WEIGHT FOR AGE (% of children under 5)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	24.6	-1.1	23.3	22.4	-1.6	19.8	-2.0	18.4
Central	28.0	-0.6	26.6	26.0	-1.0	23.6	-1.2	22.6
Eastern	29.6	-1.6	27.2	26.0	-1.9	22.8	-2.2	21.2
Northern	8.6	-2.6	8.2	6.9	-4.8	5.4	-3.7	4.6
Southern	18.4	-2.2	16.9	15.4	-3.9	11.8	-4.1	10.0
Western	27.9	-1.3	26.7	26.0	-0.9	24.0	-1.4	22.9
Less favorable agriculture conditions	32.3	-1.0	31.3	31.1	-0.6	30.0	-0.1	29.9
More favorable agriculture conditions	27.5	-1.7	25.2	24.0	-2.2	20.4	-2.4	18.8
Mineral-rich countries	28.0	-0.7	26.3	25.3	-1.5	22.2	-1.7	21.0
Middle-income countries	20.5	-1.1	19.7	18.8	-1.6	16.6	-2.4	15.2
CEN-SAD	23.7	-0.8	23.0	22.4	-1.0	20.7	-1.5	19.6
COMESA	26.1	-1.0	24.6	23.5	-1.8	20.7	-2.0	19.3
EAC	21.1	-2.4	18.8	18.0	-2.0	15.3	-2.8	14.0
ECCAS	28.0	-1.7	25.6	24.3	-2.2	20.1	-2.7	18.3
ECOWAS	27.9	-1.3	26.7	26.0	-0.9	24.0	-1.4	22.9
IGAD	30.7	-1.5	28.4	27.1	-2.0	23.7	-2.1	22.1
SADC	23.7	-1.4	22.0	20.8	-2.1	17.6	-2.5	16.1
UMA	8.6	-1.2	8.3	6.7	-6.4	4.8	-5.4	3.9
CAADP Compact 2007–09 (CC1)	31.9	-1.8	29.7	28.4	-1.7	25.4	-2.0	23.6
CAADP Compact 2010–12 (CC2)	22.7	-1.4	20.9	20.2	-1.5	17.5	-1.9	16.4
CAADP Compact 2013–15 (CC3)	27.4	-0.9	26.0	24.8	-1.8	22.2	-1.9	20.7
CAADP Compact not yet (CC0)	10.2	-0.9	10.4	9.7	-2.4	8.7	-1.5	8.1
CAADP Level 0 (CL0)	10.2	-0.9	10.4	9.7	-2.4	8.7	-1.5	8.1
CAADP Level 1 (CL1)	29.0	-0.9	27.6	26.3	-1.9	23.4	-2.0	21.7
CAADP Level 2 (CL2)	27.1	-0.6	25.5	24.7	-1.3	21.9	-1.6	20.8
CAADP Level 3 (CL3)	26.3	-0.9	25.3	24.6	-0.9	23.4	-0.6	23.0
CAADP Level 4 (CL4)	28.1	-1.9	25.9	24.6	-1.9	21.3	-2.5	19.5

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

Notes: For regions or groups, level is weighted average, where weight is country's share in population under 5 years for the region or group.

ANNEX 1e: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.2B

TABLE L1.2.2B—PREVALENCE OF STUNTING, HEIGHT FOR AGE (% of children under 5)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	41.8	-1.0	40.2	39.2	-0.9	35.3	-1.6	33.7
Central	44.9	-0.9	43.9	43.4	-0.5	41.4	-0.6	40.6
Eastern	48.5	-1.3	45.7	44.2	-1.5	39.6	-1.6	37.6
Northern	25.5	-3.1	23.1	22.3	1.9	19.4	-3.4	17.3
Southern	43.0	-1.6	40.5	38.2	-2.7	32.3	-2.7	29.5
Western	40.4	-0.4	39.6	39.3	-0.3	36.0	-1.2	35.2
Less favorable agriculture conditions	44.6	0.1	44.4	44.8	-0.1	44.1	0.2	44.5
More favorable agriculture conditions	48.5	-1.3	45.7	44.1	-1.6	39.3	-1.7	37.3
Mineral-rich countries	46.7	-0.9	45.4	44.6	-0.7	42.1	-0.8	41.0
Middle-income countries	35.7	-1.1	34.3	33.4	-0.6	29.1	-2.4	27.1
CEN-SAD	37.5	-0.8	36.4	36.2	0.0	33.2	-1.5	32.0
COMESA	45.6	-1.3	43.3	42.3	-0.7	38.6	-1.7	36.6
EAC	44.4	-1.0	42.3	41.4	-1.2	38.0	-1.4	36.7
ECCAS	46.5	-1.5	44.0	42.4	-1.6	37.6	-1.8	35.3
ECOWAS	40.4	-0.4	39.6	39.3	-0.3	36.0	-1.2	35.2
IGAD	48.2	-1.4	45.0	43.3	-1.8	38.1	-2.0	35.7
SADC	45.7	-1.3	43.7	42.2	-1.6	38.0	-1.5	36.1
UMA	23.2	-1.8	21.3	19.1	-3.2	15.6	-3.1	14.1
CAADP Compact 2007–09 (CC1)	46.9	-1.0	44.9	43.6	-1.1	39.0	-1.7	37.2
CAADP Compact 2010–12 (CC2)	41.5	-1.0	39.9	39.2	-0.9	36.1	-1.2	34.9
CAADP Compact 2013–15 (CC3)	43.4	-1.2	41.0	39.3	-1.8	34.8	-1.9	32.6
CAADP Compact not yet (CC0)	27.4	-2.1	25.9	25.1	0.3	22.3	-2.4	20.5
CAADP Level 0 (CL0)	27.4	-2.1	25.9	25.1	0.3	22.3	-2.4	20.5
CAADP Level 1 (CL1)	44.7	-1.3	41.9	40.1	-1.9	35.1	-2.1	32.6
CAADP Level 2 (CL2)	43.8	-0.9	42.7	42.2	-0.6	39.9	-0.7	38.9
CAADP Level 3 (CL3)	45.0	-0.4	43.7	43.1	-0.6	41.5	-0.4	41.2
CAADP Level 4 (CL4)	45.6	-1.1	43.4	42.2	-1.2	37.2	-2.0	35.3

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

Note: For regions or groups, level is weighted average, where weight is country's share in population under 5 years for the region or group.

ANNEX 1f: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.2C

TABLE L1.2.2C—PREVALENCE OF WASTING, WEIGHT FOR HEIGHT (% of children under 5)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	10.6	-1.2	10.1	9.9	-0.04	9.1	-1.3	8.7
Central	12.4	0.8	11.5	11.2	-1.1	9.2	-2.1	8.7
Eastern	10.2	-1.1	9.7	9.5	-1.0	8.8	-1.2	8.6
Northern	5.9	0.1	6.4	6.3	1.6	7.0	1.7	7.4
Southern	6.5	-1.6	6.3	6.1	-2.3	5.6	-0.1	5.5
Western	14.2	-2.6	12.9	12.7	1.0	11.5	-2.2	10.6
Less favorable agriculture conditions	15.5	-2.6	14.4	13.7	-1.9	12.7	-1.5	11.9
More favorable agriculture conditions	9.1	-1.3	8.5	8.4	-1.5	7.4	-1.0	7.3
Mineral-rich countries	12.7	0.6	11.5	11.1	-1.4	8.7	-2.6	8.1
Middle-income countries	10.4	-1.3	10.0	10.0	1.7	9.6	-1.2	9.2
CEN-SAD	12.3	-1.6	11.6	11.5	0.8	10.7	-1.5	10.2
COMESA	9.9	-0.1	9.5	9.5	-0.1	8.9	-0.6	8.9
EAC	6.5	-2.3	5.8	5.8	0.1	5.3	-1.4	5.2
ECCAS	11.5	0.3	10.6	10.4	-1.0	8.7	-1.8	8.2
ECOWAS	14.2	-2.6	12.9	12.7	1.0	11.5	-2.2	10.6
IGAD	11.0	-1.0	10.5	10.4	-0.8	9.8	-1.0	9.7
SADC	9.0	-0.2	8.4	8.2	-1.6	7.0	-1.5	6.6
UMA	6.1	1.7	6.9	6.0	-4.7	5.4	0.2	5.5
CAADP Compact 2007–09 (CC1)	13.5	-2.6	12.2	12.1	0.8	11.0	-2.2	10.3
CAADP Compact 2010–12 (CC2)	9.3	-0.8	8.5	8.3	-1.0	7.0	-1.7	6.7
CAADP Compact 2013–15 (CC3)	11.1	-0.2	11.1	11.0	-0.9	10.5	-0.5	10.4
CAADP Compact not yet (CC0)	6.6	0.3	7.2	6.9	0.1	7.4	1.2	7.7
CAADP Level 0 (CL0)	6.6	0.3	7.2	6.9	0.1	7.4	1.2	7.7
CAADP Level 1 (CL1)	11.9	-0.2	11.9	11.7	-1.0	11.2	-0.5	11.0
CAADP Level 2 (CL2)	12.7	0.6	11.5	11.1	-1.5	8.7	-2.6	8.1
CAADP Level 3 (CL3)	10.3	-1.8	10.0	9.8	-0.8	9.5	-0.2	9.4
CAADP Level 4 (CL4)	11.5	-2.5	10.3	10.3	0.7	9.1	-2.3	8.5

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

Note: For regions or groups, level is weighted average, where weight is country's share in population under 5 years for the region or group.

ANNEX 1g: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.2.3

TABLE L1.2.3—CEREAL IMPORT DEPENDENCY RATIO (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2000–2010)	Annual avg. change (2008–2010)	2010
Africa	27.9	2.9	29.9	30.8	1.3	31.8	0.4	31.8
Central	72.0	0.1	72.5	72.8	0.1	73.5	1.0	73.7
Eastern	14.6	5.0	16.5	17.5	2.3	20.1	2.3	20.5
Northern	48.2	0.7	44.7	46.7	3.9	50.7	0.0	50.7
Southern	18.6	8.8	25.4	26.6	0.1	23.3	-9.9	22.1
Western	16.2	7.3	20.4	20.5	-0.4	20.5	4.7	20.8
Less favorable agriculture conditions	20.7	1.1	22.5	24.9	2.4	25.5	-1.2	25.3
More favorable agriculture conditions	12.2	6.5	15.1	15.7	1.8	17.3	-0.3	17.2
Mineral-rich countries	67.2	0.0	65.4	62.8	-1.3	61.7	1.1	62.0
Middle-income countries	30.6	3.6	32.9	34.4	2.1	35.6	0.7	35.6
CEN-SAD	23.9	3.5	25.4	26.9	3.1	29.5	2.4	29.7
COMESA	30.1	1.7	31.2	31.6	1.2	34.7	2.6	35.2
EAC	13.9	2.3	14.4	17.0	5.1	19.6	2.0	19.6
ECCAS	65.8	-0.2	66.1	67.0	0.4	67.0	0.1	66.9
ECOWAS	16.2	7.3	20.4	20.5	-0.4	20.5	4.7	20.8
IGAD	15.1	6.4	17.6	18.7	3.0	22.4	1.3	22.7
SADC	33.0	3.2	36.8	37.4	0.0	36.0	-1.7	35.6
UMA	60.8	2.3	57.8	59.0	2.7	59.6	-4.4	58.3
CAADP Compact 2007–09 (CC1)	12.8	8.7	16.6	16.1	-0.8	17.1	5.8	17.5
CAADP Compact 2010–12 (CC2)	33.4	1.1	34.5	35.3	0.3	35.7	1.1	35.7
CAADP Compact 2013–15 (CC3)	31.7	4.6	38.1	40.6	1.9	42.8	-1.3	42.8
CAADP Compact not yet (CC0)	38.4	1.9	37.5	40.1	4.2	42.2	-2.0	41.7
CAADP Level 0 (CL0)	38.4	1.9	37.5	40.1	4.2	42.2	-2.0	41.7
CAADP Level 1 (CL1)	22.6	8.6	29.5	31.9	2.5	34.3	-2.1	34.3
CAADP Level 2 (CL2)	78.4	0.1	78.5	78.2	0.0	79.1	1.1	79.3
CAADP Level 3 (CL3)	14.4	2.6	16.2	15.4	-6.0	11.2	-7.6	10.7
CAADP Level 4 (CL4)	14.6	6.5	17.9	18.2	0.5	19.6	5.1	20.0

Source: ReSAKSS based on FAO (2017), World Bank (2017), and ILO (2017).

Note: Data are from 1995 to 2010. For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 1h: Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.1A

TABLE L1.3.1A—EMPLOYMENT RATE (% of labor force, 15–64 years)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	90.8	-0.03	91.0	91.5	0.21	91.9	0.04	92.1
Central	95.2	-0.01	95.3	95.5	0.13	95.6	0.00	95.6
Eastern	93.8	-0.07	93.8	94.1	0.04	94.3	0.05	94.4
Northern	84.8	0.38	86.2	88.1	0.89	88.6	-0.34	87.9
Southern	82.6	-0.35	82.4	83.2	0.47	83.7	-0.05	83.6
Western	93.6	-0.03	93.5	93.4	-0.12	93.8	0.21	94.6
Less favorable agriculture conditions	95.2	0.04	95.4	94.9	-0.22	95.0	0.02	95.0
More favorable agriculture conditions	93.1	-0.06	93.1	93.3	0.02	93.5	0.05	93.6
Mineral-rich countries	94.3	0.03	94.2	94.4	0.22	95.1	0.04	95.3
Middle-income countries	87.6	-0.05	87.9	88.8	0.41	89.4	0.01	89.7
CEN-SAD	91.4	0.08	91.5	91.5	0.04	91.6	0.05	92.0
COMESA	92.9	-0.05	92.8	93.0	0.14	93.1	-0.03	93.2
EAC	95.3	-0.03	95.3	95.4	0.06	95.1	0.02	95.4
ECCAS	95.2	-0.01	95.3	95.4	0.10	95.5	-0.01	95.5
ECOWAS	93.6	-0.03	93.5	93.4	-0.12	93.8	0.21	94.6
IGAD	92.5	-0.03	92.6	92.9	0.05	93.0	0.04	93.1
SADC	89.2	-0.23	89.0	89.6	0.26	90.2	0.03	90.2
UMA	80.2	0.76	83.5	86.5	1.19	88.6	-0.09	88.3
CAADP Compact 2007–09 (CC1)	94.0	-0.06	94.1	94.1	-0.05	94.5	0.15	95.1
CAADP Compact 2010–12 (CC2)	92.5	0.01	92.5	92.6	0.08	92.7	0.04	92.9
CAADP Compact 2013–15 (CC3)	91.6	-0.03	92.0	92.2	0.04	93.0	0.13	93.1
CAADP Compact not yet (CC0)	82.9	-0.07	83.4	85.3	0.91	85.6	-0.33	84.9
CAADP Level 0 (CL0)	82.9	-0.07	83.4	85.3	0.91	85.6	-0.33	84.9
CAADP Level 1 (CL1)	91.2	-0.04	91.4	91.4	-0.10	92.2	0.19	92.5
CAADP Level 2 (CL2)	94.9	-0.01	95.1	95.4	0.11	95.4	-0.02	95.4
CAADP Level 3 (CL3)	94.4	0.05	94.2	94.2	0.14	95.3	0.10	95.5
CAADP Level 4 (CL4)	92.7	-0.05	92.8	92.9	0.00	93.0	0.11	93.5

Source: ReSAKSS based on ILO (2017).

Note: For regions or groups, level is weighted average, where weight is country's share in total labor force for the region or group.

ANNEX 1i: *Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.1B*

TABLE L1.3.1B—EMPLOYMENT RATE (% of population, 15+ years)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	58.5	-0.1	58.5	59.0	0.3	59.8	0.2	60.3
Central	69.2	0.1	69.5	69.7	0.1	69.9	0.0	69.8
Eastern	71.3	-0.1	71.4	71.5	0.0	71.1	-0.1	70.9
Northern	39.9	0.0	40.2	41.5	1.1	42.3	-0.1	42.4
Southern	56.2	0.0	56.5	56.8	0.3	56.0	-0.1	56.1
Western	57.7	-0.2	57.1	57.1	0.1	59.0	0.6	60.1
Less favorable agriculture conditions	63.5	0.1	63.8	64.3	0.4	66.3	0.2	66.5
More favorable agriculture conditions	75.1	0.1	75.8	76.1	0.0	75.2	-0.2	74.7
Mineral-rich countries	68.2	0.1	68.2	68.1	0.0	68.6	0.2	69.1
Middle-income countries	48.1	-0.3	47.5	48.1	0.5	49.0	0.3	49.7
CEN-SAD	52.6	-0.2	52.0	52.2	0.3	53.5	0.4	54.3
COMESA	62.9	0.0	63.1	63.6	0.3	64.5	0.1	64.8
EAC	76.9	-0.4	75.7	75.3	0.0	74.2	-0.3	73.9
ECCAS	69.8	0.0	69.9	69.9	0.0	69.9	0.0	69.9
ECOWAS	57.7	-0.2	57.1	57.1	0.1	59.0	0.6	60.1
IGAD	66.6	-0.1	66.7	66.8	0.1	67.5	0.2	67.9
SADC	65.4	0.0	65.6	65.9	0.1	64.7	-0.3	64.3
UMA	38.7	0.2	39.4	40.7	0.9	41.4	0.0	41.5
CAADP Compact 2007–09 (CC1)	62.3	0.0	62.3	62.7	0.2	64.1	0.4	64.9
CAADP Compact 2010–12 (CC2)	70.1	-0.1	69.7	69.5	-0.1	69.0	-0.1	69.0
CAADP Compact 2013–15 (CC3)	62.1	0.2	63.2	63.4	-0.1	63.6	0.1	63.7
CAADP Compact not yet (CC0)	41.6	-0.3	41.3	42.5	1.1	42.8	-0.2	42.8
CAADP Level 0 (CL0)	41.6	-0.3	41.3	42.5	1.1	42.8	-0.2	42.8
CAADP Level 1 (CL1)	61.3	0.1	62.1	61.9	-0.3	61.7	0.1	61.9
CAADP Level 2 (CL2)	67.0	0.2	67.6	68.0	0.2	68.8	0.2	69.2
CAADP Level 3 (CL3)	68.1	0.1	68.0	68.4	0.5	71.4	0.4	72.2
CAADP Level 4 (CL4)	65.3	-0.2	65.1	65.1	0.0	65.1	0.1	65.4

Source: ReSAKSS based on World Bank (2017) and ILO (2017).
Note: For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 1j: *Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.3*

TABLE L1.3.3—POVERTY GAP AT $1.90 A DAY (2011 PPP) (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	25.0	-2.8	22.1	20.9	-2.2	17.1	-3.4	15.1
Central	55.2	-3.8	46.9	41.9	-4.6	28.9	-6.9	21.7
Eastern	20.9	-2.3	18.0	17.0	-2.2	14.2	-3.2	12.7
Northern	1.6	-5.5	1.2	0.9	-9.4	0.4	-16.7	0.2
Southern	20.5	-1.9	18.9	18.0	-2.9	15.3	-2.4	13.9
Western	23.5	-2.8	21.4	20.9	-0.5	18.4	-1.9	17.2
Less favorable agriculture conditions	32.0	-3.7	27.2	24.9	-4.6	16.9	-5.8	14.1
More favorable agriculture conditions	23.6	-2.4	20.7	19.4	-2.1	16.3	-3.2	14.5
Mineral-rich countries	60.7	-3.7	51.6	46.7	-4.4	32.1	-7.1	24.0
Middle-income countries	15.9	-2.2	14.8	14.7	0.0	13.8	-0.8	13.3
CEN-SAD	19.5	-2.5	17.9	17.6	-0.3	15.7	-1.8	14.8
COMESA	32.5	-2.9	28.5	26.7	-2.7	21.4	-4.0	18.3
EAC	23.4	-1.3	21.0	19.4	-3.3	15.8	-3.3	14.0
ECCAS	47.3	-3.8	40.2	36.2	-4.4	25.3	-6.5	19.5
ECOWAS	23.5	-2.8	21.4	20.9	-0.5	18.4	-1.9	17.2
IGAD	16.4	-3.7	13.4	12.5	-2.4	9.4	-5.6	7.5
SADC	36.3	-2.5	32.1	29.7	-3.5	23.2	-4.2	19.7
UMA	1.6	-5.5	1.2	0.9	-9.4	0.4	-16.7	0.2
CAADP Compact 2007–09 (CC1)	22.6	-3.0	20.1	19.7	-0.3	17.6	-1.8	16.6
CAADP Compact 2010–12 (CC2)	34.6	-3.1	30.0	27.2	-3.9	19.9	-5.6	16.0
CAADP Compact 2013–15 (CC3)	21.2	-1.7	20.0	19.1	-1.7	16.9	-2.3	15.5
CAADP Compact not yet (CC0)	6.5	-4.5	5.2	4.5	-8.6	2.7	-6.9	2.0
CAADP Level 0 (CL0)	6.5	-4.5	5.2	4.5	-8.6	2.7	-6.9	2.0
CAADP Level 1 (CL1)	24.8	-1.4	23.3	22.2	-1.7	19.7	-2.3	18.1
CAADP Level 2 (CL2)	55.0	-4.0	46.4	41.5	-4.7	27.8	-7.5	20.3
CAADP Level 3 (CL3)	28.8	-3.3	25.1	23.0	-4.6	15.7	-6.6	12.3
CAADP Level 4 (CL4)	22.1	-2.4	19.9	19.4	-0.5	17.6	-1.6	16.6

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

Note: For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 1k: *Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.4*

TABLE L1.3.4—POVERTY HEADCOUNT RATIO AT $1.90/ DAY (2011 PPP, % of population)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	49.5	-1.4	46.7	45.6	-0.9	42.2	-1.1	40.6
Central	59.0	-3.1	53.1	49.6	-2.7	40.0	-3.7	34.5
Eastern	53.8	-1.5	49.2	47.5	-1.3	42.7	-1.7	40.2
Northern	6.0	-5.6	4.6	3.8	-7.5	2.1	-11.3	1.3
Southern	45.8	-1.0	43.9	42.6	-1.7	39.3	-0.9	37.9
Western	53.8	-1.2	51.7	51.4	-0.1	49.2	-0.5	48.3
Less favorable agriculture conditions	72.8	-2.3	66.3	63.1	-2.4	51.4	-3.2	46.2
More favorable agriculture conditions	57.6	-1.5	53.2	51.3	-1.2	46.4	-1.6	43.8
Mineral-rich countries	59.1	-0.7	57.5	57.3	-0.2	53.3	-1.0	51.6
Middle-income countries	39.0	-1.3	37.4	37.1	-0.3	36.1	-0.1	35.7
CEN-SAD	45.7	-1.0	44.3	44.2	0.1	42.8	-0.4	42.3
COMESA	52.3	-1.1	49.4	48.6	-0.5	45.7	-1.0	44.2
EAC	55.3	-0.6	52.6	50.5	-1.6	46.0	-1.3	44.0
ECCAS	52.9	-2.2	48.9	46.5	-2.0	39.8	-2.5	36.2
ECOWAS	53.8	-1.2	51.7	51.4	-0.1	49.2	-0.5	48.3
IGAD	47.2	-2.2	42.0	40.3	-1.3	35.1	-2.3	32.2
SADC	52.9	-0.9	50.5	49.0	-1.5	45.5	-1.0	43.9
UMA	6.0	-5.6	4.6	3.8	-7.5	2.1	-11.3	1.3
CAADP Compact 2007–09 (CC1)	55.3	-1.7	51.6	51.0	-0.3	47.8	-0.8	46.4
CAADP Compact 2010–12 (CC2)	52.8	-1.1	50.0	48.1	-1.4	43.6	-1.5	41.3
CAADP Compact 2013–15 (CC3)	50.1	-1.6	47.9	46.3	-1.4	41.8	-1.7	39.2
CAADP Compact not yet (CC0)	19.4	-3.5	16.3	14.5	-6.2	10.2	-4.9	8.2
CAADP Level 0 (CL0)	19.4	-3.5	16.3	14.5	-6.2	10.2	-4.9	8.2
CAADP Level 1 (CL1)	54.7	-1.0	52.7	51.2	-1.2	47.1	-1.5	44.7
CAADP Level 2 (CL2)	49.5	-3.1	45.0	42.5	-1.8	34.2	-3.4	30.0
CAADP Level 3 (CL3)	64.3	-1.5	60.4	57.6	-2.0	48.7	-2.6	44.6
CAADP Level 4 (CL4)	53.3	-1.3	50.2	49.6	-0.4	47.3	-0.6	46.3

Source: ReSAKSS based on World Bank (2017) and ILO (2017).
Note: For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 1l: *Level 1—Agriculture's Contribution to Economic Growth and Inclusive Development, Indicator 1.3.5*

TABLE L1.3.5—GINI INDEX

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	43.8	-0.62	43.0	43.1	0.20	42.6	-0.21	42.3
Central	42.2	-0.04	42.2	42.4	0.24	42.8	0.08	42.9
Eastern	39.5	-0.45	38.9	39.1	0.29	39.0	-0.07	39.0
Northern	40.0	-0.05	39.9	39.7	-0.15	39.4	-0.11	39.2
Southern	55.5	-0.58	54.1	53.9	-0.43	51.7	-0.73	50.4
Western	43.1	-0.99	41.9	42.1	0.60	41.8	-0.12	41.6
Less favorable agriculture conditions	40.5	-0.32	40.0	40.0	-0.53	38.3	-0.36	38.1
More favorable agriculture conditions	41.0	-0.62	40.0	39.9	0.09	39.4	-0.32	39.0
Mineral-rich countries	44.1	-0.48	43.3	43.5	-0.15	42.4	-0.43	41.9
Middle-income countries	46.5	-0.63	45.7	46.0	0.53	46.1	0.00	46.0
CEN-SAD	43.1	-0.77	42.2	42.4	0.42	41.9	-0.16	41.7
COMESA	41.9	-0.68	40.7	40.7	-0.03	40.1	-0.38	39.6
EAC	42.2	0.30	42.5	42.6	0.08	42.4	0.01	42.5
ECCAS	44.0	-0.28	43.5	43.4	-0.12	42.8	-0.27	42.4
ECOWAS	43.1	-0.99	41.9	42.1	0.60	41.8	-0.12	41.6
IGAD	39.6	-0.98	38.4	38.3	0.10	37.8	-0.35	37.4
SADC	48.3	-0.30	47.6	47.5	-0.19	46.3	-0.39	45.7
UMA	40.0	-0.05	39.9	39.7	-0.15	39.4	-0.11	39.2
CAADP Compact 2007–09 (CC1)	40.7	-1.18	39.4	39.9	0.84	40.2	0.07	40.3
CAADP Compact 2010–12 (CC2)	41.9	-0.33	41.1	40.8	-0.17	39.7	-0.50	39.1
CAADP Compact 2013–15 (CC3)	45.2	-0.45	44.3	43.5	-0.56	42.2	-0.57	41.2
CAADP Compact not yet (CC0)	51.4	0.20	52.1	52.7	0.34	53.4	0.31	54.0
CAADP Level 0 (CL0)	51.4	0.20	52.1	52.7	0.34	53.4	0.31	54.0
CAADP Level 1 (CL1)	46.1	-0.62	44.6	43.6	-0.76	41.5	-0.89	40.1
CAADP Level 2 (CL2)	42.9	-0.27	42.6	42.4	0.00	42.0	-0.20	41.8
CAADP Level 3 (CL3)	42.5	-0.38	41.8	41.7	-0.62	39.9	-0.60	39.2
CAADP Level 4 (CL4)	42.2	-0.93	40.9	41.3	0.61	41.2	-0.09	41.1

Source: ReSAKSS based on World Bank (2017) and ILO (2017).

Note: For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 2a: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.1

TABLE L2.1.1—AGRICULTURE VALUE ADDED (billion, constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	7.2	4.8	9.0	9.8	4.2	13.2	4.7	15.5
Central	2.6	-3.1	2.3	2.4	1.2	3.1	3.5	3.6
Eastern	8.8	3.6	9.5	9.7	2.0	12.5	5.6	14.9
Northern	6.5	2.6	7.4	7.3	-1.3	10.0	6.6	12.6
Southern	3.8	1.2	4.0	4.2	4.8	5.4	3.2	6.3
Western	12.6	8.2	19.0	22.1	6.0	30.0	4.3	34.3
Less favorable agriculture conditions	1.5	4.8	1.8	2.0	2.7	2.6	4.4	3.0
More favorable agriculture conditions	3.4	0.3	3.5	4.2	7.1	6.8	6.8	8.3
Mineral-rich countries	2.7	-6.2	2.1	2.2	2.9	2.8	3.1	3.1
Middle-income countries	10.9	5.9	14.1	15.5	4.2	21.2	5.0	25.0
CEN-SAD	10.1	6.7	13.4	14.8	4.2	20.2	5.1	23.7
COMESA	8.0	3.0	8.4	8.5	1.8	10.5	5.1	12.6
EAC	5.5	0.3	5.7	6.2	3.4	9.9	7.9	12.6
ECCAS	2.6	-0.3	2.7	3.1	5.5	5.3	8.2	7.1
ECOWAS	12.6	8.2	19.0	22.1	6.0	30.0	4.3	34.3
IGAD	10.7	4.2	11.6	11.7	1.7	15.8	6.7	19.5
SADC	3.8	-0.1	3.9	4.2	4.7	5.6	3.8	6.5
UMA	6.1	2.4	6.9	6.8	-1.7	9.5	7.1	12.1
CAADP Compact 2007–09 (CC1)	13.9	7.8	20.8	24.4	6.6	33.8	4.3	38.6
CAADP Compact 2010–12 (CC2)	2.9	-0.8	2.9	3.2	3.4	4.8	7.1	6.1
CAADP Compact 2013–15 (CC3)	6.8	5.0	7.5	7.6	1.1	8.8	4.4	10.5
CAADP Compact not yet (CC0)	6.7	1.5	7.3	7.2	1.1	8.7	2.9	9.8
CAADP Level 0 (CL0)	6.7	1.5	7.3	7.2	1.1	8.7	2.9	9.8
CAADP Level 1 (CL1)	6.8	5.0	7.6	7.7	1.1	8.9	4.5	10.6
CAADP Level 2 (CL2)	2.3	-5.4	1.9	2.0	3.0	2.5	4.1	3.0
CAADP Level 3 (CL3)	1.8	2.8	1.9	2.2	5.3	3.1	4.7	3.5
CAADP Level 4 (CL4)	12.2	7.2	17.7	20.8	6.5	29.0	4.6	33.5

Source: ReSAKSS based on FAO (2017), World Bank (2016), and ILO (2017).

Note: For regions or groups, level is weighted average per country, where weight is country's share in total agricultural land area for the region or group.

ANNEX 2b: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.2*

TABLE L2.1.2—AGRICULTURAL PRODUCTION INDEX (API) (2004–2006 = 100)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (2008–2014)	2014
Africa	80.9	2.9	91.5	100.6	3.2	119.6	3.3	129.7
Central	92.1	0.0	92.9	101.8	3.7	124.4	3.2	131.7
Eastern	77.5	4.0	91.8	100.8	3.4	125.5	5.2	141.9
Northern	78.9	3.1	91.1	100.7	2.9	122.4	3.5	133.1
Southern	86.6	2.7	94.2	103.2	4.2	140.2	3.7	152.9
Western	79.6	3.4	90.7	99.6	3.0	110.6	2.5	118.0
Less favorable agriculture conditions	81.6	4.1	94.2	104.2	4.3	134.0	3.5	143.3
More favorable agriculture conditions	80.7	3.1	91.5	101.4	4.2	128.3	4.0	140.6
Mineral-rich countries	93.2	-0.6	93.6	100.9	2.6	125.8	3.4	132.7
Middle-income countries	79.7	3.3	91.2	100.2	2.9	115.9	3.0	125.3
CEN-SAD	79.7	3.5	91.4	100.4	3.0	112.9	2.3	119.7
COMESA	82.9	2.7	92.6	101.8	3.5	120.2	2.7	127.8
EAC	77.7	3.5	91.3	100.5	4.2	123.8	4.1	137.2
ECCAS	87.0	0.9	92.0	102.7	4.6	139.6	4.4	154.2
ECOWAS	79.6	3.4	90.7	99.6	3.0	110.6	2.5	118.0
IGAD	77.1	4.5	92.0	100.9	2.9	121.1	4.1	133.9
SADC	88.0	1.4	93.6	102.1	4.0	135.3	4.5	150.2
UMA	77.1	2.9	90.4	98.4	1.0	127.5	5.7	143.9
CAADP Compact 2007–09 (CC1)	77.7	3.7	90.4	99.8	3.3	113.5	3.0	122.2
CAADP Compact 2010–12 (CC2)	81.8	1.7	88.1	96.2	3.7	117.4	3.4	127.5
CAADP Compact 2013–15 (CC3)	81.3	3.6	92.3	101.7	3.1	135.3	6.6	158.9
CAADP Compact not yet (CC0)	80.7	2.9	92.0	101.0	3.0	121.8	3.1	131.5
CAADP Level 0 (CL0)	80.7	2.9	92.0	101.0	3.0	121.8	3.1	131.5
CAADP Level 1 (CL1)	82.2	3.7	93.5	101.3	2.4	133.5	6.8	158.9
CAADP Level 2 (CL2)	91.9	-0.2	92.3	101.8	4.0	123.5	2.9	130.6
CAADP Level 3 (CL3)	80.8	3.8	93.9	103.0	3.6	126.8	2.1	131.9
CAADP Level 4 (CL4)	78.4	3.5	90.3	99.8	3.5	115.5	3.3	125.3

Source: ReSAKSS based on FAO (2017) and World Bank (2017).

Note: Data are from 1995 to 2014. For regions or groups, level is weighted average, where weight is country's share in total agriculture value added for the region or group.

ANNEX 2c: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.3*

TABLE L2.1.3—LABOR PRODUCTIVITY (agriculture value-added per agricultural worker, constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	1,010.9	1.4	1,100.4	1,138.9	1.7	1,366.1	2.7	1,500.3
Central	636.0	-4.3	534.2	531.0	0.4	608.1	2.0	670.6
Eastern	545.3	-0.9	515.7	525.0	1.4	686.2	5.1	798.2
Northern	3,137.8	2.3	3,410.4	3,444.1	0.2	4,362.1	4.1	5,116.7
Southern	821.8	0.1	824.8	840.1	2.6	955.3	1.2	1,024.6
Western	1,415.6	5.3	1,874.2	2,055.5	3.7	2,495.4	2.1	2,667.0
Less favorable agriculture conditions	554.4	0.6	575.6	581.7	-0.3	635.7	2.0	693.0
More favorable agriculture conditions	392.3	-2.1	363.6	389.7	3.3	504.3	3.5	559.8
Mineral-rich countries	503.4	-4.7	407.9	412.3	1.7	444.1	-0.2	439.5
Middle-income countries	2,290.8	3.8	2,744.4	2,892.0	2.4	3,696.8	3.9	4,231.2
CEN-SAD	1,560.8	3.7	1,852.0	1,948.8	2.2	2,384.8	3.0	2,637.0
COMESA	744.7	-0.8	696.3	695.6	0.7	822.8	3.0	908.8
EAC	460.5	-2.2	431.2	442.7	0.7	585.9	5.1	686.4
ECCAS	604.9	-3.5	536.8	555.3	1.8	725.1	4.3	862.5
ECOWAS	1,415.6	5.3	1,874.2	2,055.5	3.7	2,495.4	2.1	2,667.0
IGAD	606.1	-0.6	563.6	570.2	1.5	768.7	5.9	916.8
SADC	617.1	-2.5	571.6	581.4	2.1	677.2	1.7	726.1
UMA	3,048.4	1.2	3,294.3	3,248.4	-1.6	4,312.6	6.3	5,379.8
CAADP Compact 2007–09 (CC1)	994.7	4.0	1,273.3	1,410.3	4.2	1,730.5	2.1	1,843.5
CAADP Compact 2010–12 (CC2)	508.9	-2.0	471.5	474.9	0.5	571.3	2.8	629.2
CAADP Compact 2013–15 (CC3)	1,057.8	1.6	1,068.3	1,046.0	-0.2	1,325.0	6.1	1,632.0
CAADP Compact not yet (CC0)	3,400.2	2.1	3,683.5	3,731.7	1.0	4,669.9	3.5	5,382.8
CAADP Level 0 (CL0)	3,400.2	2.1	3,683.5	3,731.7	1.0	4,669.9	3.5	5,382.8
CAADP Level 1 (CL1)	1,073.6	1.7	1,080.1	1,043.5	-0.8	1,313.4	6.5	1,630.5
CAADP Level 2 (CL2)	595.6	-4.7	489.5	500.2	2.1	566.6	1.1	599.2
CAADP Level 3 (CL3)	505.6	-0.1	489.8	512.7	2.1	589.5	1.8	613.4
CAADP Level 4 (CL4)	810.3	3.0	986.2	1,071.9	3.4	1,328.2	2.5	1,435.4

Source: ReSAKSS based on World Bank (2017) and FAO (2017).

ANNEX 2d: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.4*

TABLE L2.1.4—LAND PRODUCTIVITY (agriculture value-added per hectare of arable land, constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	164.6	3.1	190.6	205.4	3.4	292.4	5.3	346.9
Central	128.8	-2.9	116.1	121.1	2.3	153.4	3.3	176.9
Eastern	138.1	1.3	142.3	152.3	3.5	286.6	10.7	380.8
Northern	346.0	2.9	384.4	391.9	0.5	494.9	3.8	573.4
Southern	61.4	1.6	65.3	69.4	4.4	90.1	3.5	104.4
Western	258.2	6.0	350.7	390.1	4.5	523.9	3.9	593.3
Less favorable agriculture conditions	47.1	3.5	54.5	57.9	1.8	74.3	4.5	87.7
More favorable agriculture conditions	141.4	-0.4	140.9	158.5	5.2	233.7	5.8	279.1
Mineral-rich countries	137.9	-3.5	117.7	123.8	3.4	147.7	1.4	154.9
Middle-income countries	211.3	4.6	259.8	279.0	3.2	414.7	6.0	499.8
CEN-SAD	216.8	4.8	267.3	287.9	3.2	426.8	5.9	509.7
COMESA	203.9	1.0	204.7	214.1	2.6	348.4	7.9	436.4
EAC	227.5	0.0	231.6	248.8	2.5	367.5	6.9	456.1
ECCAS	105.1	-1.3	102.4	112.0	4.0	165.4	6.0	207.6
ECOWAS	258.2	6.0	350.7	390.1	4.5	523.9	3.9	593.3
IGAD	145.2	1.9	147.7	157.2	3.7	341.0	13.3	478.3
SADC	79.2	-1.1	78.2	83.6	4.0	111.3	3.9	128.5
UMA	187.8	2.1	208.9	209.0	-1.2	281.2	6.4	350.2
CAADP Compact 2007–09 (CC1)	272.9	5.7	369.7	420.5	5.6	586.3	4.1	665.3
CAADP Compact 2010–12 (CC2)	134.3	-0.3	133.3	140.2	2.2	190.8	5.0	225.7
CAADP Compact 2013–15 (CC3)	85.9	3.1	91.8	94.0	1.7	160.5	10.4	219.0
CAADP Compact not yet (CC0)	209.6	2.5	230.2	234.5	1.1	289.3	3.0	327.4
CAADP Level 0 (CL0)	209.6	2.5	230.2	234.5	1.1	289.3	3.0	327.4
CAADP Level 1 (CL1)	78.0	3.2	83.3	84.7	1.2	146.2	11.0	202.3
CAADP Level 2 (CL2)	124.3	-3.4	108.6	115.5	3.7	143.6	2.5	159.2
CAADP Level 3 (CL3)	92.4	1.2	94.9	103.2	3.8	136.5	4.2	153.9
CAADP Level 4 (CL4)	269.6	4.9	349.7	393.6	4.9	551.4	4.5	636.4

Source: ReSAKSS based on World Bank (2017) and FAO (2017).

ANNEX 2e: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5A*

TABLE L2.1.5A—YIELD, CASSAVA (metric tons per hectare)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (2008–2014)	2014
Africa	8.5	0.9	8.8	9.2	1.8	9.1	-2.9	8.3
Central	7.8	-0.2	7.6	7.8	1.3	8.1	0.4	8.3
Eastern	8.0	0.1	7.7	7.6	1.9	6.6	-2.4	6.3
Northern								
Southern	6.4	8.4	8.1	8.5	3.0	10.0	0.7	10.2
Western	9.9	-0.5	10.1	10.6	1.3	10.1	-5.6	8.3
Less favorable agriculture conditions	7.0	6.9	8.2	7.8	-0.7	9.1	3.7	10.2
More favorable agriculture conditions	7.4	2.6	7.6	7.7	1.0	7.3	-0.7	7.0
Mineral-rich countries	7.5	-0.3	7.4	7.4	-0.4	7.6	1.2	7.8
Middle-income countries	9.7	0.2	10.2	10.9	2.7	10.7	-6.3	8.8
CEN-SAD	9.6	-0.3	9.8	10.3	1.2	9.8	-5.3	8.2
COMESA	8.1	2.4	8.6	8.7	0.0	8.2	-1.1	8.1
EAC	8.4	0.2	8.1	7.8	0.6	6.4	-2.4	6.2
ECCAS	7.6	1.9	8.3	8.7	2.7	9.5	-0.8	9.6
ECOWAS	9.9	-0.5	10.1	10.6	1.3	10.1	-5.6	8.3
IGAD	10.2	9.1	12.6	11.9	-7.3	5.7	-12.1	4.2
SADC	7.3	1.3	7.5	7.8	2.8	8.5	0.4	8.6
UMA								
CAADP Compact 2007–09 (CC1)	10.2	-0.7	10.4	11.0	1.6	10.5	-5.4	8.8
CAADP Compact 2010–12 (CC2)	7.2	1.3	7.3	7.2	-0.2	6.8	-1.2	6.5
CAADP Compact 2013–15 (CC3)	7.3	4.3	8.5	9.7	6.6	11.2	-2.3	11.0
CAADP Compact not yet (CC0)	7.1	0.7	7.3	7.3	-0.2	7.5	1.2	7.7
CAADP Level 0 (CL0)	7.1	0.7	7.3	7.3	-0.2	7.5	1.2	7.7
CAADP Level 1 (CL1)	6.9	6.5	8.8	9.6	4.7	10.7	-3.4	10.2
CAADP Level 2 (CL2)	7.8	-0.5	7.6	7.9	1.7	8.3	0.3	8.4
CAADP Level 3 (CL3)	8.3	5.6	9.3	8.6	-5.3	6.2	-3.3	5.8
CAADP Level 4 (CL4)	9.0	0.0	9.2	9.7	2.3	9.6	-3.6	8.5

Source: ReSAKSS based on FAO (2017).
Note: Data are from 1995 to 2014.

ANNEX 2f: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5B*

TABLE L2.1.5B—YIELD, YAMS (metric tons per hectare)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (2008–2014)	2014
Africa	10.0	-0.5	10.2	10.6	0.3	9.3	-5.2	8.4
Central	7.4	0.0	7.2	7.7	3.3	8.3	-0.3	8.2
Eastern	4.4	0.2	4.3	4.2	0.8	7.6	22.5	11.9
Northern	6.3	-0.1	6.3	6.3	0.0	6.3	-0.1	6.2
Southern								
Western	10.3	-0.6	10.5	10.8	0.2	9.4	-5.8	8.3
Less favorable agriculture conditions	8.7	1.6	9.1	9.6	2.2	10.3	1.6	10.6
More favorable agriculture conditions	10.2	1.8	11.1	11.3	0.4	13.0	4.2	14.7
Mineral-rich countries	7.0	-1.7	6.4	6.5	1.1	7.3	1.3	7.5
Middle-income countries	10.1	-0.7	10.3	10.6	0.3	9.2	-6.0	8.0
CEN-SAD	10.1	-0.6	10.3	10.7	0.2	9.3	-5.6	8.2
COMESA	4.6	-0.9	4.4	4.2	0.6	7.1	20.1	10.8
EAC	5.3	0.1	5.4	5.5	-1.1	7.9	14.8	11.5
ECCAS	7.4	0.0	7.2	7.7	3.2	8.3	0.0	8.3
ECOWAS	10.3	-0.6	10.5	10.8	0.2	9.4	-5.8	8.3
IGAD	4.4	0.2	4.3	4.2	0.7	7.6	23.0	12.0
SADC	5.8	-6.0	4.5	4.5	0.1	4.5	-0.1	4.5
UMA	6.3	-0.1	6.3	6.3	0.0	6.3	-0.1	6.2
CAADP Compact 2007–09 (CC1)	10.4	-0.5	10.8	11.3	0.8	10.0	-6.2	8.7
CAADP Compact 2010–12 (CC2)	8.8	-1.2	8.4	8.1	-2.3	6.7	-1.5	6.5
CAADP Compact 2013–15 (CC3)	5.8	0.9	5.9	6.4	4.0	6.8	-1.5	6.5
CAADP Compact not yet (CC0)	5.3	0.2	5.3	5.4	0.2	5.4	0.1	5.4
CAADP Level 0 (CL0)	5.3	0.2	5.3	5.4	0.2	5.4	0.1	5.4
CAADP Level 1 (CL1)	5.2	-0.1	5.2	5.4	1.2	5.3	-1.5	5.1
CAADP Level 2 (CL2)	7.3	-0.7	6.8	7.5	4.7	8.6	0.1	8.5
CAADP Level 3 (CL3)	10.0	3.2	10.6	10.7	0.5	10.0	-3.1	9.4
CAADP Level 4 (CL4)	10.2	-0.7	10.5	10.8	0.2	9.5	-5.4	8.4

Source: ReSAKSS based on FAO (2017).

Note: Data are from 1995 to 2014.

ANNEX 2g: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5C

TABLE L2.1.5C—YIELD, MAIZE (metric tons per hectare)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (2008–2014)	2014
Africa	1.7	1.4	1.7	1.7	2.7	2.0	0.8	2.0
Central	1.1	0.3	1.1	1.1	1.6	1.2	1.3	1.2
Eastern	1.6	0.2	1.6	1.5	5.2	1.9	4.1	2.0
Northern	5.5	3.7	6.1	6.3	0.6	6.5	1.4	6.7
Southern	1.6	1.8	1.6	1.7	2.9	2.2	1.1	2.2
Western	1.4	1.8	1.5	1.6	2.0	1.7	-1.7	1.6
Less favorable agriculture conditions	1.1	0.6	1.1	1.2	3.0	1.8	3.2	1.9
More favorable agriculture conditions	1.4	-0.4	1.3	1.3	4.0	1.6	3.2	1.7
Mineral-rich countries	1.0	-0.1	1.1	1.2	1.1	1.5	4.8	1.5
Middle-income countries	2.1	3.7	2.3	2.5	2.6	2.7	-1.9	2.6
CEN-SAD	1.9	2.3	2.0	2.1	0.6	2.1	-1.2	2.0
COMESA	1.8	0.5	1.8	1.9	2.6	2.3	3.1	2.4
EAC	1.6	-0.6	1.5	1.4	4.7	1.6	2.3	1.7
ECCAS	0.9	0.5	0.9	1.0	1.3	1.1	3.2	1.2
ECOWAS	1.4	1.8	1.5	1.6	2.0	1.7	-1.7	1.6
IGAD	1.6	1.3	1.6	1.8	3.9	2.2	5.1	2.5
SADC	1.5	0.9	1.5	1.5	3.6	1.8	1.1	1.9
UMA	0.6	3.3	0.8	0.7	-2.7	0.8	-1.1	0.7
CAADP Compact 2007–09 (CC1)	1.4	1.3	1.5	1.6	4.2	1.9	0.5	1.9
CAADP Compact 2010–12 (CC2)	1.4	-0.2	1.3	1.3	4.1	1.5	1.9	1.6
CAADP Compact 2013–15 (CC3)	1.1	-0.9	1.0	1.0	-2.7	1.0	4.1	1.1
CAADP Compact not yet (CC0)	3.0	4.6	3.5	4.0	5.8	5.0	0.7	5.2
CAADP Level 0 (CL0)	3.0	4.6	3.5	4.0	5.8	5.0	0.7	5.2
CAADP Level 1 (CL1)	1.0	-2.5	0.8	0.8	-5.6	0.8	6.7	0.9
CAADP Level 2 (CL2)	1.1	1.4	1.1	1.1	0.8	1.2	0.8	1.2
CAADP Level 3 (CL3)	1.4	1.5	1.5	1.6	4.7	2.2	0.9	2.2
CAADP Level 4 (CL4)	1.4	0.3	1.4	1.5	4.4	1.7	1.4	1.7

Source: ReSAKSS based on FAO (2017).
Notes: Data are from 1995 to 2014.

ANNEX 2h: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5D

TABLE L2.1.5D—YIELD, MEAT (indigenous cattle, kilograms per head)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2013)	Annual avg. change (2008–2013)	2013
Africa	141.7	0.6	147.1	152.8	1.4	155.2	-0.4	153.8
Central	143.8	-0.8	139.7	139.3	0.2	141.5	0.6	143.4
Eastern	116.4	1.0	125.4	129.5	1.0	129.0	-1.1	125.6
Northern	176.0	1.4	185.3	212.7	6.1	238.0	0.1	238.6
Southern	211.6	0.5	214.5	223.4	1.2	227.3	-0.2	225.6
Western	124.3	-0.3	122.8	122.4	0.0	119.4	-0.6	118.1
Less favorable agriculture conditions	123.1	-0.4	121.6	121.6	0.1	116.4	-1.0	114.4
More favorable agriculture conditions	122.2	0.8	130.3	135.1	1.2	134.2	-1.2	130.5
Mineral-rich countries	136.5	0.4	137.5	135.0	-0.2	139.0	0.8	140.7
Middle-income countries	164.8	0.7	170.1	181.4	2.5	192.5	0.4	193.3
CEN-SAD	131.8	1.0	141.4	149.5	2.2	153.2	-0.7	150.5
COMESA	131.0	1.3	143.1	153.1	2.4	158.8	-0.6	156.9
EAC	122.3	1.8	142.2	152.3	2.1	148.3	-2.6	139.1
ECCAS	148.7	-0.2	145.1	142.1	-0.4	142.6	0.5	144.1
ECOWAS	124.3	-0.3	122.8	122.4	0.0	119.4	-0.6	118.1
IGAD	118.0	1.7	132.1	137.6	1.2	138.2	-1.1	134.6
SADC	169.6	0.6	172.8	178.1	1.0	177.9	-0.6	175.1
UMA	179.8	1.5	187.0	187.5	0.5	187.9	0.5	190.0
CAADP Compact 2007–09 (CC1)	121.0	-0.3	119.7	119.5	0.0	117.1	-0.5	116.2
CAADP Compact 2010–12 (CC2)	124.7	1.0	136.1	142.1	1.5	141.9	-1.3	137.0
CAADP Compact 2013–15 (CC3)	134.0	1.0	137.3	136.4	-0.1	137.0	0.3	137.8
CAADP Compact not yet (CC0)	191.8	0.8	199.8	219.9	3.9	240.1	0.2	239.9
CAADP Level 0 (CL0)	191.8	0.8	199.8	219.9	3.9	240.1	0.2	239.9
CAADP Level 1 (CL1)	133.4	1.1	137.3	136.4	-0.2	136.4	0.1	136.8
CAADP Level 2 (CL2)	133.9	-0.2	132.4	130.8	-0.1	132.6	0.8	134.7
CAADP Level 3 (CL3)	136.4	0.1	136.8	136.7	0.0	133.3	-0.4	132.3
CAADP Level 4 (CL4)	118.4	0.4	125.0	129.2	1.1	128.7	-1.2	125.0

Source: ReSAKSS based on FAO (2017).
Note: Data are from 1995 to 2013.

ANNEX 2i: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.1.5E*

TABLE L2.1.5E—YIELD, MILK (whole fresh cow, kilograms per head)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (2008–2014)	2014
Africa	484.9	1.6	519.9	504.9	-0.5	514.8	1.8	536.4
Central	340.2	-0.5	334.8	338.1	0.6	348.4	1.1	361.9
Eastern	375.4	2.9	433.7	402.0	-2.4	379.3	0.0	376.2
Northern	1,067.4	3.9	1,198.7	1,357.0	5.0	1,717.0	4.0	1,847.0
Southern	1,036.6	-1.5	1,033.4	1,082.4	1.7	1,132.4	1.4	1,163.3
Western	208.3	0.0	208.5	215.4	1.8	225.8	0.8	235.1
Less favorable agriculture conditions	303.0	-1.3	286.0	289.8	1.2	301.3	0.9	317.9
More favorable agriculture conditions	333.2	4.9	428.2	404.1	-2.4	372.8	-0.2	368.5
Mineral-rich countries	243.4	-0.3	240.5	237.8	-0.3	261.4	3.8	285.3
Middle-income countries	712.1	-1.0	674.7	673.8	1.3	806.7	6.1	920.3
CEN-SAD	476.9	1.5	496.2	480.8	0.2	519.8	1.9	541.2
COMESA	451.9	2.9	522.1	494.0	-1.4	470.0	-0.2	462.3
EAC	379.7	3.2	424.5	404.3	-1.3	430.9	1.7	444.6
ECCAS	391.2	-0.2	385.3	390.1	0.8	415.4	1.7	433.3
ECOWAS	208.3	0.0	208.5	215.4	1.8	225.8	0.8	235.1
IGAD	413.3	2.7	479.6	439.1	-2.6	406.8	-0.4	398.5
SADC	552.6	-0.8	531.6	524.2	-0.5	532.3	1.8	555.7
UMA	1,020.9	3.5	1,103.1	1,223.7	4.6	1,648.0	7.0	1,901.3
CAADP Compact 2007–09 (CC1)	269.2	6.9	407.6	385.4	-2.9	310.2	-2.0	295.3
CAADP Compact 2010–12 (CC2)	335.8	2.7	372.5	359.9	-1.0	380.7	1.7	393.5
CAADP Compact 2013–15 (CC3)	416.4	-0.4	405.5	374.2	-1.9	367.1	0.3	368.4
CAADP Compact not yet (CC0)	1,152.7	1.6	1,211.6	1,318.8	3.5	1,549.6	3.2	1,640.2
CAADP Level 0 (CL0)	1,152.7	1.6	1,211.6	1,318.8	3.5	1,549.6	3.2	1,640.2
CAADP Level 1 (CL1)	412.3	-0.3	402.2	370.7	-1.9	362.2	0.1	362.0
CAADP Level 2 (CL2)	319.7	-0.5	312.8	313.5	0.4	331.0	1.9	349.7
CAADP Level 3 (CL3)	315.0	0.3	323.4	331.1	0.7	334.7	0.3	344.6
CAADP Level 4 (CL4)	310.6	5.5	412.8	387.8	-2.5	355.5	-0.2	351.0

Source: ReSAKSS based on FAO (2017).

Note: Data are from 1995 to 2014.

ANNEX 2j: *Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.2.1A*

TABLE L2.2.1A—INTRA-AFRICAN AGRICULTURAL TRADE, EXPORTS (million, constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	601.4	-1.3	516.3	453.4	6.4	1,620.1	16.4	2,176.1
Central	27.7	5.9	34.5	38.8	3.3	34.2	-4.0	32.3
Eastern	300.3	-2.3	289.3	304.9	7.2	461.9	2.4	460.3
Northern	72.4	8.6	107.1	189.1	20.6	415.0	2.9	437.2
Southern	1,085.1	-1.3	952.5	852.7	4.9	2,901.6	13.8	3,648.0
Western	166.6	5.7	179.9	160.3	6.3	280.8	7.9	357.3
Less favorable agriculture conditions	66.0	2.0	75.3	101.2	18.7	118.8	1.3	130.7
More favorable agriculture conditions	320.8	-4.7	267.5	255.8	6.1	387.0	3.4	400.5
Mineral-rich countries	103.5	24.9	186.5	252.4	13.0	415.8	9.1	508.8
Middle-income countries	680.6	-0.9	590.5	514.1	6.2	1,921.3	16.8	2,582.7
CEN-SAD	186.7	3.8	200.8	204.9	8.4	365.5	5.4	425.3
COMESA	275.8	-1.5	248.6	272.3	7.5	466.1	4.0	494.2
EAC	374.1	-0.6	365.6	368.1	5.5	508.9	1.0	504.5
ECCAS	26.9	5.0	30.8	32.6	-0.7	30.3	2.7	35.5
ECOWAS	166.6	5.7	179.9	160.3	6.3	280.8	7.9	357.3
IGAD	349.9	-2.2	334.1	368.8	8.8	583.3	2.4	583.8
SADC	1,044.8	-1.0	917.6	804.6	4.4	2,705.5	14.0	3,430.9
UMA	68.0	4.8	79.8	128.4	22.0	294.7	7.1	355.9
CAADP Compact 2007–09 (CC1)	111.1	-0.5	113.1	93.9	13.3	201.3	6.0	216.7
CAADP Compact 2010–12 (CC2)	279.6	3.4	284.5	284.8	1.9	359.6	3.2	408.7
CAADP Compact 2013–15 (CC3)	235.6	-8.7	162.7	125.3	-0.8	122.0	6.0	132.9
CAADP Compact not yet (CC0)	1,070.7	-0.9	935.9	833.8	5.5	2,848.8	13.7	3,579.1
CAADP Level 0 (CL0)	1,070.7	-0.9	935.9	833.8	5.5	2,848.8	13.7	3,579.1
CAADP Level 1 (CL1)	276.9	-2.9	209.9	166.5	-5.5	144.7	4.8	157.6
CAADP Level 2 (CL2)	49.6	3.5	55.4	78.6	9.4	66.2	-0.7	68.9
CAADP Level 3 (CL3)	91.2	12.2	145.9	208.3	16.9	449.4	11.4	568.8
CAADP Level 4 (CL4)	210.7	3.1	219.6	199.6	5.0	329.5	6.1	387.4

Source: ReSAKSS based on UNCTAD (2017) and World Bank (2017).

Note: For regions and groups, level is weighted average per country, where weight is country's share in intra-African total exports for the region or group.

ANNEX 2k: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.2.1B

TABLE L2.2.1B—INTRA-AFRICAN AGRICULTURAL TRADE, IMPORTS (million, constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	252.2	4.9	286.5	303.6	4.5	514.0	6.4	602.1
Central	114.8	-7.2	111.4	171.1	16.8	233.5	7.7	295.6
Eastern	107.1	4.7	143.9	174.1	7.3	254.9	-0.6	232.9
Northern	138.7	8.5	187.1	198.2	4.9	301.0	1.9	307.8
Southern	340.6	5.2	406.2	413.8	3.0	722.8	6.8	832.4
Western	189.6	7.0	195.6	240.8	8.5	344.9	1.3	383.2
Less favorable agriculture conditions	52.3	11.3	78.0	107.4	9.6	168.5	5.4	194.9
More favorable agriculture conditions	196.8	-2.5	232.6	330.9	16.2	413.5	-1.1	403.2
Mineral-rich countries	220.1	5.1	285.2	270.5	1.1	376.0	7.3	500.1
Middle-income countries	287.5	6.5	319.3	314.5	1.4	581.7	8.0	689.9
CEN-SAD	169.8	8.7	194.2	227.9	7.0	335.0	0.3	343.7
COMESA	237.1	1.9	286.9	340.5	9.7	431.0	0.4	443.4
EAC	107.4	5.2	146.3	190.3	8.9	269.6	-0.2	258.8
ECCAS	317.5	12.9	361.7	289.2	-8.7	276.4	4.7	345.2
ECOWAS	189.6	7.0	195.6	240.8	8.5	344.9	1.3	383.2
IGAD	125.3	9.3	177.6	221.9	8.4	319.4	-2.8	268.6
SADC	322.2	4.3	374.8	385.7	3.6	679.3	7.0	788.5
UMA	126.3	7.9	162.3	157.8	2.5	274.1	4.9	295.2
CAADP Compact 2007–09 (CC1)	226.5	5.9	220.8	259.5	6.9	368.2	1.4	413.5
CAADP Compact 2010–12 (CC2)	145.6	0.2	153.9	190.0	8.6	249.0	1.4	251.3
CAADP Compact 2013–15 (CC3)	312.0	6.0	375.0	400.4	4.9	421.6	0.1	448.7
CAADP Compact not yet (CC0)	274.5	4.4	319.7	328.7	4.4	734.2	9.6	864.6
CAADP Level 0 (CL0)	274.5	4.4	319.7	328.7	4.4	734.2	9.6	864.6
CAADP Level 1 (CL1)	329.8	6.0	389.9	419.6	4.7	443.7	1.0	477.8
CAADP Level 2 (CL2)	126.5	-8.3	125.5	206.1	22.8	319.3	-0.1	292.8
CAADP Level 3 (CL3)	144.5	12.1	210.7	198.8	-0.4	271.2	10.4	406.2
CAADP Level 4 (CL4)	199.5	5.3	206.3	242.5	6.2	361.0	2.2	404.7

Source: ReSAKSS based on UNCTAD (2017) and World Bank (2017).

Notes: For regions and groups, level is weighted average per country, where weight is country's share in intra-African total imports for the region or group

ANNEX 2I: Level 2—Agricultural Transformation and Sustained Inclusive Agricultural Growth, Indicator 2.2.2

TABLE L2.2.2—DOMESTIC FOOD PRICE VOLATILITY (index)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2012)	Annual avg. change (2008–2012)	2012
Africa	11.0		11.6	12.7	3.7	12.6	-11.0	10.6
Central	8.3		7.8	8.7	1.2	9.2	-4.9	6.7
Eastern	10.5		11.5	13.5	6.8	14.1	-14.7	10.7
Northern	6.0		8.7	10.2	7.6	11.4	-4.8	10.7
Southern	11.3		8.9	7.9	6.1	14.8	-21.1	8.2
Western	14.4		14.8	15.8	0.9	12.0	-6.7	11.7
Less favorable agriculture conditions	12.7		11.5	15.7	3.1	13.5	-8.2	11.1
More favorable agriculture conditions	11.8		12.8	14.7	6.3	15.1	-13.5	11.8
Mineral-rich countries	18.3		16.7	11.6	-5.2	8.9	-8.5	7.9
Middle-income countries	10.3		11.1	11.8	2.9	11.7	-10.2	10.2
CEN-SAD	11.0		12.5	14.0	3.6	12.4	-10.2	11.1
COMESA	8.6		10.7	12.9	8.1	14.7	-9.4	12.9
EAC	11.4		12.7	16.0	7.6	15.5	-17.7	11.0
ECCAS	18.6		10.9	9.2	-1.9	8.6	-4.9	7.3
ECOWAS	14.4		14.8	15.8	0.9	12.0	-6.7	11.7
IGAD	11.3		11.8	15.4	9.7	16.9	-15.7	13.4
SADC	10.3		9.6	8.5	3.8	12.9	-19.8	7.3
UMA	8.7		8.5	9.2	3.9	9.5	-2.5	8.8
CAADP Compact 2007–09 (CC1)	13.5		14.1	15.1	1.0	11.5	-6.3	11.3
CAADP Compact 2010–12 (CC2)	12.2		12.7	14.8	6.1	14.6	-13.7	11.9
CAADP Compact 2013–15 (CC3)	15.6		10.4	8.1	-3.4	8.5	-6.1	5.9
CAADP Compact not yet (CC0)	6.1		8.0	9.3	8.4	13.1	-13.9	9.6
CAADP Level 0 (CL0)	6.1		8.0	9.3	8.4	13.1	-13.9	9.6
CAADP Level 1 (CL1)	20.1		12.4	8.4	-6.1	8.6	-5.6	6.2
CAADP Level 2 (CL2)	9.8		9.6	9.2	-3.2	8.3	-12.2	5.6
CAADP Level 3 (CL3)	15.8		14.4	17.5	4.3	15.7	-0.8	15.3
CAADP Level 4 (CL4)	12.8		13.7	14.7	2.8	12.4	-10.8	11.2

Source: ReSAKSS based on FAO (2017).

Note: Data are from 2000 to 2012. For regions or groups, level is weighted average, where weight is country's share in total food production for the region or group.

ANNEX 3a: *Level 3—Strengthening Systemic Capacity to Deliver Results, Indicator 3.5.1*

TABLE L3.5.1—PUBLIC AGRICULTURE EXPENDITURE (million, constant 2010 US$)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	706.3	11.5	939.5	1,157.5	11.0	1,111.5	-4.8	929.2
Central	53.6	6.7	76.0	96.3	9.2	172.6	9.5	228.9
Eastern	198.1	5.8	276.5	331.0	6.5	398.7	-1.4	373.3
Northern	1,520.2	6.4	1,678.6	1,502.8	-5.9	1,741.3	7.5	2,240.3
Southern	437.6	19.9	711.1	941.5	12.2	925.9	-3.3	815.1
Western	576.1	20.1	910.5	1,367.9	23.0	1,222.3	-11.7	700.3
Less favorable agriculture conditions	101.5	4.9	142.4	178.5	2.9	192.1	4.2	215.9
More favorable agriculture conditions	172.2	4.2	227.9	279.6	7.8	363.7	0.2	356.0
Mineral-rich countries	48.2	8.1	62.5	100.7	19.8	166.3	4.1	202.6
Middle-income countries	919.9	11.3	1,181.7	1,467.5	11.6	1,404.8	-5.0	1,160.1
CEN-SAD	873.1	9.4	1,055.1	1,310.3	12.6	1,134.1	-9.1	758.1
COMESA	1,045.9	5.4	1,075.8	904.2	-8.3	725.5	0.9	775.9
EAC	186.1	3.5	235.0	211.4	-4.2	281.4	-4.0	220.4
ECCAS	80.7	3.4	92.4	223.9	34.9	313.1	-5.0	217.2
ECOWAS	576.1	20.1	910.5	1,367.9	23.0	1,222.3	-11.7	700.3
IGAD	229.1	5.5	311.9	393.5	9.3	472.3	0.7	472.6
SADC	343.9	18.3	556.1	708.6	10.7	693.3	-4.8	581.3
UMA	816.3	13.5	1,316.1	1,477.1	4.0	2,491.0	8.6	3,208.8
CAADP Compact 2007–09 (CC1)	611.6	21.2	974.1	1,430.9	21.7	1,248.9	-11.4	735.4
CAADP Compact 2010–12 (CC2)	146.2	0.0	163.0	161.1	0.3	255.8	2.2	248.4
CAADP Compact 2013–15 (CC3)	91.3	1.1	95.0	222.4	34.2	310.1	-5.7	213.5
CAADP Compact not yet (CC0)	1,335.8	8.5	1,586.3	1,536.3	-2.3	1,760.2	5.9	2,188.8
CAADP Level 0 (CL0)	1,335.8	8.5	1,586.3	1,536.3	-2.3	1,760.2	5.9	2,188.8
CAADP Level 1 (CL1)	95.3	-1.8	82.5	259.2	45.1	339.0	-10.1	180.3
CAADP Level 2 (CL2)	60.9	5.8	81.5	97.1	7.4	176.9	10.9	247.1
CAADP Level 3 (CL3)	69.1	12.3	102.7	136.3	10.4	176.3	2.1	192.1
CAADP Level 4 (CL4)	524.6	18.5	835.3	1,231.6	21.5	1,097.2	-11.1	655.1

Source: ReSAKSS based on IFPRI (2015), World Bank (2017), and national sources.
Note: For regions or groups, level is weighted average per country, where weight is country's share in total agriculture value added for the region or group.

ANNEX 3b: *Level 3—Strengthening Systemic Capacity to Deliver Results, Indicator 3.5.2*

TABLE L3.5.2—SHARE OF AGRICULTURE EXPENDITURE IN TOTAL PUBLIC EXPENDITURE (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	3.2	3.4	3.6	3.5	-1.7	3.0	-1.3	2.9
Central	2.0	-1.1	2.3	3.0	6.2	3.6	1.9	3.9
Eastern	5.7	-0.2	6.0	6.2	0.3	5.1	-10.3	3.3
Northern	4.6	2.8	4.6	3.9	-10.4	2.8	1.9	3.1
Southern	1.6	10.1	2.2	2.5	3.6	2.1	-2.4	2.1
Western	3.5	-2.0	3.5	3.9	5.9	4.1	1.0	4.1
Less favorable agriculture conditions	10.7	-1.1	11.4	12.2	-2.5	9.1	-1.6	8.1
More favorable agriculture conditions	6.6	-2.8	6.4	6.9	3.3	6.6	-6.0	5.1
Mineral-rich countries	5.2	2.1	5.3	7.0	13.7	8.0	0.4	9.1
Middle-income countries	2.8	4.9	3.2	3.1	-2.7	2.5	-1.3	2.4
CEN-SAD	4.7	-1.1	4.3	3.9	-4.9	2.9	-2.1	2.7
COMESA	5.8	0.6	5.3	4.5	-7.3	2.9	-3.7	2.8
EAC	4.9	0.0	4.9	4.2	-6.5	3.7	-11.8	2.1
ECCAS	1.3	-4.2	1.3	2.1	14.9	1.8	-6.9	1.5
ECOWAS	3.5	-2.0	3.5	3.9	5.9	4.1	1.0	4.1
IGAD	5.9	0.7	6.5	7.2	2.6	5.7	-8.2	3.9
SADC	1.9	8.2	2.5	2.7	2.2	2.3	-3.8	2.1
UMA	3.5	5.6	4.2	4.2	-3.4	4.2	3.7	4.7
CAADP Compact 2007–09 (CC1)	3.2	1.8	3.8	4.4	6.0	4.2	-0.1	4.2
CAADP Compact 2010–12 (CC2)	5.3	-1.9	5.1	5.3	2.4	5.6	-2.9	4.8
CAADP Compact 2013–15 (CC3)	2.0	-7.6	1.6	2.3	12.2	2.0	-8.8	1.6
CAADP Compact not yet (CC0)	3.1	6.6	3.5	3.1	-7.3	2.4	0.5	2.5
CAADP Level 0 (CL0)	3.1	6.6	3.5	3.1	-7.3	2.4	0.5	2.5
CAADP Level 1 (CL1)	2.0	-8.6	1.5	2.1	12.8	1.7	-11.2	1.2
CAADP Level 2 (CL2)	4.2	-2.5	4.0	4.1	1.6	5.2	5.7	6.2
CAADP Level 3 (CL3)	5.9	1.3	6.4	7.7	7.4	7.6	-1.7	7.4
CAADP Level 4 (CL4)	3.7	-1.1	3.9	4.3	4.6	4.3	-1.5	3.9

Source: ReSAKSS based on IFPRI (2015), World Bank (2017), and national sources.

ANNEX 3c: Level 3—Strengthening Systemic Capacity to Deliver Results, Indicator 3.5.3

TABLE L3.5.3—PUBLIC AGRICULTURE EXPENDITURE AS SHARE OF AGRICULTURE GDP (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	5.6	3.5	5.8	6.2	2.7	5.5	-2.8	5.0
Central	2.0	2.4	2.6	3.1	4.8	4.2	6.8	5.0
Eastern	3.9	5.4	5.1	5.0	-1.8	3.8	-9.0	2.7
Northern	10.2	3.6	10.8	10.1	-3.2	9.7	1.6	10.0
Southern	8.7	8.8	11.2	14.9	9.5	14.3	-1.8	13.4
Western	3.2	0.6	2.8	3.3	9.5	2.8	-6.5	2.1
Less favorable agriculture conditions	5.7	0.8	7.1	7.8	-3.3	5.8	-0.9	5.3
More favorable agriculture conditions	4.1	1.3	4.7	5.0	2.6	4.7	-4.5	3.9
Mineral-rich countries	4.3	-0.1	4.3	6.1	15.9	11.8	11.1	19.1
Middle-income countries	6.1	3.9	6.1	6.5	2.5	5.6	-3.0	5.0
CEN-SAD	5.3	-0.5	4.5	4.3	-0.6	3.3	-4.7	2.7
COMESA	7.0	1.7	6.9	6.3	-3.5	5.0	-2.0	4.9
EAC	3.1	4.5	3.9	3.4	-5.3	2.9	-11.4	1.7
ECCAS	3.1	-1.2	2.9	5.4	22.4	4.8	-8.9	3.0
ECOWAS	3.2	0.6	2.8	3.3	9.5	2.8	-6.5	2.1
IGAD	3.8	7.1	5.4	5.4	-0.9	3.8	-6.4	3.0
SADC	7.2	7.8	9.1	11.5	7.8	10.8	-3.6	9.5
UMA	10.7	8.4	14.2	15.8	6.1	17.4	-1.6	15.8
CAADP Compact 2007–09 (CC1)	2.8	6.7	3.0	3.5	8.4	2.6	-8.6	1.9
CAADP Compact 2010–12 (CC2)	4.1	-1.1	4.3	4.7	5.7	5.6	-0.4	5.4
CAADP Compact 2013–15 (CC3)	4.8	-4.9	3.9	6.3	18.6	5.5	-10.6	3.3
CAADP Compact not yet (CC0)	10.3	6.1	12.0	12.4	0.1	12.0	0.9	12.2
CAADP Level 0 (CL0)	10.3	6.1	12.0	12.4	0.1	12.0	0.9	12.2
CAADP Level 1 (CL1)	6.7	-6.7	4.9	8.1	20.1	6.5	-13.7	3.3
CAADP Level 2 (CL2)	3.0	1.5	3.4	3.4	0.4	4.4	6.8	5.4
CAADP Level 3 (CL3)	3.9	6.5	5.1	6.1	6.6	6.7	2.0	7.8
CAADP Level 4 (CL4)	3.2	2.0	3.1	3.6	7.6	3.0	-7.2	2.2

Source: ReSAKSS based on IFPRI (2015), World Bank (2017), and national sources.

ANNEX 3d: *Level 3—Strengthening Systemic Capacity to Deliver Results*

TABLE L 3(a)—PROGRESS IN CAADP IMPLEMENTATION PROCESS AS OF AUGUST 2017

Country/Region	Roundtable held and compact signed	First generation investment plan drafted, reviewed, and validated	Business meeting held	GAFSP funding approved (million US$)	JSR assessment conducted/ initiated	Second generation investment plan			Inaugural biennial review (BR) process	
						Malabo domestication event held	Malabo Status assessment and profile finalized	Malabo goals and milestones report finalized	BR launched	BR report drafted, validated, and submitted to REC[a]
AFRICA*	**42**	**33**	**28**	**17**	**30**	**8**	**13**	**4**	**52**	**31**
Central Africa*	***9***	***6***	***3***	***1***	***3***				***9***	***8***
Burundi	August 25, 2009	August 31, 2011	March 15, 2012	$30	Initiated				yes	yes
Cameroon	July 17, 2013	August 22, 2014							yes	yes
Central African Republic	April 15, 2011	May 21, 2012	December 21, 2013						yes	yes
Chad	December 16, 2013								yes	yes
Congo, Dem. Republic	March 18, 2011	May 21, 2013	November 8, 2013		yes				yes	yes
Congo, Republic	December 10, 2013	July 25, 2015			Initiated				yes	yes
Equatorial Guinea	December 5, 2013								yes	yes
Gabon	May 10, 2013								yes	
Sao Tome and Principe	October 17, 2013	September 2, 2014							yes	yes
Eastern Africa*	***10***	***8***	***7***	***4***	***8***	***5***	***5***		***14***	***7***
Comoros									yes	
Djibouti	April 19, 2012	November 22, 2012			Initiated				yes	yes
Eritrea									yes	
Ethiopia	September 28, 2009	September 25, 2010	December 7, 2010	$51.5	yes	yes	yes	Initiated	yes	yes
Kenya	July 24, 2010	September 14, 2010	September 27, 2010	$30	yes	yes	yes	Initiated	yes	yes
Madagascar	October 21, 2013				Initiated				yes	yes
Mauritius	July 23, 2015				Initiated				yes	
Rwanda	March 31, 2007	December 8, 2009	December 9, 2009	$50		yes	yes		yes	
Seychelles	September 16, 2011	Yes	November 19, 2015		Initiated	Initiated			yes	yes
Somalia									yes	
South Sudan									yes	
Sudan	July 29, 2013	September 7, 2015	October 18, 2016						yes	
Tanzania	July 8, 2010	May 31, 2011	November 10, 2011	$22.9	yes	yes	yes		yes	yes
Uganda	March 31, 2010	September 10, 2010	September 17, 2010	$27.6	yes	yes	yes	In progress	yes	yes

TABLE L 3(a)—PROGRESS IN CAADP IMPLEMENTATION PROCESS AS OF AUGUST 2017 *continued*

Country/Region	Roundtable held and compact signed	First generation investment plan drafted, reviewed, and validated	Business meeting held	GAFSP funding approved (million US$)	JSR assessment conducted/ initiated	Second generation investment plan			Inaugural biennial review (BR) process	
						Malabo domestication event held	Malabo Status assessment and profile finalized	Malabo goals and milestones report finalized	BR launched	BR report drafted, validated, and submitted to REC[a]
Northern Africa*	*1*	*1*	*1*						*4*	*1*
Algeria										
Egypt									yes	
Libya									yes	
Mauritania	July 28, 2011	February 16, 2012	March 21, 2012						yes	
Morocco										
Tunisia									yes	yes
Western Sahara										
Southern Africa*	*7*	*3*	*3*	*2*	*7*	*1*	*1*		*10*	*6*
Angola	August 5, 2014								yes	
Botswana									yes	yes
Lesotho	September 4, 2013				Initiated				yes	yes
Malawi	April 19, 2010	September 16, 2010	September 29, 2011	$39.6	yes	yes	yes		yes	yes
Mozambique	December 9, 2011	December 13, 2012	April 12, 2013		yes		Initiated		yes	yes
Namibia					Initiated				yes	
South Africa									yes	
Swaziland	March 4, 2010				yes				yes	yes
Zambia	January 18, 2011	March 15, 2013	May 30, 2013	$31.1	yes				yes	
Zimbabwe	November 22, 2013				yes				yes	yes
Western Africa*	*15*	*15*	*14*	*9*	*12*	*2*	*7*	*4*	*15*	*9*
Benin	October 16, 2009	September 25, 2010	June 7, 2011	$24	yes		Initiated	Initiated	yes	yes
Burkina Faso	July 22, 2010	January 17, 2012	March 26, 2012	$37.1	yes		Initiated	Initiated	yes	yes
Cabo Verde	December 11, 2009	September 25, 2010	November 17, 2010		Initiated		Initiated		yes	yes
Côte d'Ivoire	July 27, 2010	June 20, 2012	September 14, 2012		yes		yes	yes	yes	
Gambia	October 28, 2009	September 25, 2010	November 5, 2010	$28			Initiated		yes	yes
Ghana	October 28, 2009	June 9, 2010	June 17, 2010		yes	yes	yes	yes	yes	
Guinea	April 7, 2010	September 25, 2010	June 5, 2013		Initiated		yes	yes	yes	yes
Guinea Bissau	January 18, 2011	June 3, 2011					Initiated		yes	

TABLE L 3(a)—PROGRESS IN CAADP IMPLEMENTATION PROCESS AS OF AUGUST 2017 *continued*

Country/Region	Roundtable held and compact signed	First generation investment plan drafted, reviewed, and validated	Business meeting held	GAFSP funding approved (million US$)	JSR assessment conducted/ initiated	Second generation investment plan: Malabo domestication event held	Second generation investment plan: Malabo Status assessment and profile finalized	Second generation investment plan: Malabo goals and milestones report finalized	Inaugural biennial review (BR) process: BR launched	Inaugural biennial review (BR) process: BR report drafted, validated, and submitted to REC[a]
Western Africa* *cont'd*	***15***	***15***	***14***	***9***	***12***	***2***	***7***	***4***	***15***	***9***
Liberia	October 6, 2009	June 9, 2010	June 17, 2010	$46.5	Initiated		Initiated		yes	
Mali	October 13, 2009	September 25, 2010	November 5, 2010	$37.2	yes		yes	Initiated	yes	yes
Niger	September 30, 2009	September 25, 2010	December 15, 2010	$33	yes		yes	Initiated	yes	yes
Nigeria	October 30, 2009	June 9, 2010	June 17, 2010		Initiated	yes	yes	Initiated	yes	
Senegal	February 10, 2010	June 9, 2010	June 17, 2010	$40	yes		yes	yes	yes	yes
Sierra Leone	September 18, 2009	June 9, 2010	June 17, 2010	$50			Initiated		yes	yes
Togo	July 30, 2009	June 9, 2010	June 17, 2010	$39	yes		Initiated	Initiated	yes	
RECS*	***5***	***3***	***1***		***2***					
CEN-SAD										
COMESA	November 14, 2014									
EAC	June 23, 2017				Initiated					
ECCAS	July 10, 2013	September 5, 2013								
ECOWAS	November 12, 2009	June 9, 2010	June 17, 2010		yes					
IGAD	October 21, 2013	August 30, 2016								
SADC	In progress									
UMA										

Source: Authors' compilation based on NEPAD (November, 2015) and ReSAKSS (2017).

Note: [a] Biennial Review reporting is as of September 7, 2017.
* The item in this row are the number of countries in Africa of the subregion that have achieved the milestone. ** The item in this row are the number of RECs that have achieved the milestone.
GAFSP=Global Agriculture and Food Security Program; JSR=Joint Sector Review

ReSAKSS-ECA

Burundi (COMESA, EAC, ECCAS)
Central African Rep. (Cen-SAD, ECCAS)
Comoros (CEN-SAD, COMESA)
Congo, D.R. (COMESA, ECCAS, SADC)
Congo, R. (ECCAS)
Djbouti (CEN-SAD, COMESA, IGAD)
Egypt (CEN-SAD, COMESA)
Eritrea (COMESA, IGAD)
Ethiopia (COMESA, IGAD)
Gabon (ECCAS)
Kenya (Cen-SAD, COMESA, EAC, IGAD)
Libya (CEN-SAD, COMESA, UMA)
Rwanda (COMESA, EAC, ECCAS)
Seychelles (COMESA, SADC)
South Sudan (IGAD)
Sudan (CEN-SAD, COMESA, IGAD)
Tanzania (SADC)
Uganda (COMESA, EAC, IGAD)

ReSAKSS-SA

Angola (ECCAS, SADC)
Botswana (SADC)
Lesotho (SADC)
Madagascar (COMESA, SADC)
Malawi (COMESA, SADC)
Mauritius (COMESA, SADC)
Mozambique (SADC)
Namibia (SADC)
Swaziland (COMESA, SADC)
Zambia (COMESA, SADC)
Zimbabwe (COMESA, SADC)

ReSAKSS-WA

Benin (CEN-SAD, ECOWAS
Burkina Faso (CEN-SAD, ECOWAS)
Cameroon (ECCAS)
Cabo Verde (ECOWAS)
Chad (CEN-SAD, ECCAS)
Côte d'Ivoire (CEN-SAD, ECOWAS)
Gambia (CEN-SAD, ECOWAS)
Ghana (CEN-SAD, ECOWAS)
Guinea (CEN-SAD, ECOWAS)
Guinea-Bissau (CEN-SAD, ECOWAS)
Liberia (CEN-SAD, ECOWAS)
Mali (CEN-SAD, ECOWAS)
Mauritania (CEN-SAD, UMA)
Niger (CEN-SAD, ECOWAS)
Nigeria (CEN-SAD, ECOWAS)
Senegal (CEN-SAD, ECOWAS)
Sierra Leone (CEN-SAD, ECOWAS)
Togo (CEN-SAD, ECOWAS)

ANNEX 3d: Level 3—Strengthening Systemic Capacity to Deliver Results

TABLE L 3(b)—PROGRESS IN STRENGTHENING SYSTEMIC CAPACITY

Country/region	L2.4.2-Existence of food reserves, local purchases for relief programs, early warning systems and food feeding programs**	L3.1.1-Existence of a new NAIP/NAFSIP developed through an inclusive and participatory process	L3.2.1-Existence of inclusive institutionalized mechanisms for mutual accountability and peer review	L3.3.1-Existence of and quality in the implementation of evidence-informed policies and corresponding human resources	L3.4.1-Existence of a functional multisectoral and multistakeholder coordination body	L3.4.2-Cumulative number of agriculture-related public-private partnerships (PPPs) that are successfully undertaken	L3.4.3-Cumulative value of investments in the PPPs	L3.4.6-Existence of an operational country SAKSS
AFRICA*	**38**	**15**	**21**	**28**	**22**	**16**	**16**	**14**
Central Africa*	***4***	***0***	***2***	***2***	***1***	***2***	***2***	***1***
Burundi	yes		yes	yes	yes	Several PPPs	€18 million	
Cameroon								
Central African Republic	yes							
Chad								
Congo, Dem. Rep.	yes		yes	yes		Several PPPs	Not stated	yes
Congo, Rep.	yes							
Equatorial Guinea								
Gabon								
Sao Tome and Principe								
Eastern Africa*	***12***	***7***	***5***	***8***	***7***	***6***	***6***	***5***
Comoros	yes							
Djibouti	yes	yes		yes		Several PPPs	Not stated	
Eritrea	yes							
Ethiopia	yes	yes	yes	yes	yes	Several PPPs	Over $11 million	yes
Kenya	yes			yes	yes	Several PPPs	Over $200 million	yes
Madagascar								
Mauritius					yes			
Rwanda	yes	yes	yes	yes	yes	Several PPPs	Over €8 million	yes
Seychelles	yes	yes		yes	yes			
Somalia	yes							
South Sudan	yes							
Sudan	yes	yes	yes	yes				

ANNEX 3d: Level 3—Strengthening Systemic Capacity to Deliver Results, continued

TABLE L 3(b)—PROGRESS IN STRENGTHENING SYSTEMIC CAPACITY *continued*

Country/region	L2.4.2-Existence of food reserves, local purchases for relief programs, early warning systems and food feeding programs**	L3.1.1-Existence of a new NAIP/NAFSIP developed through an inclusive and participatory process	L3.2.1-Existence of inclusive institutionalized mechanisms for mutual accountability and peer review	L3.3.1-Existence of and quality in the implementation of evidence-informed policies and corresponding human resources	L3.4.1-Existence of a functional multisectoral and multistakeholder coordination body	L3.4.2-Cumulative number of agriculture-related public-private partnerships (PPPs) that are successfully undertaken	L3.4.3-Cumulative value of investments in the PPPs	L3.4.6-Existence of an operational country SAKSS
Eastern Africa** cont'd	***12***	***7***	***5***	***8***	***7***	***6***	***6***	***5***
Tanzania	yes	yes	yes	yes	yes	SAGCOT with several projects	$3.2 billion by 2030	yes
Uganda	yes	yes	yes	yes	yes	Several PPPs	Over $314 million	yes
Northern Africa*	***1***	***0***	***0***	***2***	***1***	***1***	***1***	***0***
Algeria								
Egypt	yes			yes	yes	Few PPPs in agric.	$30.1 million	
Libya				yes				
Mauritania								
Morocco								
Tunisia								
Western Sahara								
Southern Africa*	***10***	***1***	***6***	***7***	***2***	***4***	***4***	***2***
Angola	yes							
Botswana	yes			yes				
Lesotho	yes			yes				
Malawi	yes	yes	yes	yes				
Mozambique	yes		yes		yes	Two	Not stated	yes
Namibia	yes							
South Africa	yes		yes	yes				
Swaziland	yes		yes	yes		Three	Not stated	
Zambia	yes		yes	yes		One	Not stated	
Zimbabwe	yes		yes	yes	yes	Several PPPs	Not stated	yes

ANNEX 3d: *Level 3—Strengthening Systemic Capacity to Deliver Results, continued*

TABLE L 3(b)—PROGRESS IN STRENGTHENING SYSTEMIC CAPACITY *continued*

Country/region	L2.4.2-Existence of food reserves, local purchases for relief programs, early warning systems and food feeding programs**	L3.1.1-Existence of a new NAIP/NAFSIP developed through an inclusive and participatory process	L3.2.1-Existence of inclusive institutionalized mechanisms for mutual accountability and peer review	L3.3.1-Existence of and quality in the implementation of evidence-informed policies and corresponding human resources	L3.4.1-Existence of a functional multisectoral and multistakeholder coordination body	L3.4.2-Cumulative number of agriculture-related public-private partnerships (PPPs) that are successfully undertaken	L3.4.3-Cumulative value of investments in the PPPs	L3.4.6-Existence of an operational country SAKSS
Western Africa*	***11***	***7***	***8***	***9***	***11***	***3***	***3***	***6***
Benin	yes	yes	yes		yes			yes
Burkina Faso	yes	yes		yes	yes			yes
Cabo Verde								
Côte d'Ivoire				yes	yes	Two	Not stated	
Gambia	yes		yes	yes	yes			
Ghana	Yes		yes	yes	yes			yes
Guinea	yes	yes		yes				
Guinea-Bissau								
Liberia								
Mali	yes	yes	yes	yes	yes	Two	Over 10 billion CFA franc	yes
Niger	yes	yes	yes	yes	yes			
Nigeria	yes				yes			
Senegal	yes	yes	yes	yes	yes	Two	$798 million	yes
Sierra Leone	yes		yes		yes			
Togo	yes	yes	yes	yes	yes			yes

Note: * The item in this row are the number of countries in Africa of the sub region corresponding to each indicator.
** This indicator is from level 2 of the CAADP Results Framework.
SAKSS=Strategic Analysis and Knowledge Support System

ANNEX 4: Distribution of countries by year of signing CAADP compact and level of CAADP implementation reached by end of 2015

PERIOD WHEN CAADP COMPACT WAS SIGNED				LEVEL OR STAGE OF CAADP IMPLEMENTATION REACHED BY END OF 2015				
2007–2009	2010–2012	2013–2015	Not signed	LEVEL 0 Not started or pre-compact	LEVEL 1 Signed compact	LEVEL 2 Level 1 plus NAIP	LEVEL 3 Level 2 plus one external funding source	LEVEL 4 Level 3 plus other external funding source
CC1	**CC2**	**CC3**	**CC0**	**CL0**	**CL1**	**CL2**	**CL3**	**CL4**
Benin	Burkina Faso	Angola	Algeria	Algeria	Angola	Cameroon	Burundi	Benin
Burundi	Central Afr. Rep.	Cameroon	Botswana	Botswana	Chad	Cabo Verde	Gambia	Burkina Faso
Cabo Verde	Congo, Dem. Rep.	Chad	Comoros	Comoros	Congo, Rep.	Central Afr. Rep.	Liberia	Côte d'Ivoire
Ethiopia	Côte d'Ivoire	Congo, Rep.	Egypt	Egypt	Eq. Guinea	Congo, Dem. Rep.	Mali	Ethiopia
Gambia	Djibouti	Eq. Guinea	Eritrea	Eritrea	Gabon	Djibouti	Niger	Ghana
Ghana	Guinea	Gabon	Libya	Libya	Lesotho	Guinea	Sierra Leone	Kenya
Liberia	Guinea Bissau	Lesotho	Morocco	Morocco	Madagascar	Guinea Bissau	Togo	Malawi
Mali	Kenya	Madagascar	Namibia	Namibia	Mauritius	Mauritania	Uganda	Mozambique
Niger	Malawi	Mauritius	Somalia	Somalia	Seychelles	S. T. & Principe	Zambia	Nigeria
Nigeria	Mauritania	Sudan	South Africa	South Africa	Sudan			Rwanda
Rwanda	Mozambique	S. T. & Principe	South Sudan	South Sudan	Swaziland			Senegal
Sierra Leone	Senegal	Zimbabwe	Tunisia	Tunisia	Zimbabwe			Tanzania
Togo	Seychelles							
	Swaziland							
	Tanzania							
	Uganda							
	Zambia							
Count								
13	17	12	12	12	12	9	9	12
AgShare in GDP (%)								
26.1	23.2	22.2	7.5	7.5	19.7	22.1	25.5	25.5

Note: NAIP = national agricultural investment plan. There are three external funding sources considered—Grow Africa, New Alliance Cooperation, and the Global Agriculture and Food Security Program (GAFSP).
AgShare in GDP is the average share of agricultural GDP in total GDP for 2003–2016.

ANNEX 5: Supplementary Data Tables

TABLE O.1.1A—AGRICULTURAL ODA (% total ODA)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2015)	Annual avg. change (2008–2015)	2015
Africa	3.8	3.6	3.1	5.8	5.0	6.8
Central	2.1	2.2	19.9	3.2	11.5	4.0
Eastern	4.6	4.2	-1.9	6.2	5.1	7.5
Northern	3.8	3.6	-3.0	4.8	5.7	5.9
Southern	2.9	3.5	3.9	5.6	6.2	6.3
Western	5.2	4.2	1.5	7.3	2.6	8.2
Less favorable agriculture conditions	6.7	6.0	-2.0	8.0	2.2	8.2
More favorable agriculture conditions	5.0	5.1	-1.9	6.8	2.9	7.5
Mineral-rich countries	1.5	2.1	24.9	3.3	5.4	3.8
Middle-income countries	3.3	2.6	0.9	5.1	8.3	6.7
CEN-SAD	4.8	3.8	-1.2	6.2	4.0	7.2
COMESA	3.2	3.4	6.8	5.8	8.8	7.9
EAC	4.3	5.0	6.0	6.2	1.7	6.8
ECCAS	2.0	2.3	24.6	4.1	10.3	5.2
ECOWAS	5.2	4.2	1.5	7.3	2.6	8.2
IGAD	4.4	3.8	-2.3	6.2	8.0	7.8
SADC	2.8	3.5	9.4	4.9	3.9	5.6
UMA	5.0	3.9	-10.5	4.7	1.7	3.7
CAADP Compact 2007–09 (CC1)	4.2	3.5	-0.2	7.1	5.1	8.2
CAADP Compact 2010–12 (CC2)	3.8	4.5	10.4	5.8	3.4	7.0
CAADP Compact 2013–15 (CC3)	3.8	2.8	-4.3	5.4	10.5	6.3
CAADP Compact not yet (CC0)	3.5	3.2	-6.6	3.9	8.9	5.0
CAADP Level 0 (CL0)	3.5	3.2	-6.6	3.9	8.9	5.0
CAADP Level 1 (CL1)	3.8	3.0	-3.5	5.6	10.1	6.7
CAADP Level 2 (CL2)	2.7	2.7	14.0	3.0	1.4	3.1
CAADP Level 3 (CL3)	4.2	5.0	7.0	7.5	2.6	7.6
CAADP Level 4 (CL4)	4.5	4.0	1.1	6.8	4.5	8.4

Source: ReSAKSS based on OECD (2017) and World Bank (2017).
Note: Data are from 2002 to 2015.
ODA refers to gross disbursements.

ANNEX 5: *Supplementary Data Tables*

TABLE O.1.1B—AGRICULTURAL ODA DISBURSEMENTS (as % of agricultural ODA commitments)						
Region	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2015)	Annual avg. change (2008–2015)	2015
Africa	80.5	75.7	-5.7	67.7	5.6	79.9
Central	73.0	79.7	12.5	68.0	-0.5	70.6
Eastern	73.4	78.3	-3.3	74.8	0.4	76.0
Northern	116.5	70.5	-19.7	72.6	17.8	96.0
Southern	85.2	89.3	-1.7	84.6	1.5	100.0
Western	84.2	75.1	-7.5	65.3	6.1	75.8
Less favorable agriculture conditions	91.8	85.5	-6.5	73.4	-0.3	66.3
More favorable agriculture conditions	79.5	83.2	0.9	78.7	-3.7	72.8
Mineral-rich countries	65.5	86.6	13.1	88.8	-0.4	112.0
Middle-income countries	81.0	70.9	-12.9	65.7	17.1	98.6
CEN-SAD	86.1	67.3	-8.8	64.6	9.6	80.4
COMESA	76.3	79.2	-5.3	70.7	1.7	78.2
EAC	60.6	84.8	15.2	82.9	-1.9	72.8
ECCAS	75.3	78.8	6.4	74.3	2.3	82.0
ECOWAS	84.2	75.1	-7.5	65.3	6.1	75.8
IGAD	67.6	75.7	-5.7	72.7	1.5	74.1
SADC	80.0	85.6	1.3	84.3	-0.7	91.7
UMA	99.3	77.1	-22.5	104.2	31.5	166.5
CAADP Compact 2007–09 (CC1)	79.3	74.9	-10.7	74.1	0.1	69.8
CAADP Compact 2010–12 (CC2)	74.0	84.8	7.1	72.5	3.7	86.6
CAADP Compact 2013–15 (CC3)	91.0	77.5	-10.2	69.4	4.8	78.1
CAADP Compact not yet (CC0)	123.5	88.8	-25.7	75.0	22.1	107.6
CAADP Level 0 (CL0)	123.5	88.8	-25.7	75.0	22.1	107.6
CAADP Level 1 (CL1)	80.2	72.5	-11.2	75.5	7.2	91.4
CAADP Level 2 (CL2)	83.9	88.7	6.9	76.1	-6.6	75.0
CAADP Level 3 (CL3)	79.5	99.6	-0.7	75.7	-2.3	65.5
CAADP Level 4 (CL4)	76.6	71.0	-2.4	68.9	4.5	80.6

Source: ReSAKSS based on OECD (2017) and World Bank (2017).
Note: Data are from 2002 to 2015.

TABLE O.1.1C—EMERGENCY FOOD AID (% of total ODA)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2015)	Annual avg. change (2008–2015)	2015
Africa	4.4	4.7	-1.7	4.6	-4.8	4.1
Central	1.7	3.0	27.2	5.1	0.7	5.0
Eastern	9.9	10.9	-8.1	8.8	-5.6	8.1
Northern	1.1	1.6	9.5	1.4	-9.5	1.0
Southern	4.2	3.5	1.1	2.4	-15.8	1.3
Western	0.9	0.8	-7.7	1.7	22.6	2.2
Less favorable agriculture conditions	4.3	5.1	-14.7	6.4	6.6	6.0
More favorable agriculture conditions	5.4	6.0	-4.9	4.8	-12.4	3.2
Mineral-rich countries	1.8	2.2	12.1	2.7	2.6	3.3
Middle-income countries	5.5	5.1	-2.8	4.6	-2.0	4.8
CEN-SAD	3.8	4.8	6.6	5.7	-1.9	5.5
COMESA	7.3	9.3	3.5	8.5	-5.8	7.9
EAC	3.2	3.7	-1.9	3.1	-9.2	2.2
ECCAS	3.9	3.3	1.2	4.3	0.1	4.1
ECOWAS	0.9	0.8	-7.7	1.7	22.6	2.2
IGAD	15.2	16.4	-9.3	12.7	-4.6	12.3
SADC	2.6	2.5	10.1	2.3	-13.2	1.5
UMA	1.1	1.6	9.5	1.4	-9.5	1.0
CAADP Compact 2007–09 (CC1)	5.7	4.5	-15.7	4.3	-2.6	4.0
CAADP Compact 2010–12 (CC2)	1.6	2.2	9.9	2.5	-2.4	2.4
CAADP Compact 2013–15 (CC3)	11.9	12.3	4.9	12.3	-12.5	7.3
CAADP Compact not yet (CC0)	5.4	4.2	-46.1	3.3	55.2	7.3
CAADP Level 0 (CL0)	5.4	4.2	-46.1	3.3	55.2	7.3
CAADP Level 1 (CL1)	15.4	15.4	5.1	13.8	-13.3	7.9
CAADP Level 2 (CL2)	1.3	2.1	20.8	3.4	3.0	4.0
CAADP Level 3 (CL3)	3.0	3.0	-9.5	3.2	12.2	4.1
CAADP Level 4 (CL4)	3.7	3.5	-10.1	3.3	-7.9	2.5

Source: ReSAKSS based on OECD (2017) and World Bank (2017).
Note: Data are from 2002 to 2015.
ODA and food aid refer to gross disbursements.

TABLE O.1.2A—GENERAL GOVERNMENT GROSS DEBT (% of GDP)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	63.9	-3.7	51.1	32.4	-18.1	23.1	3.6	26.4
Central	125.6	-3.9	93.8	56.1	-22.0	19.2	-4.7	18.1
Eastern	92.4	-3.2	82.3	51.6	-21.4	35.4	1.6	35.1
Northern	48.2	-6.1	38.5	27.2	-15.3	18.3	2.0	19.8
Southern	45.3	-2.5	36.7	28.0	-7.0	34.6	7.8	43.6
Western	83.2	-3.0	62.1	30.6	-30.6	11.4	1.3	13.1
Less favorable agriculture conditions	101.0	-0.7	85.8	52.1	-21.2	34.1	3.6	38.2
More favorable agriculture conditions	73.7	-2.2	67.5	46.8	-19.0	30.6	3.2	35.2
Mineral-rich countries	204.0	0.9	176.0	103.2	-22.1	30.6	-10.8	23.9
Middle-income countries	57.2	-4.4	44.6	28.2	-17.4	21.7	4.4	25.0
CEN-SAD	69.8	-3.2	57.4	35.0	-20.6	19.8	0.9	20.9
COMESA	76.6	-2.9	68.4	46.1	-17.9	28.4	0.6	29.5
EAC	62.4	-2.6	58.0	37.2	-21.9	22.9	2.9	25.3
ECCAS	124.8	-6.6	84.5	47.9	-25.1	20.3	0.3	23.3
ECOWAS	83.2	-3.0	62.1	30.6	-30.6	11.4	1.3	13.1
IGAD	98.4	-2.5	90.3	56.3	-21.3	35.1	-0.5	32.6
SADC	54.6	-3.0	43.4	31.8	-9.9	34.8	6.8	42.7
UMA	55.8	-6.4	40.2	25.7	-17.6	18.6	2.4	19.8
CAADP Compact 2007–09 (CC1)	75.0	-3.0	56.8	25.1	-38.9	7.6	5.7	9.5
CAADP Compact 2010–12 (CC2)	116.7	-2.3	96.9	63.6	-18.6	34.6	-1.5	35.9
CAADP Compact 2013–15 (CC3)	111.2	-5.5	83.9	50.9	-21.2	36.6	4.9	42.4
CAADP Compact not yet (CC0)	37.4	-3.9	31.6	24.6	-7.8	24.9	5.1	28.7
CAADP Level 0 (CL0)	37.4	-3.9	31.6	24.6	-7.8	24.9	5.1	28.7
CAADP Level 1 (CL1)	114.0	-5.1	87.1	53.3	-20.3	39.7	5.0	46.0
CAADP Level 2 (CL2)	144.4	-2.4	114.0	74.1	-19.5	27.9	-8.6	22.0
CAADP Level 3 (CL3)	119.8	1.4	112.9	63.3	-25.2	29.3	1.6	34.7
CAADP Level 4 (CL4)	79.2	-3.9	59.5	30.1	-30.9	12.8	3.2	15.1

Source: ReSAKSS based on ADB (2017) and World Bank (2017).

TABLE O.1.2B—GENERAL GOVERNMENT GROSS REVENUE (% of GDP)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	23.8	2.5	25.2	25.8	0.7	23.5	-2.0	21.6
Central	18.2	4.5	20.8	25.7	8.2	24.8	-2.8	22.2
Eastern	15.6	2.4	18.2	19.1	-0.5	16.5	-2.5	15.3
Northern	26.4	-0.3	26.3	28.9	4.4	27.8	-2.6	25.4
Southern	26.1	0.5	25.6	27.6	3.3	29.2	-0.3	29.2
Western	22.3	10.6	27.4	23.0	-8.6	15.7	-2.7	13.1
Less favorable agriculture conditions	17.7	3.5	20.7	22.5	2.5	22.1	0.6	21.8
More favorable agriculture conditions	19.0	-0.2	19.8	19.2	-3.5	18.8	1.3	19.3
Mineral-rich countries	14.4	1.8	16.1	15.8	-1.0	16.9	1.1	17.1
Middle-income countries	24.8	2.6	26.2	26.9	1.0	24.3	-2.4	22.1
CEN-SAD	21.6	3.8	23.7	22.5	-2.4	18.7	-2.4	17.9
COMESA	19.9	-1.7	19.8	20.6	1.3	19.5	-1.8	19.2
EAC	18.0	0.7	19.0	19.4	-0.8	18.3	0.2	18.4
ECCAS	26.4	3.2	26.6	31.7	7.2	30.5	-4.2	26.5
ECOWAS	22.3	10.6	27.4	23.0	-8.6	15.7	-2.7	14.6
IGAD	15.5	2.7	18.7	19.2	-1.0	16.1	-3.1	14.8
SADC	24.6	0.7	24.4	26.3	3.1	27.6	-0.4	26.6
UMA	28.5	2.0	30.3	33.3	4.1	31.9	-2.7	29.5
CAADP Compact 2007–09 (CC1)	22.7	12.3	28.4	23.5	-9.5	15.4	-3.0	12.6
CAADP Compact 2010–12 (CC2)	18.3	0.6	19.2	19.5	-0.8	19.3	1.0	19.8
CAADP Compact 2013–15 (CC3)	24.2	2.1	25.0	28.8	5.0	26.8	-4.2	22.3
CAADP Compact not yet (CC0)	25.3	0.0	25.2	27.5	4.0	27.9	-1.2	27.1
CAADP Level 0 (CL0)	25.3	0.0	25.2	27.5	4.0	27.9	-1.2	27.1
CAADP Level 1 (CL1)	25.7	1.7	26.2	29.5	4.2	27.7	-4.3	23.0
CAADP Level 2 (CL2)	13.3	5.2	16.0	19.1	4.0	18.1	0.0	17.8
CAADP Level 3 (CL3)	19.1	1.5	20.2	20.5	-1.2	18.4	0.6	18.4
CAADP Level 4 (CL4)	21.9	9.1	26.5	22.6	-8.0	16.3	-2.0	14.2

Source: ReSAKSS based on ADB (2017) and World Bank (2017).

TABLE O.1.3—ANNUAL INFLATION, GDP DEFLATOR (%)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	11.4	-3.1	8.4	9.0	0.8	9.3	0.2	4.6
Central	5.1	-0.7	3.1	9.6	2.9	0.7	0.2	-10.2
Eastern	14.2	-4.0	7.6	11.0	1.4	12.8	-1.2	7.5
Northern	6.6	-1.3	5.8	8.4	1.1	6.5	0.2	2.6
Southern	9.0	-0.7	8.7	7.2	0.5	6.8	-0.2	5.9
Western	21.5	-9.0	13.7	10.9	0.1	14.7	1.3	6.4
Less favorable agriculture conditions	6.1	-1.5	4.0	7.7	1.5	3.6	0.0	-0.1
More favorable agriculture conditions	9.2	-1.4	7.2	9.7	1.5	9.9	-1.5	7.5
Mineral-rich countries	16.2	-1.0	14.0	14.7	-0.9	8.9	0.0	7.2
Middle-income countries	11.7	-3.4	8.6	8.9	0.8	9.4	0.4	4.3
CEN-SAD	13.9	-5.1	9.2	9.2	0.6	11.9	0.5	6.2
COMESA	9.8	-2.1	8.4	10.0	1.0	12.0	-1.0	7.8
EAC	10.8	-1.1	6.3	10.9	1.1	9.4	-1.6	7.2
ECCAS	5.4	-0.8	3.5	9.8	2.7	1.1	0.2	-9.2
ECOWAS	21.5	-9.0	13.7	10.9	0.1	14.7	1.3	6.4
IGAD	15.0	-4.7	7.5	10.7	1.5	14.8	-1.5	8.3
SADC	9.3	-0.8	8.7	7.6	0.6	6.8	-0.2	5.9
UMA	7.3	-1.7	4.9	7.7	1.1	3.2	0.7	-1.2
CAADP Compact 2007–09 (CC1)	23.3	-9.9	14.8	12.0	0.2	15.9	1.2	7.1
CAADP Compact 2010–12 (CC2)	8.9	-1.2	6.0	7.5	1.0	6.8	-0.7	5.5
CAADP Compact 2013–15 (CC3)	11.4	-4.0	6.7	9.6	1.7	8.3	-0.7	-1.6
CAADP Compact not yet (CC0)	7.4	-0.9	6.8	7.7	0.9	6.5	0.1	4.0
CAADP Level 0 (CL0)	7.4	-0.9	6.8	7.7	0.9	6.5	0.1	4.0
CAADP Level 1 (CL1)	12.7	-4.4	7.6	10.7	1.8	9.6	-0.3	-0.1
CAADP Level 2 (CL2)	4.3	-0.7	3.3	5.5	0.6	2.5	-1.7	-4.6
CAADP Level 3 (CL3)	10.6	-1.4	8.1	8.3	0.5	8.3	-2.0	5.4
CAADP Level 4 (CL4)	20.5	-7.8	13.1	11.4	0.4	14.3	1.0	7.1

Source: ReSAKSS based on World Bank (2017).

ANNEX 5: Supplementary Data Tables

TABLE O.2.1A—AGRICULTURAL EXPORTS (% of total merchandise exports)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	11.1	-3.4	9.5	7.4	-7.7	9.4	7.3	12.7
Central	5.2	-9.2	3.3	2.7	-4.7	3.1	1.1	3.9
Eastern	45.8	-7.0	33.3	28.5	-5.8	34.2	7.8	42.7
Northern	6.0	-7.1	4.6	4.5	0.1	7.3	10.2	11.1
Southern	11.0	-1.8	10.1	7.7	-9.4	8.4	4.5	9.9
Western	11.6	1.1	11.8	8.0	-11.7	10.6	9.4	16.0
Less favorable agriculture conditions	22.4	-6.5	15.0	11.2	-2.8	12.3	2.6	15.1
More favorable agriculture conditions	49.9	-3.0	41.2	37.9	-2.2	38.3	0.7	40.0
Mineral-rich countries	7.1	1.1	7.8	7.8	-5.5	7.5	3.4	9.0
Middle-income countries	8.6	-2.6	7.7	5.8	-8.5	7.6	7.6	10.5
CEN-SAD	12.8	-2.4	11.1	8.3	-8.7	11.2	9.8	17.0
COMESA	21.7	-6.4	14.1	11.0	-7.3	16.5	12.2	25.0
EAC	56.7	-3.9	44.5	43.0	-0.5	42.4	1.1	45.4
ECCAS	3.1	-9.4	2.0	1.5	-8.6	1.7	4.0	2.3
ECOWAS	11.6	1.1	11.8	8.0	-11.7	10.6	9.4	16.0
IGAD	48.5	-8.9	31.7	26.0	-7.7	35.1	11.0	46.5
SADC	12.4	-2.0	11.4	8.9	-9.2	9.4	4.4	11.1
UMA	5.6	-8.7	3.9	3.6	-0.4	5.7	12.6	9.4
CAADP Compact 2007–09 (CC1)	6.6	2.1	7.4	5.4	-11.4	8.1	11.1	12.5
CAADP Compact 2010–12 (CC2)	42.4	-1.3	37.1	32.4	-4.3	29.5	0.2	31.4
CAADP Compact 2013–15 (CC3)	9.6	-6.3	7.2	4.4	-16.8	4.0	7.2	5.4
CAADP Compact not yet (CC0)	7.7	-3.9	6.6	5.6	-3.5	8.2	7.3	11.0
CAADP Level 0 (CL0)	7.7	-3.9	6.6	5.6	-3.5	8.2	7.3	11.0
CAADP Level 1 (CL1)	9.9	-5.8	7.4	4.5	-17.4	3.8	7.1	5.0
CAADP Level 2 (CL2)	17.5	-2.4	16.1	14.4	-5.3	14.6	1.5	18.2
CAADP Level 3 (CL3)	18.7	1.9	20.6	20.6	-0.4	18.6	-1.5	19.3
CAADP Level 4 (CL4)	15.8	-0.8	14.6	10.7	-8.9	14.5	9.6	21.3

Source: ReSAKSS based on UNCTAD (2017) and World Bank (2017).

ANNEX 5: *Supplementary Data Tables*

TABLE O.2.1B—AGRICULTURAL IMPORTS (% of total merchandise imports)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	15.2	-0.4	14.7	13.4	-3.4	14.0	0.8	14.1
Central	17.1	-1.5	16.9	17.0	-1.3	16.3	2.1	17.9
Eastern	15.1	0.3	14.7	13.0	-3.4	14.0	-0.7	13.3
Northern	20.1	-3.0	17.7	15.7	-2.3	16.1	0.8	16.0
Southern	9.3	1.2	9.6	8.6	-3.6	9.7	1.1	10.4
Western	17.0	3.0	18.0	16.4	-5.1	16.6	1.5	16.5
Less favorable agriculture conditions	21.7	-0.8	19.8	20.4	-1.8	18.4	-1.2	17.7
More favorable agriculture conditions	13.9	0.1	14.8	14.0	-2.3	13.4	-1.4	13.0
Mineral-rich countries	15.8	0.3	16.7	14.4	-3.2	12.9	-1.7	12.5
Middle-income countries	15.1	-0.5	14.5	13.1	-3.5	14.0	1.2	14.2
CEN-SAD	16.7	-0.1	16.1	14.7	-3.2	15.7	0.9	15.4
COMESA	17.6	-0.5	17.2	15.4	-2.6	16.7	0.1	16.0
EAC	13.6	-2.6	12.2	11.6	-2.1	11.5	-1.0	10.8
ECCAS	20.2	-0.5	19.5	17.9	-3.8	16.8	1.9	18.1
ECOWAS	17.0	3.0	18.0	16.4	-5.1	16.6	1.5	16.5
IGAD	14.6	0.9	14.0	12.3	-3.7	13.7	-1.4	12.9
SADC	10.1	0.7	10.5	9.5	-3.4	10.4	0.8	10.9
UMA	19.6	-3.9	16.5	14.8	-1.3	14.8	1.1	15.3
CAADP Compact 2007–09 (CC1)	15.8	3.2	16.6	15.2	-5.7	15.1	1.3	14.9
CAADP Compact 2010–12 (CC2)	17.9	-0.3	17.6	16.0	-2.6	14.6	-1.9	13.9
CAADP Compact 2013–15 (CC3)	17.3	0.7	17.6	16.0	-2.5	17.9	2.1	19.1
CAADP Compact not yet (CC0)	13.8	-2.3	12.8	11.6	-2.4	12.6	0.9	12.7
CAADP Level 0 (CL0)	13.8	-2.3	12.8	11.6	-2.4	12.6	0.9	12.7
CAADP Level 1 (CL1)	17.5	0.8	17.7	16.0	-2.8	18.1	2.5	19.4
CAADP Level 2 (CL2)	22.0	-0.4	21.8	21.2	0.3	20.8	-1.4	20.4
CAADP Level 3 (CL3)	14.8	-0.5	15.2	13.4	-4.7	11.5	-1.1	11.4
CAADP Level 4 (CL4)	16.2	2.4	16.6	15.1	-5.0	14.7	0.2	14.2

Source: ReSAKSS based on UNCTAD (2017) and World Bank (2017).

ANNEX 5: Supplementary Data Tables

TABLE O.2.2—RATIO OF AGRICULTURAL EXPORTS TO AGRICULTURAL IMPORTS

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	0.8	-1.2	0.8	0.7	-5.6	0.6	1.4	0.7
Central	0.5	-6.7	0.4	0.3	-3.7	0.3	-7.4	0.2
Eastern	1.6	-5.3	1.3	1.2	-5.2	1.1	3.7	1.3
Northern	0.3	1.4	0.3	0.4	1.5	0.4	0.6	0.4
Southern	1.3	-3.0	1.1	0.9	-4.2	0.9	1.8	0.9
Western	1.0	-0.8	1.1	0.8	-10.8	0.8	1.8	0.9
Less favorable agriculture conditions	0.5	-8.3	0.4	0.4	3.4	0.5	2.0	0.5
More favorable agriculture conditions	2.1	-3.4	1.7	1.4	-5.4	1.3	2.5	1.4
Mineral-rich countries	0.5	-6.4	0.4	0.5	3.0	0.5	2.6	0.6
Middle-income countries	0.7	0.2	0.7	0.6	-6.4	0.6	1.0	0.6
CEN-SAD	0.8	-0.4	0.8	0.7	-8.4	0.6	1.6	0.7
COMESA	0.9	-1.7	0.8	0.7	-5.4	0.6	2.8	0.7
EAC	2.2	-1.9	2.1	1.8	-6.6	1.4	1.2	1.7
ECCAS	0.3	-9.5	0.2	0.2	0.7	0.2	-4.6	0.2
ECOWAS	1.0	-0.8	1.1	0.8	-10.8	0.8	1.8	0.9
IGAD	1.7	-7.0	1.3	1.1	-4.1	1.1	3.8	1.2
SADC	1.3	-2.9	1.1	0.9	-4.8	0.9	2.3	1.0
UMA	0.3	-0.4	0.3	0.4	2.6	0.4	0.6	0.4
CAADP Compact 2007–09 (CC1)	0.6	-0.3	0.7	0.6	-10.1	0.6	2.3	0.7
CAADP Compact 2010–12 (CC2)	2.0	-2.7	1.7	1.5	-4.8	1.4	1.1	1.5
CAADP Compact 2013–15 (CC3)	0.8	-5.4	0.6	0.5	-10.0	0.3	-0.9	0.3
CAADP Compact not yet (CC0)	0.5	1.8	0.5	0.5	-2.5	0.5	1.9	0.6
CAADP Level 0 (CL0)	0.5	1.8	0.5	0.5	-2.5	0.5	1.9	0.6
CAADP Level 1 (CL1)	0.8	-4.4	0.6	0.5	-10.1	0.3	-1.0	0.3
CAADP Level 2 (CL2)	0.9	-7.2	0.6	0.6	-4.8	0.5	-0.2	0.6
CAADP Level 3 (CL3)	0.9	-1.4	0.8	0.9	6.1	1.1	0.0	1.1
CAADP Level 4 (CL4)	1.3	-2.5	1.3	1.0	-8.4	1.0	2.6	1.1

Source: ReSAKSS based on UNCTAD (2017) and World Bank (2017).

TABLE O.3.1—TOTAL FERTILIZER CONSUMPTION (kilogram per hectare)

Region	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2014)	Annual avg. change (2008–2014)	2014
Africa	23.0	22.4	-1.2	24.4	3.7	26.5
Central	5.7	4.1	-1.6	4.4	4.6	4.6
Eastern	8.0	8.6	6.5	12.7	4.8	13.4
Northern	99.6	102.7	-1.2	107.9	2.4	114.0
Southern	35.3	33.7	1.1	35.0	1.8	37.1
Western	6.6	7.4	-0.2	9.7	13.6	12.8
Less favorable agriculture conditions	4.5	6.2	41.1	6.7	17.3	9.2
More favorable agriculture conditions	11.3	12.0	4.5	15.0	3.9	16.2
Mineral-rich countries	9.3	7.6	7.5	10.0	5.3	11.6
Middle-income countries	33.1	32.5	-1.9	35.8	3.7	38.9
CEN-SAD	26.4	26.3	-2.7	28.2	3.5	30.5
COMESA	37.0	35.1	-1.2	37.6	1.3	38.8
EAC	9.4	10.4	1.9	11.6	-0.8	10.9
ECCAS	4.8	4.1	5.2	5.6	7.0	6.2
ECOWAS	6.6	7.4	-0.2	9.7	13.6	12.8
IGAD	8.7	9.3	8.0	14.7	5.4	15.7
SADC	25.0	22.6	0.4	23.2	1.5	24.3
UMA	37.2	37.2	-1.1	38.4	6.9	43.8
CAADP Compact 2007–09 (CC1)	6.2	7.4	9.0	11.3	11.4	14.0
CAADP Compact 2010–12 (CC2)	9.8	9.8	0.3	10.9	3.8	12.0
CAADP Compact 2013–15 (CC3)	8.6	7.7	-2.7	10.8	7.1	12.0
CAADP Compact not yet (CC0)	81.8	83.2	-0.4	86.8	1.8	90.7
CAADP Level 0 (CL0)	81.8	83.2	-0.4	86.8	1.8	90.7
CAADP Level 1 (CL1)	8.3	7.5	-2.2	11.2	7.5	12.8
CAADP Level 2 (CL2)	5.1	3.7	-2.4	3.8	3.1	3.7
CAADP Level 3 (CL3)	6.6	7.7	7.8	9.0	11.5	11.5
CAADP Level 4 (CL4)	9.3	10.4	4.2	14.4	7.8	16.9

Source: ReSAKSS based on World Bank (2017) and FAO (2017).
Note: Data are from 2002 to 2014.

ANNEX 5: Supplementary Data Tables

TABLE O.3.2—AGRICULTURAL VALUE ADDED (% GDP)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	16.1	0.0	16.3	15.4	-2.0	15.5	0.6	15.5
Central	23.5	-4.6	18.8	18.4	-1.3	17.6	0.0	18.0
Eastern	34.2	-2.5	30.0	27.6	-3.1	28.6	2.0	30.0
Northern	13.2	-1.2	12.5	11.4	-4.2	11.2	0.8	11.7
Southern	5.5	-1.9	4.9	4.5	-1.7	4.0	-2.7	3.7
Western	24.9	3.0	28.3	25.8	-2.4	24.0	-1.0	23.4
Less favorable agriculture conditions	39.0	-1.5	34.2	37.4	4.1	37.7	-0.2	37.5
More favorable agriculture conditions	30.4	-2.8	27.7	27.7	0.1	28.7	-0.2	28.3
Mineral-rich countries	32.0	-4.2	25.5	23.5	-2.4	19.4	-4.5	16.3
Middle-income countries	13.3	1.3	14.2	13.1	-2.9	13.1	0.7	13.5
CEN-SAD	22.0	1.1	22.9	21.3	-2.6	20.4	0.1	20.7
COMESA	23.9	-2.0	21.4	19.9	-2.9	19.3	0.6	19.6
EAC	31.6	-3.4	27.6	25.9	-3.1	27.4	1.7	28.9
ECCAS	19.6	-1.5	19.7	19.2	-1.8	18.3	0.1	18.6
ECOWAS	24.9	3.0	28.3	25.8	-2.4	24.0	-1.0	23.4
IGAD	36.7	-2.1	31.8	29.0	-3.3	30.3	2.6	32.5
SADC	8.4	-3.7	7.3	6.8	-1.6	6.7	-0.8	6.6
UMA	11.6	-1.8	10.9	9.8	-5.2	10.5	3.2	11.8
CAADP Compact 2007–09 (CC1)	26.6	2.5	29.7	27.2	-2.1	25.5	-0.9	24.9
CAADP Compact 2010–12 (CC2)	28.2	-2.7	25.1	23.4	-2.7	23.1	-0.5	22.7
CAADP Compact 2013–15 (CC3)	21.0	1.6	22.5	20.6	-4.0	19.8	3.0	22.0
CAADP Compact not yet (CC0)	8.7	-1.0	8.3	7.5	-3.6	7.4	0.3	7.6
CAADP Level 0 (CL0)	8.7	-1.0	8.3	7.5	-3.6	7.4	0.3	7.6
CAADP Level 1 (CL1)	20.6	2.1	22.4	20.2	-5.0	19.1	3.5	21.6
CAADP Level 2 (CL2)	29.7	-4.8	23.8	22.7	-0.5	21.9	-2.2	20.5
CAADP Level 3 (CL3)	31.5	-2.4	27.2	26.3	-0.6	25.0	-1.1	23.6
CAADP Level 4 (CL4)	26.2	1.6	28.4	26.2	-2.4	25.0	-0.6	24.6

Source: ReSAKSS based on UNCTAD (2017) and World Bank (2017).

TABLE O.4.1—GROSS DOMESTIC PRODUCT (constant 2010 US$, billion)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	64.8	3.2	77.2	92.7	7.0	127.1	4.0	143.6
Central	11.7	-0.3	12.3	14.1	5.3	20.2	6.3	24.6
Eastern	16.3	4.2	19.3	23.3	7.9	35.5	6.4	43.7
Northern	98.3	4.3	115.3	131.0	5.4	174.1	3.7	196.8
Southern	106.0	2.2	116.2	130.3	4.9	153.3	1.6	161.1
Western	86.2	3.7	111.7	145.3	9.5	217.1	4.8	248.6
Less favorable agriculture conditions	3.6	5.0	4.5	5.3	6.2	7.7	5.7	9.1
More favorable agriculture conditions	12.3	3.5	14.2	16.8	7.6	27.0	7.5	34.0
Mineral-rich countries	10.5	-1.4	10.7	12.5	6.3	19.0	6.9	23.5
Middle-income countries	110.9	3.6	134.4	162.8	7.2	223.6	4.0	252.3
CEN-SAD	78.3	3.9	97.5	121.1	8.0	173.4	4.5	198.1
COMESA	38.5	3.4	43.6	49.7	5.8	67.0	4.0	76.8
EAC	15.7	3.6	18.3	21.4	6.4	31.3	6.0	37.9
ECCAS	14.1	1.0	15.2	19.5	10.7	30.4	5.5	36.2
ECOWAS	86.2	3.7	111.7	145.3	9.5	217.1	4.8	248.6
IGAD	18.2	4.1	21.4	25.8	8.1	39.6	6.4	48.7
SADC	64.4	1.9	69.9	78.1	4.8	92.8	2.0	99.0
UMA	71.1	3.9	83.8	94.2	4.2	119.5	3.9	135.8
CAADP Compact 2007–09 (CC1)	77.0	3.6	99.3	129.3	9.6	195.8	5.1	226.0
CAADP Compact 2010–12 (CC2)	12.6	2.1	14.0	16.2	5.9	23.4	6.2	28.6
CAADP Compact 2013–15 (CC3)	19.7	4.4	23.0	28.7	10.0	41.5	3.7	47.1
CAADP Compact not yet (CC0)	132.9	3.6	152.8	171.6	4.6	212.5	3.2	235.5
CAADP Level 0 (CL0)	132.9	3.6	152.8	171.6	4.6	212.5	3.2	235.5
CAADP Level 1 (CL1)	20.1	4.3	23.4	29.8	10.9	43.7	3.6	49.4
CAADP Level 2 (CL2)	12.0	-0.4	12.5	14.3	5.3	20.5	6.5	25.3
CAADP Level 3 (CL3)	6.1	5.2	7.5	8.9	7.1	13.4	5.4	15.8
CAADP Level 4 (CL4)	62.6	3.6	80.1	103.7	9.4	156.5	5.1	181.4

Source: ReSAKSS based on World Bank (2017) and ILO (2017).
Notes: For regions or groups, level is weighted average, where weight is country's share in total population for the region or group.

ANNEX 5: Supplementary Data Tables

TABLE O.5.1—GLOBAL HUNGER INDEX (GHI)

Region	Annual avg. level (1995–2003)	Annual avg. change (1995–2003)	2003	Annual avg. level (2003–2008)	Annual avg. change (2003–2008)	Annual avg. level (2008–2016)	Annual avg. change (2008–2016)	2016
Africa	36.8	-1.8	33.9	32.1	-2.4	27.2	-2.7	24.6
Central	43.0	-1.4	40.4	38.9	-1.5	34.5	-2.1	31.9
Eastern	46.8	-2.1	42.5	39.8	-3.0	33.2	-2.8	29.8
Northern	16.0	-1.8	15.0	14.3	-1.9	12.5	-2.2	11.5
Southern	36.5	-1.6	33.9	32.2	-2.2	27.9	-2.4	25.5
Western	41.2	-2.2	37.5	35.2	-2.6	29.1	-3.2	25.8
Less favorable agriculture conditions	49.9	-2.0	45.6	42.7	-3.1	36.0	-2.4	32.8
More favorable agriculture conditions	46.2	-2.1	42.0	39.3	-3.0	32.9	-2.8	29.6
Mineral-rich countries	47.2	-1.2	44.5	43.1	-1.3	38.9	-1.9	36.2
Middle-income countries	29.1	-1.9	26.8	25.4	-2.1	21.6	-2.9	19.3
CEN-SAD	34.0	-1.9	31.4	29.8	-2.2	25.3	-2.8	22.7
COMESA	38.9	-1.8	35.9	33.9	-2.4	28.9	-2.6	26.2
EAC	34.8	-1.6	32.0	30.3	-2.3	25.8	-2.7	23.2
ECCAS	48.3	-1.9	44.2	41.7	-2.6	35.3	-2.7	31.9
ECOWAS	41.2	-2.2	37.5	35.2	-2.6	29.1	-3.2	25.8
IGAD	49.2	-2.4	44.3	41.1	-3.3	33.4	-3.3	29.5
SADC	37.6	-1.5	35.1	33.4	-2.1	29.4	-2.1	27.1
UMA	15.2	-2.4	13.7	12.7	-3.6	10.3	-3.0	9.2
CAADP Compact 2007–09 (CC1)	45.7	-2.4	41.1	38.2	-3.2	30.8	-3.4	27.0
CAADP Compact 2010–12 (CC2)	32.4	-1.7	29.8	28.2	-2.3	24.2	-2.5	22.0
CAADP Compact 2013–15 (CC3)	32.3	-1.4	30.1	28.8	-1.9	25.6	-2.0	23.7
CAADP Compact not yet (CC0)	14.6	-1.8	13.6	13.0	-1.7	11.4	-2.2	10.5
CAADP Level 0 (CL0)	14.6	-1.8	13.6	13.0	-1.7	11.3	-2.2	10.5
CAADP Level 1 (CL1)	31.0	-1.3	29.1	28.0	-1.7	25.2	-1.7	23.6
CAADP Level 2 (CL2)	16.5	-1.9	15.0	14.0	-2.9	11.6	-3.1	10.3
CAADP Level 3 (CL3)	40.4	-1.7	37.4	35.3	-2.5	30.4	-2.3	27.9
CAADP Level 4 (CL4)	44.4	-2.3	40.2	37.5	-2.9	30.7	-3.3	27.2

Source: ReSAKSS based on IFPRI, WHH, and Concern Worldwide (2016), World Bank (2017) and ILO (2017).

References

ARRANGED BY CHAPTER

Executive Summary

Sulser, T. B., D. Mason-D'Croz, S. Islam, S. Robinson, K. Wiebe, and M. W. Rosegrant. 2015. "Africa in the Global Agricultural Economy in 2030 and 2050." In *Beyond a Middle Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes*. ReSAKSS Annual Trends and Outlook Report 2014, edited by O. Badiane and T. Makombe, 5–37. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/publication/africa-global-agricultural-economy-2030-and-2050.

Chapter 1

Below, T. B., K. D. Mutabazi, D. Kirschke, C. Franke, S. Sieber, R. Siebert, and K. Tscherning. 2012. "Can Farmers' Adaptation to Climate Change Be Explained by Socio-economic Household-Level Variables?" *Global Environmental Change* 22: 223–235. doi:10.1016/j.gloenvcha.2011.11.012.

FAO (Food and Agriculture Organization of the United Nations) and PAR (Platform for Agrobiodiversity Research). 2011. *Biodiversity for Food and Agriculture: Contributing to Food Security and Sustainability in a Changing World*. Rome: FAO.

Hachigonta, S., G. C. Nelson, T. S. Thomas, and L. M. Sibanda. 2013. *Southern African Agriculture and Climate Change: A Comprehensive Analysis*. Research Monograph. Washington, DC: International Food Policy Research Institute.

Hatfield, J. L., and J. H. Pruege. 2015. "Temperature Extremes: Effect on Plant Growth and Development." *Weather and Climate Extremes* 10: 4–10.

Hatfield, J. L., G. Takle, R. Grothjahn, P. Holden, R. C. Izaurralde, T. Mader, E. Marshall, and D. Liverman. 2014. "Agriculture." In *Climate Change Impacts in the United States: The Third National Climate Assessment*, edited by J. M. Melillo, T. C. Richmond, and G. W. Yohe, 150–174. Washington, DC: US Global Change Research Program. doi:10.7930/J02Z13FR.

IPCC (Intergovernmental Panel on Climate Change). 2014. Climate Change 2014: *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva.

Jalloh, A., G. C. Nelson, T. S. Thomas, R. Zougmoré, and H. Roy-Macauley, eds. 2013. *West African Agriculture and Climate Change: A Comprehensive Analysis*. Research Monograph. Washington, DC: International Food Policy Research Institute.

Jarvis, A., C. Lau, S. Cook, E. Wollenberg, J. Hansen, O. Bonilla, and A. Challinor. 2011. "An Integrated Adaptation and Mitigation Framework for Developing Agricultural Research: Synergies and Trade-Offs." *Experimental Agriculture* 47: 185–203.

Jones, P. G., and P. K. Thornton. 2008. "Croppers to Livestock Keepers: Livelihood Transitions to 2050 in Africa due to Climate Change." *Environmental Science & Policy* 12 (4): 427–437.

Lobell, D. B., and C. B. Field. 2007. "Global Scale Climate–Crop Yield Relationships and the Impacts of Recent Warming." *Environmental Research Letters* 2 (1): 014002.

Lobell, D. B., W. Schlenker, and J. Costa-Roberts. 2011. "Climate Trends and Global Crop Production Since 1980." *Science* 333 (6042): 616–620.

McCarthy, N., L. Lipper, and G. Branca. 2011. *Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation*. Mitigation of Climate Change in Agriculture Series 4. Rome: Food and Agriculture Organization of the United Nations.

Morton, J. F. 2007. "The Impact of Climate Change on Smallholder and Subsistence Agriculture." *Proceedings of the National Academy of Sciences of the United States of America* 104 (50): 19680–19685. doi:10.1073/pnas.0701855104.

National Research Council. 2011. *America's Climate Choices*. Washington, DC: The National Academies Press.

Nelson, G. C., M. W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. B. Sulser, C. Ringler, S. Msangi, and L. You. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy*

Options. Research Monograph. Washington, DC: International Food Policy Research Institute. doi:10.2499/9780896291867.

Sulser, T. B., D. Mason-D'Croz, S. Islam, S. Robinson, K. Wiebe, and M. W. Rosegrant. 2015. "Africa in the Global Agricultural Economy in 2030 and 2050." In *Beyond a Middle Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes*. ReSAKSS Annual Trends and Outlook Report 2014, edited by O. Badiane and T. Makombe, 5–37. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/publication/africa-global-agricultural-economy-2030-and-2050.

Waithaka, M., G. C. Nelson, T. S. Thomas, and M. Kyotalimye. 2013. *East African Agriculture and Climate Change: A Comprehensive Analysis*. Research Monograph. Washington, DC: International Food Policy Research Institute.

Chapter 2

De Onis, M., M. Blossner, and E. Borghi. 2010. "Global Prevalence and Trends of Overweight and Obesity among Preschool Children." *American Journal of Clinical Nutrition* 92: 1257–1264.

———. 2012. "Prevalence and Trends of Stunting among Pre-school Children, 1990–2020. *Public Health Nutrition* 15 (1): 142–148.

De Pinto, A., K. Wiebe, and M. W. Rosegrant. 2016. *Climate Change and Agricultural Policy Options: A Global-to-Local Approach*. Policy Brief. Washington, DC: International Food Policy Research Institute.

FAO (Food and Agriculture Organization of the United Nations). 2016. *The State of Food and Agriculture: Climate Change, Agriculture and Food Security*. Rome.

———. 2017. FAOSTAT database. Accessed July 7. http://faostat.fao.org.

Fuglie, K., and N. Rada. 2013. *Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa*. Economic Research Report ERR-145. Washington, DC: United States Department of Agriculture, Economic Research Service.

Fuglie, K., and S. L. Wang. 2012. "Productivity Growth in Global Agriculture Shifting to Developing Countries." *Choices* 27 (4): 1–7.

Hachigonta, S., G. Nelson, T. S. Thomas, and L. M. Sibanda, eds. 2013. *Southern African Agriculture and Climate Change: A Comprehensive Analysis*. Washington, DC: International Food Policy Research Institute.

IFPRI (International Food Policy Research Institute). 2017. "International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)." In *Global Food Policy Report 2017*, 110–118. Washington, DC: International Food Policy Research Institute.

Islam, S., N. Cenacchi, T. B. Sulser, S. Gbegbelegbe, G. Hareau, U. Kleinwechter, D. Mason-D'Croz, S. Nedumaran, R. Robertson, S. Robinson, and K. Wiebe. 2016. "Structural Approaches to Modeling the Impact of Climate Change and Adaptation Technologies on Crop Yields and Food Security." *Global Food Security* 10: 63–70.

Jalloh, A., G. C. Nelson, T. S. Thomas, R. Zougmoré, and H. Roy-Macauley, eds. 2013. *West African Agriculture and Climate Change: A Comprehensive Analysis*. Washington, DC: International Food Policy Research Institute.

Jones, C. D., J. K. Hughes, N. Bellouin, S. C. Hardiman, G. S. Jones, J. Knight, S. Liddicoat, et al. 2011. "The HadGEM2-ES Implementation of CMIP5 Centennial Simulations." *Geoscientific Model Development* 4 (3): 543–570.

Mason-D'Croz, D., T. B. Sulser, K. Wiebe, M. W. Rosegrant, S. Lowder, A. Nin-Pratt, T. Zhu, and N. Cenacchi. 2016. *IMPACT Projections of Investments in Agriculture and Implications for Reducing Hunger in Africa by 2030: Results from the IMPACT Model, Version 3.3*. Project Report. Washington DC, USA: International Food Policy Research Institute (IFPRI).

Moss, R., M. Babiker, S. Brinkman, E. Calvo, T. Carter, J. Edmonds, I. Elgizouli, et al. 2008. *Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies*. Technical Summary. Geneva: Intergovernmental Panel on Climate Change.

Nowak, R. S. 2017. "CO2 Fertilization: Average Is Best." *Nature Climate Change* 7: 101–102. doi:10.1038/nclimate3212.

Obermeier, W. A., L. W. Lehnert, C. I. Kammann, C. Müller, L. Grünhage, J. Luterbacher, M. Erbs, et al. 2016. "Reduced CO2 Fertilization Effect in Temperate C3 Grasslands under More Extreme Weather Conditions." *Nature Climate Change* 7: 137–141. doi: 10.1038/NCLIMATE3191.

O'Neill, B. C., E. Kriegler, K. Riahi, K. L. Ebi, S. Hallegatte, T. R. Carter, R. Mathur, and D. P. van Vuuren. 2014. "A New Scenario Framework for Climate Change Research: The Concept of Shared Socioeconomic Pathways." *Climatic Change* 122 (3): 387–400.

Robertson, R. 2015. Background report for presentation "Trends and Scenarios for Food Security" by M. W. Rosegrant, "IFPRI at 40: Looking Back, Looking Forward." Special Event on 18 November 2015.

Robinson, S., D. Mason-D'Croz, S. Islam, T. B. Sulser, R. Robertson, T. Zhu, A. Gueneau, G. Pitois, and M. W. Rosegrant. 2015. *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3*. Discussion Paper 01483. Washington, DC: International Food Policy Research Institute.

Rosegrant, M. W., J. Koo, N. Cenacchi, C. Ringler, R. Robertson, M. Fisher, C. Cox, K. Garrett, N. D. Perez, and P. Sabbagh. 2014. *Food Security in a World of Natural Resource Scarcity: The Role of Agricultural Technologies*. Washington, DC: International Food Policy Research Institute.

Rosegrant, M. W., C. Ringler, S. Msangi, T. B. Sulser, T. Zhu, and S. A. Cline. 2008. *International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description*. Washington, DC: International Food Policy Research Institute.

Rosegrant, M. W., T. B. Sulser, D. Mason-D'Croz, N. Cenacchi, A. Nin-Pratt, S. Dunston, T. Zhu, et al. 2017. *Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio*. Project Report. Washington, DC: International Food Policy Research Institute.

Sulser, T. B., D. Mason-D'Croz, S. Islam, S. Robinson, K. Wiebe, and M. W. Rosegrant. 2015. "Africa in the Global Agricultural Economy in 2030 and 2050." In *Beyond a Middle Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes*. ReSAKSS Annual Trends and Outlook Report 2014, edited by O. Badiane and T. Makombe, 5–37. Washington, DC: International Food Policy Research Institute.

Thomas, T. S., and M. W. Rosegrant. 2015. "Climate Change Impact on Key Crops in Africa: Using Crop Models and General Equilibrium Models to Bound the Prediction." In *Climate Change and Food Systems: Global Assessments and Implications for Food Security and Trade*, edited by A. Elbehri, 146–175. Rome: Food and Agriculture Organization of the United Nations.

United Nations, Department of Economic and Social Affairs, Population Division. 2014. *World Urbanization Prospects: The 2014 Revision*. New York: United Nations. CD-ROM.

———. 2017. *World Population Prospects: The 2017 Revision*. New York: United Nations.

van Ittersum, M. K., L. G. J. van Bussel, J. Wolf, P. Grassini, J. van Wart, N. Guilpart, L. Claessens, et al. 2016. "Can Sub-Saharan Africa Feed Itself?" *Proceedings of the National Academy of Sciences* 52 (113): 14964–14969.

Waithaka, M., G. Nelson, T. S. Thomas, and M. Kyotalimye, eds. 2013. *East African Agriculture and Climate Change: A Comprehensive Analysis*. Washington, DC: International Food Policy Research Institute.

Wiebe, K., H. Lotze-Campen, R. Sands, A. Tabeau, D. van der Mensbrugghe, A. Biewald, B. Bodirsky, et al. 2015. "Climate Change Impacts on Agriculture in 2050 under a Range of Plausible Socioeconomic and Emissions Scenarios." *Environmental Research Letters* 10 (8): 085010. doi:10.1088/1748-9326/10/8/085010.

Chapter 3

Agegnehu, G., C. vanBeek, and M. I. Bird. 2014. "Influence of Integrated Soil Fertility Management in Wheat and Tef Productivity and Soil Chemical Properties in the Highland Tropical Environment." *Journal of Soil Science and Plant Nutrition* 14 (3): 532–545. doi:10.4067/S0718-95162014005000042.

Ayres, R.U., L. W. Ayres, and B. Warr. 2003. "Exergy, Power and Work in the U. S. Economy, 1900–1998." *Energy* 28 (3): 219–273.

Bandaogo, A., F. Bidjokazo, S. Youl, E. Safo, R. Abaidoo, and O. Andrews. 2015. "Effect of Fertilizer Deep Placement with Urea Supergranule on Nitrogen Use Efficiency of Irrigated Rice in Sourou Valley (Burkina Faso)." *Nutrient Cycling in Agroecosystems* 102 (1): 79–89. doi:10.1007/s10705-014-9653-6.

Below, T. B., K. D. Mutabazi, D. Kirschke, C. Franke, S. Sieber, R. Siebert, and K. Tscherning. 2012. "Can Farmers' Adaptation to Climate Change Be Explained by Socio-economic Household-Level Variables?" *Global Environmental*

Change 22 (1): 223–235. doi:10.1016/j.gloenvcha.2011.11.012.

Bewket, W. 2007. “Soil and Water Conservation Intervention with Conventional Technologies in Northwestern Highlands of Ethiopia: Acceptance and Adoption by Farmers.” *Land Use Policy* 24: 404–416.

Carlson, K.M., J.S. Gerber, N.D. Mueller, M. Herrero, G.K. MacDonald, K.A. Brauman, P. Havlik, et al. 2016. “Greenhouse Gas Emissions Intensity of Global Croplands.” *Nature Climate Change* 7 (1): 63–68. doi:10.1038/nclimate3158.

Chivenge, P., B. Vanlauwe, and J. Six. 2011. “Does the Combined Application of Organic and Mineral Nutrient Sources Influence Maize Productivity? A Meta-analysis.” *Plant and Soil* 342: 1–30.

Comas, J., D. Connor, M. E. M. Isselmou, L. Mateos, and H. Gómez-Macpherson. 2012. “Why Has Small-Scale Irrigation Not Responded to Expectations with Traditional Subsistence Farmers along the Senegal River in Mauritania?” *Agricultural Systems* 110: 152–161.

Corbeels, M., J. de Graaff, T. H. Ndah, E. Penot, F. Baudron, K. Naudin, N. Andrieu, et al. 2014. “Understanding the Impact and Adoption of Conservation Agriculture in Africa: A Multi-scale Analysis.” *Agriculture, Ecosystems & Environment* 187: 155–170. doi:10.1016/j.agee.2013.10.011.

Darwin, R., M. Tsigas, J. Lewandrowski, and A. Raneses. 1995. *World Agriculture and Climate Change: Economic Adaptations*. Agricultural Economic Report AER-703. Washington, DC: US Department of Agriculture Economic Research Service.

———. 1996. “Land Use and Cover in Ecological Economics.” *Ecological Economics* 17: 157–181. doi:10.1016/S0921-8009(96)80004-8.

de Nijs, P. J., N. J. Berry, G. J. Wells, and D. S. Reay. 2015. “Quantification of Biophysical Adaptation Benefits from Climate-Smart Agriculture Using a Bayesian Belief Network.” *Scientific Reports* 4:6682. doi:10.1038/srep06682.

de Vries, M. E., J. Rodenburg, B. V. Bado, A. Sow, P. A. Leffelaar, and K. E. Giller. 2010. “Rice Production with Less Irrigation Water Is Possible in a Sahelian Environment.” *Field Crops Research* 116 (1–2): 154–164.

Devkota, K. P., A. M. Manschadi, J. P. A. Lamers, E. Humphreys, M. Devkota, O. Egamberdiev, R. K. Gupta, K. D. Sayre, and P. L. G. Vlek. 2013. “Field Crops Research Growth and Yield of Rice (Oryza sativa L.) under Resource Conservation Technologies in the Irrigated Drylands of Central Asia.” *Field Crops Research* 149: 115–126. doi:10.1016/j.fcr.2013.04.015.

Dunne, J. P., J. G. John, A. J. Adcroft, S. M. Griffies, R. W. Hallberg, E. Shevliakova, R. J. Stouffer, et al. 2012. “GFDL’s ESM2 Global Coupled Climate–Carbon Earth System Models. Part I: Physical Formulation and Baseline Simulation Characteristics.” *Journal of Climate* 25: 6646–6665. doi:10.1175/JCLI-D-11-00560.1.

Easterling, W. E., P. K. Aggarwal, P. Batima, K. M. Brander, L. Erda, S. M. Howden, A. Kirilenko, J. Morton, J. F. Soussana, J. Schmidhuber, and F. N. Tubiello. 2007. “Food, Fibre and Forest Products.” In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, 273–313. Cambridge, UK: Cambridge University Press.

Elbehri, A., J. Elliott, and T. Wheele. 2015. “Climate Change, Food Security and Trade: An Overview of Global Assessments and Policy Insights.” In *Climate Change and Food Systems: Global Assessments and Implications for Food Security and Trade*, edited by A. Elbehri, 1–27. Rome: Food Agriculture Organization of the United Nations.

Enfors, E. I., and L. J. Gordon. 2008. “Dealing with Drought: The Challenge of Using Water System Technologies to Break Dryland Poverty Traps.” *Global Environmental Change—Human and Policy Dimensions* 18: 607–616.

Erenstein, O., U. Farooq, R. K. Malik, and M. Sharif. 2008. “On-Farm Impacts of Zero Tillage Wheat in South Asia’s Rice–Wheat Systems.” *Field Crops Research* 105: 240–252. doi:10.1016/j.fcr.2007.10.010.

Erenstein, O., K. Sayre, P. Wall, J. Hellin, and J. Dixon. 2012. “Conservation Agriculture in Maize- and Wheat-Based Systems in the (Sub)tropics: Lessons from Adaptation Initiatives in South Asia, Mexico, and Southern Africa.” *Journal of Sustainable Agriculture* 36: 180–206.

FAO (Food and Agriculture Organization of the United Nations). 2009a. *Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies*. Rome.

———. 2009b. *The State of Food Insecurity in the World 2009: Economic Crises—Impacts and Lessons Learned.* Rome.

———. 2010. *"Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation*. Rome.

———. 2013. *Climate-Smart Agriculture Sourcebook*. Rome.

———. 2017. *The State of Food and Agriculture*. Rome.

———. 2017. FAOSTAT database. Accessed June 2017. www.fao.org/faostat/en/#home.

Fischer, G., K. Frohberg, M. L. Parry, and C. Rosenzweig. 1993. "Climate Change and World Food Supply, Demand and Trade." In *Costs, Impacts and Benefits of CO_2 Mitigation*, edited by Y. Kaya, N. Nakicenovic, W. D. Nordhaus, and F. L. Toth, 133–152. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Fischer, G., and H. T. van Velthuizen. 1996. *Climate Change and Global Agricultural Potential Project: A Case of Kenya*. Working Paper WP-96-071. Laxenburg, Austria: International Institute for Applied Systems Analysis.

Frelat, R., S. Lopez-Ridaura, K. E. Giller, M. Herrero, S. Douxchamps, A. A. Djurfeldt, O. Erenstein, et al. 2016. "Drivers of Household Food Availability in Sub-Saharan Africa Based on Big Data from Small Farms." *Proceedings of the National Academy of Sciences of the United States of America* 113: 458–463. doi:10.1073/pnas.1518384112.

Gaihre, Y. K., U. Singh, S. M. Mofijul Islam, A. Huda, M. R. Islam, M. A. Satter, J. Sanabria, Md. R. Islam, and A. L. Shah. 2015. "Impacts of Urea Deep Placement on Nitrous Oxide and Nitric Oxide Emissions from Rice Fields in Bangladesh." *Geoderma* 259: 370–379. doi: 10.1016/j.geoderma.2015.06.001.

Gentile, R., B. Vanlauwe, P. Chivenge, and J. Six. 2008. "Interactive Effects from Combining Fertilizer and Organic Residue Inputs on Nitrogen Transformations." *Soil Biology and Biochemistry* 40: 2375–2384. doi: 10.1016/j.soilbio.2008.05.018.

Hachigonta, S., G. C. Nelson, T. S. Thomas, and L. M. Sibanda. 2013. *Southern African Agriculture and Climate Change: A Comprehensive Analysis*. Washington, DC: International Food Policy Research Institute.

Hobbs, P. R., K. Sayre, and R. Gupta. 2008. "The Role of Conservation Agriculture in Sustainable Agriculture." *Philosophical Transactions of the Royal Society B—Biological Sciences* 363: 543–555.

Huda, A., Y. K. Gaihre, M. R. Islam, U. Singh, Md. R. Islam, J. Sanabria, M. A. Satter, H. Afroz, A. Halder, and M. Jahiruddin. 2016. "Floodwater Ammonium, Nitrogen Use Efficiency and Rice Yields with Fertilizer Deep Placement and Alternate Wetting and Drying under Triple Rice Cropping Systems." *Nutrient Cycling in Agroecosystems* 104: 53–66. doi:10.1007/s10705-015-9758-6.

IFDC (International Fertilizer Development Center). 2011. "Urea Deep Placement: Hope for Food Self-Sufficiency in West Africa." September 23. https://ifdc.org/2011/09/23/urea-deep-placement-hope-for-food-self-sufficiency-in-west-africa/.

Jalloh, A., G. C. Nelson, T. S. Thomas, R. Zougmoré, and H. Roy-Macauley, eds. 2013. *West African Agriculture and Climate Change: A Comprehensive Analysis*. Washington, DC: International Food Policy Research Institute.

Jones, C. D., J. K. Hughes, N. Bellouin, S. C. Hardiman, G. S. Jones, J. Knight, S. Liddicoat, et al. 2011. "The HadGEM2-ES Implementation of CMIP5 Centennial Simulations." *Geoscientific Model Development* 4: 543–570.

Jones, J. W., G. Hoogenboom, C. H. Porter, K. J. Boote, W. D. Batchelor, L. A. Hunt, P. W. Wilkens, U. Singh, A. J. Gijsman, and J. T. Ritchie. 2003. "The DSSAT Cropping System Model." *European Journal of Agronomy* 18: 235–265.

Kassam, A., T. Friedrich, F. Shaxson, and J. Pretty. 2009. "The Spread of Conservation Agriculture: Justification, Sustainability and Uptake." *International Journal of Agricultural Sustainability* 7 (4): 292–320.

Knight, J., and S. Harrison. 2012. "The Impacts of Climate Change on Terrestrial Earth Surface Systems." *Nature Climate Change* 3: 24–29. doi:10.1038/nclimate1660.

Lal, R. 2015. "Sequestering Carbon and Increasing Productivity by Conservation Agriculture." *Journal of Soil and Water Conservation* 70: 55A–62A.

Lampayan, R.M. 2012. Water Saving Work Group. "Development, Dissemination, and Adoption of Technologies to Help Farmers Cope with Water Scarcity." Presentation at the Meta-impact Assessment Inception Meeting, International Rice Research Institute, Los Baños, Philippines.

Leys, C. C. Ley, O. Klein, P. Bernard, and L. Licata. 2013. "Detecting Outliers: Do Not Use Standard Deviation Around the Mean, Use Absolute Deviation Around the Median." *Journal of Experimental Social Psycology* 49 (4): 764–766.

Lobell, D. B., and S. M. Gourdji. 2012. "The Influence of Climate Change on Global Crop Productivity." *Plant Physiology* 160: 1686–1697. doi:10.1104/pp.112.208298.

McCarthy, N., L. Lipper, and G. Branca. 2011. *Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation*. Mitigation of Climate Change in Agriculture Series 4. Rome: Food and Agriculture Organization of the United Nations.

Morton, J. F. 2007. "The Impact of Climate Change on Smallholder and Subsistence Agriculture." *Proceedings of the National Academy of Sciences of the United States of America* 104:19680–19685. doi:10.1073/pnas.0701855104.

Nelson, G. C., M. W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T. B. Sulser, C. Ringler, S. Msangi, and L. You. 2010. *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options*. Washington, DC: International Food Policy Research Institute. doi:10.1111/an.1995.36.5.41.

Niang, I., O. C. Ruppel, M. A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart. 2014. "Africa." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by V. R. Barros, C. B. Field, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, et al., 1199–1265. Cambridge, UK: Cambridge University Press.

O'Neill, B. C., E. Kriegler, K. Riahi, K. L. Ebi, S. Hallegatte, T. R. Carter, R. Mathur, and D. P. van Vuuren. 2014. "A New Scenario Framework for Climate Change Research: The Concept of Shared Socioeconomic Pathways." *Climatic Change* 122: 387–400.

Pandey, A., V. T. Mai, D. Q. Vu, T. P. L. Bui, T. L. A. Mai, L. S. Jensen, and A. de Neergaard. 2014. "Organic Matter and Water Management Strategies to Reduce Methane and Nitrous Oxide Emissions from Rice Paddies in Vietnam." *Agriculture, Ecosystems & Environment* 196: 137–146. doi:10.1016/j.agee.2014.06.010.

Parry, M. L., C. Rosenzweig, A. Iglesias, M. Livermore, and G. Fischer. 2004. "Effects of Climate Change on Global Food Production under SRES Emissions and Socio-economic Scenarios." *Global Environmental Change* 14: 53-67.

Pittelkow, C. M., X. Q. Liang, B. A. Linquist, K. J. van Groenigen, J. Lee, M. E. Lundy, N. van Gestel, J. Six, R. T. Venterea, and C. van Kessel. 2015. "Productivity Limits and Potentials of the Principles of Conservation Agriculture." *Nature* 517: 365–482.

Pittelkow, C. M., B. A. Linquist, M. E. Lundy, X. Liang, K. J. van Groenigen, J. Lee, N. van Gestel, J. Six, R. T. Venterea, and C. van Kessel. 2015. "When Does No-Till Yield More? A Global Meta-analysis." *Field Crops Research* 183: 156–168. doi: 10.1016/j.fcr.2015.07.020.

Powlson, D. S., C. M. Stirling, M. L. Jat, B. G. Gerard, C. A. Palm, P. A. Sanchez, and K. G. Cassman. 2014. "Limited Potential of No-Till Agriculture for Climate Change Mitigation." *Nature Climate Change* 4: 678–683.

Reicosky, D. C., M. J. Lindstrom, T. E. Schumacher, D. E. Lobb, and D. D. Malo. 2005. "Tillage-Induced CO2 Loss across an Eroded Landscape." *Soil and Tillage Research* 81: 183–194. doi:10.1016/j.still.2004.09.007.

Rejesus, R. M., F. G. Palis, D. Gracia, P. Rodriguez, R. M. Lampayan, and B. A. M. Bouman. 2010. "Impact of the Alternate Wetting and Drying (AWD) Water-Saving Irrigation Technique: Evidence from Rice Producers in the Philippines." *Food Policy* 36 (2): 280–288. doi:10.1016/j.foodpol.2010.11.026.

Robinson, S., D. Mason-D'Croz, S. Islam, T. B. Sulser, R. Robertson, T. Zhu, A. Gueneau, G. Pitois, and M. W. Rosegrant. 2015. *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description for Version 3*. Discussion Paper 01483. Washington, DC: International Food Policy Research Institute.

Rosegrant, M. W. 2008. *Biofuels and Grain Prices: Impacts and Policy Responses*. Testimony for the U.S. Senate Committee on Homeland Security and Governmental Affairs.

Washington, DC: International Food Policy Research Institute. www.ifpri.org/publication/biofuels-and-grain-prices.

Rosegrant, M. W., J. Koo, N. Cenacchi, C. Ringler, R. Robertson, M. Fisher, C. Cox, K. Garrett, N. D. Perez, and P. Sabbagh. 2014. *Food Security in a World of Natural Resource Scarcity: The Role of Agricultural Technologies*. Washington, DC: International Food Policy Research Institute.

Rosenstock, T. S., C. Lamanna, S. Chesterman, P. Bell, A. Arslan, M. Richards, J. Rioux, et al. 2016. "The Scientific Basis of Climate-Smart Agriculture: A Systematic Review Protocol." CCAFS Working Paper 138, CGIAR Research Program on Climate Change, Agriculture and Food Security, Copenhagen, Denmark.

Rosenthal, S., and P. Kurukulasuriya. 2003. *Climate Change and Agriculture: A Review of Impacts and Adaptations*. Climate Change Series 91. Washington, DC: World Bank. doi:10.1016/0169-5347(91)90186-2.

Rosenzweig, C., J. Elliott, D. Deryng, A. C. Ruane, C. Müller, A. Arneth, K. J. Boote, et al. 2014. "Assessing Agricultural Risks of Climate Change in the 21st Century in a Global Gridded Crop Model Intercomparison." *Proceedings of the National Academy of Sciences of the United States of America* 111: 3268–3273. doi:10.1073/pnas.1222463110.

Rosenzweig, C., and M. L. Parry. 1994. "Potential Impact of Climate Change on World Food Supply." *Nature* 367: 133–138. doi:10.1038/367133a0.

Sain, G., A. M. Loboguerrero, C. Corner-Dolloff, M. Lizarazo, A. Nowak, D. Martínez-Barón, and N. Andrieu. 2017. "Costs and Benefits of Climate-Smart Agriculture: The Case of the Dry Corridor in Guatemala." *Agricultural Systems* 151: 163–173. doi:10.1016/j.agsy.2016.05.004.

Schlenker, W., and D. B. Lobell. 2010. "Robust Negative Impacts of Climate Change on African Agriculture." *Environmental Research Letters* 5: 14010. doi:10.1088/1748-9326/5/1/014010.

Shiferaw, B. A., J. Okello, and R. V. Reddy. 2009. "Adoption and Adaptation of Natural Resource Management Innovations in Smallholder Agriculture: Reflections on Key Lessons and Best Practices." *Environment, Development and Sustainability* 11: 601–619. doi:10.1007/s10668-007-9132-1.

Smith, P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, et al. 2014. "Agriculture, Forestry and Other Land Use (AFOLU)." In *Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, et al., 811–922. New York: Cambridge University Press.

Springmann, M., D. Mason-D'Croz, S. Robinson, T. Garnett, H. C. J. Godfray, D. Gollin, M. Rayner, P. Ballon, and P. Scarborough. 2016. "Global and Regional Health Effects of Future Food Production under Climate Change: A Modelling Study." *Lancet* 387: 1937–1946. doi:10.1016/S0140-6736(15)01156-3.

Teklewold, H., and G. Kohlin. 2011. "Risk Preferences as Determinants of Soil Conservation Decisions in Ethiopia." *Journal of Soil and Water Conservation* 66: 87–96.

Thierfelder, C., M. Mwila, and L. Rusinamhodzi. 2013. "Conservation Agriculture in Eastern and Southern Provinces of Zambia: Long-Term Effects on Soil Quality and Maize Productivity." *Soil and Tillage Research* 126: 246–258.

Thomas, T. S., and M. C. Rosegrant. 2015. "Climate Change Impact on Key Crops in Africa: Using Crop Models and General Equilibrium Models to Bound the Prediction." In *Climate Change and Food Systems: Global Assessments and Implications for Food Security and Trade*, edited by A. Elbehri, 146–175. Rome: Food and Agriculture Organization of the United Nations.

Thornton, P. K., P. G. Jones, P. J. Ericksen, and A. J. Challinor. 2010. "Agriculture and Food Systems in Sub-Saharan Africa in a 4°C+ World." *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 369: 117–136.

Tyagi, L., B. Kumari, and S. N. Singh. 2010. "Water Management—A Tool for Methane Mitigation from Irrigated Paddy Fields." *Science of the Total Environment* 408: 1085–1090. doi:10.1016/j.scitotenv.2009.09.010.

Vanlauwe, B., A. B. Bationo, J. N. Chianu, K. E. Giller, R. Merckx, U. Mokwunye, O. Ohiokpehai, et al., . 2010. "Integrated Soil Fertility Management Operational Definition and Consequences for Implementation and Dissemination." *Outlook on Agriculture* 39 (1): 17–24.

Vanlauwe, B., J. Kihara, P. Chivenge, P. Pypers, R. Coe, and J. Six. 2011. "Agronomic Use Efficiency of N Fertilizer in Maize-Based Systems in Sub-Saharan Africa within the Context of Integrated Soil Fertility Management." *Plant and Soil* 339: 35–50.

Vermeulen, S., and E. Wollenberg. 2017. *A Rough Estimate of the Proportion of Global Emissions from Agriculture due to Smallholders*. CGIAR Program on Climate Change, Agriculture and Food Security Info Note. Montpellier, France: CGIAR.

Waha, K., C. Müller, A. Bondeau, J. P. Dietrich, P. Kurukulasuriya, J. Heinke, and H. Lotze-Campen. 2013. "Adaptation to Climate Change through the Choice of Cropping System and Sowing Date in Sub-Saharan Africa." *Global Environmental Change* 23:130–143. doi:10.1016/j.gloenvcha.2012.11.001.

Waithaka, M., G. C. Nelson, T. S. Thomas, and M. Kyotalimye. 2013. *East African Agriculture and Climate Change: A Comprehensive Analysis*. Washington, DC: International Food Policy Research Institute.

Wheeler, T., and J. von Braun. 2013. "Climate Change Impacts on Global Food Security." *Science* 341: 508–513. doi:10.1126/science.1239402.

Yan, X., H. Akiyama, K. Yagi, and H. Akimoto. 2009. "Global Estimations of the Inventory and Mitigation Potential of Methane Emissions from Rice Cultivation Conducted Using the 2006 Intergovernmental Panel on Climate Change Guidelines." *Global Biogeochemical Cycles* 23 (2): 3–25. doi:10.1029/2008GB003299.

You, L. Z., S. Wood, and U. Wood-Sichra. 2006. "Generating Global Crop Maps: From Census to Grid." Paper presented at International Association of Agricultural Economists conference, Gold Coast, Australia, August 11–18.

Zougmoré, R., S. Partey, M. Ouédraogo, B. Omitoyin, T. Thomas, A. Ayantunde, P. Ericksen, M. Said, and A. Jalloh. 2016. "Toward Climate-Smart Agriculture in West Africa: A Review of Climate Change Impacts, Adaptation Strategies and Policy Developments for the Livestock, Fishery and Crop Production Sectors." *Agriculture & Food Security* 5: 26. doi:10.1186/s40066-016-0075-3.

Chapter 4

Affognon, H., C. Mutungi, P. Sanginga, and C. Borgemeister. 2015. "Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-analysis." *World Development* 66: 49–68.

Amede, T., M. Menza, and S. B. Awlachew. 2011. "Zai Improves Nutrient and Water Productivity in the Ethiopian Highlands." *Experimental Agriculture* 47: 7–20.

Barrett, C. B., T. Reardon, and P. Webb. 2001. "Nonfarm Income Diversification and Household Livelihood Strategies in Rural Africa: Concepts, Dynamics, and Policy Implications." *Food Policy* 26: 315–331.

Barton, A. P., M. A. Fullen, D. J. Mitchell, T. J. Hocking, L. Liu, Z. W. Bo, Y. Zheng, and Z. Y. Xia. 2004. "Effects of Soil Conservation Measures on Erosion Rates and Crop Productivity on Subtropical Ultisols in Yunnan Province, China." *Agriculture, Ecosystems & Environment* 104 (2): 343–357.

Bryan, E., C. Ringler, B. Okoba, J. Koo, M. Herrero, and S. Silvestri. 2013. "Can Agriculture Support Climate Change Adaptation, Greenhouse Gas Mitigation and Rural Livelihoods? Insights from Kenya." *Climatic Change* 118 (2): 151–165.

Burney, J. A., and R. L. Naylor. 2012. "Smallholder Irrigation as a Poverty Alleviation Tool in Sub-Saharan Africa." *World Development* 40 (1): 110–123.

Challinor, A. J., J. Watson, D. B. Lobell, S. M. Howden, D. R. Smith, and N. Chhetri. 2014. "A Meta-analysis of Crop Yield under Climate Change and Adaptation." *Nature Climate Change* 4 (4): 287–291.

Chantarat, S., A. G. Mude, C. B. Barrett, and M. R. Carter. 2013. "Designing Index-Based Livestock Insurance for Managing Asset Risk in Northern Kenya." *Journal of Risk and Insurance* 80 (1): 205–237.

CIESIN (Center for International Earth Science Information Network). 2005. Gridded Population of the World Version 3: Population Grids. Socioeconomic Data and Applications Center, Columbia University. Accessed March 23, 2015. http://sedac.ciesin.columbia.edu/gpw.

Davies, M., B. Guenther, J. Leavy, T. Mitchell, and T. Tanner. 2009. *Climate Change Adaptation, Disaster Risk Reduction and Social Protection: Complementary Roles in Agriculture and Rural*

Growth? Working Paper 320. Sussex, UK: Institute of Development Studies.

Dercon, S. 1996. "Risk, Crop Choice, and Savings: Evidence from Tanzania." *Economic Development and Cultural Change* 44: 485–513.

Descheemaeker, K., T. Amede, and A. Haileslassie. 2010. "Improving Water Productivity in Mixed Crop–Livestock Farming Systems of Sub-Saharan Africa." *Agricultural Water Management* 97: 579–586.

Deshingkar, P. 2012. "Environmental Risk, Resilience and Migration: Implications for Natural Resource Management and Agriculture." *Environmental Research Letters* 7 (1): 015603.

Ehui, S., and J. Pender. 2005. "Resource Degradation, Low Agricultural Productivity, and Poverty in Sub-Saharan Africa: Pathways Out of the Spiral." *Agricultural Economics* 32 (S1): 225–242. http://onlinelibrary.wiley.com/doi/10.1111/j.0169-5150.2004.00026.x/epdf.

FAO (Food and Agriculture Organization of the United Nations). 2013. *Climate-Smart Agriculture Sourcebook*. Rome.

Galukande, E., H. Mulindwa, H. Wurzinger, M. Roschinsky, R. Mwai, and A. O. Solkner. 2013. "Cross-breeding Cattle for Milk Production in the Tropics: Achievements, Challenges and Opportunities." *Animal Genetic Resources* 52: 111–125.

Gebrehiwot, N. T., K. A. Mesfin, and J. Nyssen. 2015. "Small-Scale Irrigation: The Driver for Promoting Agricultural Production and Food Security (the Case of Tigray Regional State, Northern Ethiopia)." *Irrigation and Drainage Systems Engineering* 4: 141. http://dx.doi.org/10.4172/2168-9768.1000141.

Ghosh, P. K., M. Mohanty, K. K. Bandyopadhyay, D. K. Painuli, and A. K. Misra. 2006. "Growth, Competition, Yield Advantage and Economics in Soybean/Pigeonpea Intercropping System in Semi-arid Tropics of India: I. Effect of Subsoiling." *Field Crops Research* 96 (1): 80–89.

Giller, K. E., J. A. Andersson, M. Corbeels, J. Kirkegaard, D. Mortensen, O. Erenstein, and B. Vanlauwe. 2015. "Beyond Conservation Agriculture." *Frontiers in Plant Science* 6: 870.

Greatrex, H., J. W. Hansen, S. Garvin, R. Diro, S. Blakeley, M. Le Guen, K. N. Rao, and D. E. Osgood. 2015. *Scaling Up Index Insurance for Smallholder Farmers: Recent Evidence and Insights*. Report 14. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security. https://cgspace.cgiar.org/rest/bitstreams/38716/retrieve.

Hansen, J. W., S. J. Mason, L. Sun, and A. Tall. 2011. "Review of Seasonal Climate Forecasting for Agriculture in Sub-Saharan Africa." *Experimental Agriculture* 47 (2): 205–240.

Harris, D., and A. Orr. 2014. "Is Rainfed Agriculture Really a Pathway from Poverty?" *Agricultural Systems* 123: 84–96.

Henderson, B., P. Gerber, T. Hilinski, A. Falcucci, D. S. Ojima, M. Salvatore, and R. T. Conant. 2015. "Greenhouse Gas Mitigation Potential of the World's Grazing Lands: Modelling Soil Carbon and Nitrogen Fluxes of Mitigation Practices." *Agriculture, Ecosystems & Environment* 207: 91–100.

Herrero, M., P. Havlík, H. Valin, A. M. Notenbaert, M. Rufino, P. K. Thornton, M. Blummel, F. Weiss, and M. Obersteiner. 2013. "Global Livestock Systems: Biomass Use, Production, Feed Efficiencies and Greenhouse Gas Emissions." *Proceedings of the National Academy of Sciences* 110 (52): 20888–20893.

Herrero, M., P. K. Thornton, A. Notenbaert, S. Msangi, S. Wood, R. L. Kruska, J. Dixon, et al. 2009. *Drivers of Change in Crop-Livestock Systems and Their Potential Impacts on Agro-ecosystems Services and Human Well-Being to 2030*. Nairobi, Kenya: International Livestock Research Institute.

Herrero, M., P. K. Thornton, A. Notenbaert, S. Wood, S. Msangi, H. A. Freeman, D. Bossio, et al. 2010. "Smart Investments in Sustainable Food Production: Revisiting Mixed Crop-Livestock Systems." *Science* 327: 822–825.

Hoffmann, I. 2010. "Climate Change and the Characterization, Breeding and Conservation of Animal Genetic Resources." *Animal Genetics* 41 (S1): 32–46.

Kerr, K. B., S. S. Snapp, M. Chirwa, L. Shumba, and R. Msachi. 2007. "Participatory Research on Legume Diversification with Malawian Smallholder Farmers for Improved Human Nutrition and Soil Fertility." *Experimental Agriculture* 43 (4): 437–453.

Kimaro, A. A., M. Mpanda, J. Rioux, E. Aynekulu, S. Shaba, M. Thiong'o, P. Mutuo, et al. 2015. "Is Conservation Agriculture 'Climate-

Smart' for Maize Farmers in the Highlands of Tanzania?" *Nutrient Cycling in Agroecosystems* 105 (3): 217–228.

Kitinoja, L., and A. A. Kader. 2003. *Small-Scale Postharvest Handling Practices: A Manual for Horticultural Crops*. Davis, CA, US: Postharvest Technology Research and Information Centre.

Kraaijvanger, R., and T. Veldkamp. 2015. "Rain Productivity, Fertilizer Response and Nutrient Balance of Farming Systems in Tigray, Ethiopia: A Multi-perspective View in Relation to Soil Fertility Degradation." *Land Degradation and Development* 26: 701–710.

Kurwakumire, N., R. Chikowo, F. Mtambanengwe, P. Mapfumo, S. Snapp, A. Johnston, and S. Zingore. 2014. "Maize Productivity and Nutrient and Water Use Efficiencies across Soil Fertility Domains on Smallholder Farms in Zimbabwe." *Field Crops Research* 164: 136–147.

La Rovere, R., T. Abdoulaye, G. Kostandini, Z. Guo, W. Mwangi, J. MacRobert, and J. Dixon. 2014. "Economic, Production, and Poverty Impacts of Investing in Maize Tolerant to Drought in Africa: An Ex-Ante Assessment." *Journal of Developing Areas* 48 (1): 199–225.

Lal, R. 1997. "Residue Management, Conservation Tillage and Soil Restoration for Mitigating Greenhouse Effect by CO2-Enrichment." *Soil and Tillage Research* 43: 81–107.

Liu, J., L. You, M. Amini, M. Obersteiner, M. Herrero, A. J. B. Zehnder, and H. Yang. 2010. "A High-Resolution Assessment on Global Nitrogen Flows in Cropland." *Proceedings of the National Academy of Sciences* 107 (17): 8035–8040.

Lowder, S. K., J. Skoet, and S. Singh. 2014. *What Do We Really Know about the Number and Distribution of Farms and Family Farms Worldwide?* Agricultural Development Economics Division (ESA) Working Paper 14-02. Rome: Food and Agriculture Organization of the United Nations.

Mulumba, L. N., and R. Lal. 2008. "Mulching Effects on Selected Soil Physical Properties." *Soil and Tillage Research* 98 (1): 106–111.

Mureithi, J. G., C. K. K. Gachene, and J. Ojiem. 2003. "The Role of Green Manure Legumes in Smallholder Farming Systems in Kenya: The Legume Research Network Project." *Tropical and Subtropical Agroecosystems* 1: 57–70.

Ramirez-Villegas, J., and P. K. Thornton. 2015. *Climate Change Impacts on Crop Production*. Working Paper 119. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Rao, I. M., M. Peters, R. van der Hoek, A. Castro, G. Subbarao, and G. Cadisch, and A. Rincón. 2014. "Tropical Forage–Based Systems for Climate-Smart Livestock Production in Latin America." *Rural21* 48 (4): 12–15. www.rural21.com/english/news/detail/article/tropical-forage-based-systems-for-climate-smart-livestock-production-in-latin-america-00001322/.

Rosenstock, T. S., C. Lamanna, A. Arslan, and M. Richards. 2015. *What Is the Scientific Basis for Climate-Smart Agriculture? Preliminary Findings from a Quantitative Synthesis of What Works*. Info Note. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Rosenstock, T. S., C. Lamanna, S. Chesterman, P. Bell, A. Arslan, M. Richards, J. Rioux, et al. 2016. *The Scientific Basis of Climate-Smart Agriculture: A Systematic Review Protocol*. Working Paper 138. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Rufino, M. C., P. K. Thornton, S. K. Ng'ang'a, I. Mutie, P. G. Jones, M. T. van Wijk, and M. Herrero. 2013. "Transitions in Agro-pastoralist Systems of East Africa: Impacts on Food Security and Poverty." *Agriculture, Ecosystems and Environment* 179: 215–230.

Russelle, M. P., M. H. Entz, and A. J. Franzluebbers. 2007. "Reconsidering Integrated Crop–Livestock Systems in North America." *Agronomy Journal* 99: 325–334.

Seebauer, M. 2014. "Whole Farm Quantification of GHG Emissions within Smallholder Farms in Developing Countries." *Environmental Research Letters* 9 (3): 035006. doi:10.1088/1748-9326/9/3/035006.

Seré, C., and H. Steinfeld. 1996. *World Livestock Production Systems: Current Status, Issues and Trends*. Animal Production and Health Paper 127. Rome: Food and Agriculture Organization of the United Nations.

Shumba, E. M., S. R. Waddington, and M. Rukuni. 1992. "The Use of Tine-Tillage, with Atrazine Weed Control, to Permit Earlier Planting of Maize by Smallholder Farmers in Zimbabwe." *Experimental Agriculture* 28 (4): 443–452.

Smith, C. 1984. “Rates of Genetic Change in Farm Livestock.” *Research and Development in Agriculture* 1:79–85.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, et al. 2008. “Greenhouse Gas Mitigation in Agriculture.” *Philosophical Transactions of the Royal Society B* 363: 789–813.

Snapp, S. S., S. M. Swinton, R. Labarta, D. Mutch, J. R. Black, R. Leep, J. Nyiraneza, and K. O’Neil. 2005. “Evaluating Cover Crops for Benefits, Costs and Performance within Cropping System Niches.” *Agronomy Journal* 97 (1): 322–332.

Srinivasarao, C., B. Venkateswarlu, A. K. Singh, K. P. R. Vittal, S. Kundu, G. R. Chary, G. N. Gajanan, and B. K. Ramachandrappa. 2012. “Critical Carbon Inputs to Maintain Soil Organic Carbon Stocks under Long-Term Finger-Millet (Eleusine coracana [L.] Gaertn.) Cropping on Alfisols in Semiarid Tropical India.” *Journal of Plant Nutrition and Soil Science* 175 (5): 681–688.

St. Clair, S. B., and J. P. Lynch. 2010. “The Opening of Pandora’s Box: Climate Change Impacts on Soil Fertility and Crop Nutrition in Developing Countries.” *Plant Soil* 335: 101–115.

Sumberg, J. 2003. “Toward a Disaggregated View of Crop–Livestock Integration in Western Africa.” *Land Use Policy* 20: 253–264.

Taddesse, G., D. Peden, A. Abiye, and A. Wagnew. 2003. “Effect of Manure on Grazing Lands in Ethiopia, East African Highlands.” *Mountain Research and Development* 23 (2): 156–160.

Thierfelder, C., and P. C. Wall. 2009. “Effects of Conservation Agriculture Techniques on Infiltration and Soil Water Content in Zambia and Zimbabwe.” *Soil and Tillage Research* 105: 217–227.

Thomas, D. S. G., C. Twyman, H. Osbahr, and B. Hewitson. 2007. “Adaptation to Climate Change and Variability: Farmer Responses to Intra-seasonal Precipitation Trends in South Africa.” *Climatic Change* 83: 301–322.

Thornton, P. K., R. B. Boone, K. A. Galvin, S. B. BurnSilver, M. M. Waithaka, J. Kuyiah, S. Karanja, E. González-Estrada, and M. Herrero. 2007. “Coping Strategies in Livestock-Dependent Households in East and Southern Africa: A Synthesis of Four Case Studies.” *Human Ecology* 35 (4): 461–476.

Thornton P. K., and M. Herrero. 2010. “The Potential for Reduced Methane and Carbon Dioxide Emissions from Livestock and Pasture Management in the Tropics.” *Proceedings of the National Academy of Sciences* 107 (46): 19667–19672.

———. 2014. “Climate Change Adaptation in Mixed Crop-Livestock Systems in Developing Countries.” *Global Food Security* 3: 99–107.

———. 2015. “Adapting to Climate Change in the Mixed Crop-Livestock Farming Systems in Sub-Saharan Africa.” *Nature Climate Change* 5: 830–836.

van Keulen, H., and H. Schiere. 2004. “Crop-Livestock Systems: Old Wine in New Bottles?” In *New Directions for a Diverse Planet: Proceedings of the Fourth International Crop Science Congress, 26 Sep–1 Oct 2004, Brisbane, Australia*. Madison, WI, US: Crop Science Society of America. www.cropscience.org.au/icsc2004/symposia/2/1/211_vankeulenh.htm.

van Wijk, M. T., P. Tittonell, M. C. Rufino, M. Herrero, C. Pacini, N. de Ridder, and K. E. Giller. 2009. “Identifying Key Entry-Points for Strategic Management of Smallholder Farming Systems in Sub-Saharan Africa Using the Dynamic Farm-Scale Simulation Model NUANCES-FARMSIM.” *Agricultural Systems* 102 (1): 89–101.

Vermeulen, S. J., A. J. Challinor, P. K. Thornton, B. M. Campbell, N. Eriyagama, J. M. Vervoort, J. Kinyangi, et al. “Addressing Uncertainty in Adaptation Planning for Agriculture.” *Proceedings of the National Academy of Sciences* 110 (21): 8357–8362.

Walraevens, K., T. Gebreyohannes Tewolde, K. Amare, A. Hussein, G. Berhane, R. Baert, S. Ronsse, et al. 2015. “Water Balance Components for Sustainability Assessment of Groundwater-Dependent Agriculture: Example of the Mendae Plain (Tigray, Ethiopia).” *Land Degradation & Development* 26 (7): 725–736.

Westermann O., P. Thornton, and W. Förch. 2015. *Reaching More Farmers: Innovative Approaches to Scaling Up Climate Smart Agriculture*. Working Paper 135. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Zingore, S., H. K. Murwira, R. J. Delve, and K. E. Giller. 2007. “Influence of Nutrient Management Strategies on Variability of Soil

Fertility, Crop Yields and Nutrient Balances on Smallholder Farms in Zimbabwe." *Agriculture, Ecosystems & Environment* 119: 112–126.

Zougmoré, R., A. Mando, and L. Stroosnijder. 2004. "Effect of Soil and Water Conservation and Nutrient Management on the Soil-Plant Water Balance in Semi-arid Burkina Faso." *Agricultural Water Management* 65: 103–120.

Chapter 5

African Union Commission. 2015. *Agenda 2063: The Africa We Want*. Addis Ababa, Ethiopia.

Barrett, C. 2008. "Smallholder Market Participation: Concepts and Evidence from Eastern and Southern Africa." *Food Policy* 33: 299–317.

Berg, A., N. de Noblet-Ducoudre, B. Sultan, M. Lengaigne, and M. Guimberteau. 2013. "Projections of Climate Change Impacts on Potential C4 Crop Productivity over Tropical Regions." *Agricultural and Forest Meteorology* 170: 89–102.

Bewket, W. 2007. "Soil and Water Conservation Intervention with Conventional Technologies in Northwestern Highlands of Ethiopia: Acceptance and Adoption by Farmers." *Land Use Policy* 24: 404–416.

Cameron, A. C., and P. K. Trivedi. 2005. *Microeconometrics: Methods and Applications*. New York: Cambridge University Press.

Campbell, B., P. Thornton, R. Zougmoré, P. Asten, and L. Lipper. 2014. "Sustainable Intensification: What Is Its Role in Climate Smart Agriculture?" *Current Opinion in Environmental Sustainability* 8: 39–43.

Corbeels, M., J. de Graaff, T. Ndah, E. Penot, F. Baudron, K. Naudin, N. Andrieu, et al. 2014. "Understanding the Impact and Adoption of Conservation Agriculture in Africa: A Multi-scale Analysis." *Agriculture, Ecosystems & Environment* 187: 155–170.

Davis, W. 2016. "Tracking Regional Integration in Africa." *Bridges Africa* 5 (8): 18–20.

Dillon, B., and C. Barrett. 2016. "Agricultural Factor Markets in Sub-Saharan Africa: An Updated View with Formal Tests for Market Failure." *Food Policy* 67: 64–77.

Enfors, E. I., and L. J. Gordon. 2008. "Dealing with Drought: The Challenge of Using Water System Technologies to Break Dryland Poverty Traps." *Global Environmental Change—Human and Policy Dimensions*18: 607–616.

Erenstein, O., K. Sayre, P. Wall, J. Hellin, and J. Dixon. 2012. "Conservation Agriculture in Maize- and Wheat-Based Systems in the (Sub) tropics: Lessons from Adaptation Initiatives in South Asia, Mexico, and Southern Africa." *Journal of Sustainable Agriculture* 36: 180–206.

FAO (Food and Agriculture Organization of the United Nations). 2013. "Module 1: Why Climate-Smart Agriculture, Forestry and Fisheries." In *Climate Smart Agriculture Sourcebook*, 1–40. Rome.

———. 2017. FAOSTAT database. Accessed May 10. www.fao.org/faostat.

Foster, A., and M. Rosenzweig. 2010. "Microeconomics of Technology Adoption." *Annual Review of Economics* 2: 1–29.

Hebebrand, C. 2009. "Climate Change, Agriculture and Trade: Understanding the Linkages." *BIORES* 3 (1): 4.

Hobbs, P. R., K. Sayre, and R. Gupta. 2008. "The Role of Conservation Agriculture in Sustainable Agriculture." *Philosophical Transactions of the Royal Society B–Biological Sciences* 363: 543–555.

Hoogenboom, G., J. W. Jones, P. W. Wilkens, C. H. Porter, K. J. Boote, L. A. Hunt, U. Singh, et al. 2015. *Decision Support System for Agrotechnology Transfer (DSSAT) Version 4.6*. Prosser, Wash., US: DSSAT Foundation.

Huang, H., M. Lampe, and F. Tongeren. 2011. "Climate Change and Trade in Agriculture." *Food Policy* 36 (1S): S9–S13.

IFPRI (International Food Policy Research Institute) and IIASA (International Institute for Applied Systems Analysis). 2016. Global Spatially-Disaggregated Crop Production Statistics Data for 2005 Version 3.1. Accessed March 7, 2017. https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/DHXBJX.

IMF (International Monetary Fund). 2016. *Regional Economic Outlook: sub-Saharan Africa. Time for a Policy Reset*. Washington, DC.

IPCC (Intergovernmental Panel on Climate Change). 2007. *Climate Change 2007: Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press.

IRI (International Research Institute for Climate and Society), MSU (Michigan State University), HarvestChoice, and IFPRI. 2015. Global High-Resolution Soil Profile Database for Crop Modeling Applications. Accessed March 7, 2017. https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/1PEEY0.

Jones, J. W., G. Hoogenboom, C. H. Porter, K. J. Boote, W. D. Batchelor, L. A. Hunt, P. W. Wilkens, U. Singh, A. J. Gijsman, and J. T. Ritchie. 2003. "DSSAT Cropping System Model." *European Journal of Agronomy* 18: 235–265.

Kang, Y., S. Khan, and X. Ma. 2009. "Climate Change Impacts on Crop Yield, Crop Water Productivity and Food Security—A Review." *Progress in Natural Science* 19 (12): 1665–1674.

Khandelwal, P. 2005. *COMESA and SADC: Prospects and Challenges for Regional Trade Integration.* Occasional Paper 0-2005/1. Brugge, Belgium: United Nations University–Comparative Regional Integration Studies.

Knox, J., T. Hess, A. Daccache, and T. Wheeler. 2012. "Climate Change Impacts on Crop Productivity in Africa and South Asia." *Environmental Research Letters* 7 (3): 034032.

Lal, R. 2015. "Sequestering Carbon and Increasing Productivity by Conservation Agriculture." *Journal of Soil and Water Conservation* 70: 55A–62A.

Lesk, C., and P. R. N. Ramankutty. 2016. "Influence of Extreme Weather Disasters on Global Crop Production." *Nature* 529 (2): 84–87.

McCarthy, N., L. Lipper, and G. Branca. 2011. *Climate-Smart Agriculture: Smallholder Adoption and Implications for Climate Change Adaptation and Mitigation*. Mitigation of Climate Change in Agriculture Series 4. Rome: Food and Agriculture Organization of the United Nations.

Müller, C., and R. D. Robertson. 2014. "Projecting Future Crop Productivity for Global Economic Modeling." *Agricultural Economics* 45: 37–50.

Pittelkow, C. M., X. Q. Liang, B. A. Linquist, K. J. van Groenigen, J. Lee, M. E. Lundy, N. van Gestel, J. Six, R. T. Venterea, and C. van Kessel. 2015. "Productivity Limits and Potentials of the Principles of Conservation Agriculture." *Nature* 517: 365–368.

Rakotoarisoa, M. A., M. Iafrate, and M. Paschali. 2011. *Why Has Africa Become a Net Food Importer? Explaining African Agricultural and Food Trade Deficits.* Rome: Food and Agriculture Organization of the United Nations.

Reicosky, D. C., M. J. Lindstrom, T. E. Schumacher, D. E. Lobb, and D. D. Malo. 2005. "Tillage-Induced CO_2 Loss across an Eroded Landscape." *Soil and Tillage Research* 81: 183–194.

Rejesus, R. M., F. G. Palis, D. Gracia, P. Rodriguez, R. M. Lampayan, and B. A. M. Bouman. 2011. "Impact of the Alternate Wetting and Drying (AWD) Water-Saving Irrigation Technique: Evidence from Rice Producers in the Philippines." *Food Policy* 36 (2): 280–288.

Roobroeck, D., P. Van Asten, B. Jama, R. Harawa, and B. Vanlauwe, B. 2016. "Integrated Soil Fertility Management: Contributions of Framework and Practices to Climate-Smart Agriculture." Practice Brief Climate-smart agriculture. Global Alliance for Climate-Smart Agriculture.

Ruane, A. C., R. Goldberg, and J. Chryssanthacopoulos. 2015. "AgMIP Climate Forcing Datasets for Agricultural Modeling: Merged Products for Gap-Filling and Historical Climate Series Estimation." *Agricultural and Forest Meteorology* 200: 233–248.

Seid, E. H. 2013. *Regional Integration and Trade in Africa: Augmented Gravity Model Approach*. Addis Ababa, Ethiopia: The Horn Economic and Social Policy Institute.

Serdeczny, O., S. Adams, F. Baarsch, D. Coumou, A. Robinson, B. Hare, M. Schaeffer, M. Perrette, and J. Reinhardt. 2017. "Climate Change Impacts in Sub-Saharan Africa: From Physical Changes to Their Social Repercussions." *Regional Environmental Change* 17 (6): 1585–1600.

Shiferaw, B. A., J. Okello, and R. V. Reddy. 2009. "Adoption and Adaptation of Natural Resource Management Innovations in Smallholder Agriculture: Reflections on Key Lessons and Best Practices." *Environment, Development and Sustainability* 11: 601–619. doi:10.1007/s10668-007-9132-1.

Smith, P., M. Bustamante, H. Ahammad, H. Clark, H. Dong, E. A. Elsiddig, H. Haberl, et al. 2014. "Agriculture, Forestry and Other Land Use (AFOLU)." In *Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, et al., 811–922. New York: Cambridge University Press.

Sommer, L. and D. Luke. 2016. "How Can Trade Policy Be Used to Transform African Livelihoods?" *Bridges Africa* 5 (8): 7–10.

Sultan, B., P. Roudier, P. Quirion, A. Alhassane, B. Muller, M. Dingkuhn, P. Ciais, M. Guimberteau, S. Traore, and C. Baron. 2013. "Assessing Climate Change Impacts on Sorghum and Millet Yields in the Sudanian and Sahelian Savannas of West Africa." *Environmental Research Letters* 8 (1): 014040.

Suri, T. 2011. "Selection and Comparative Advantage in Technology Adoption." *Econometrica* 79: 159–209.

Tamiotti, L., R. Teh, V. Kulaçoğlu, A. Olhoff, B. Simmons, and H. Abaza. 2009. *Trade and Climate Change: A Report by the United Nations Environment Programme and the World Trade Organization*. Geneva.

Teklewold, H., and G. Kohlin. 2011. "Risk Preferences as Determinants of Soil Conservation Decisions in Ethiopia." *Journal of Soil and Water Conservation* 66: 87–96.

Thierfelder, C., M. Mwila, and L. Rusinamhodzi. 2013. "Conservation Agriculture in Eastern and Southern Provinces of Zambia: Long-Term Effects on Soil Quality and Maize Productivity." *Soil & Tillage Research* 126: 246–258.

Tubiello, F., M. Salvatore, R. Cóndor Golec, A. Ferrara, S. Rossi, R. Biancalani, S. Federici, H. Jacobs, and A. Flammini. 2014. *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks: 1990–2011 Analysis*. Working Paper ESS/14-02. Rome: Food and Agriculture Organization of the United Nations.

Tyagi, L., B. Kumari, and S. N. Singh. 2010. "Water Management—A Tool for Methane Mitigation from Irrigated Paddy Fields." *Science of the Total Environment* 408: 1085–1090.

UNCTAD (United Nations Conference on Trade and Development). 2016. *African Continental Free Trade Area: Developing and Strengthening Regional Value Chains in Agricultural Commodities and Processed Food Products*. New York: United Nations.

UN DESA (United Nations Department of Economic and Social Affairs) Population Division. 2017. World Population Prospects: The 2015 Revision. https://esa.un.org/unpd/wpp/. Accessed May 10.

USDA (US Department of Agriculture). 2014. *A Turning Point for Agricultural Exports to Sub-Saharan Africa*. International Agricultural Trade Report. Washington, DC.

Vanlauwe, B., J. Kihara, P. Chivenge, P. Pypers, R. Coe, and J. Six. 2011. "Agronomic Use Efficiency of N Fertilizer in Maize-Based Systems in Sub-Saharan Africa within the Context of Integrated Soil Fertility Management." *Plant and Soil* 339: 35–50.

Wheeler, D. 2011. *Quantifying Vulnerability to Climate Change: Implications for Adaptation Assistance*. Working Paper 240. Washington, DC: Center for Global Development.

Wooldridge, J. 2010. *Econometric Analysis of Cross Section and Panel Data*, 2nd ed. Cambridge, Mass., US: Massachusetts Institute of Technology Press.

World Bank. 2017a. World Bank Open Data. http://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD. Accessed in May 10.

World Bank. 2017b. World Bank Open Data. http://data.worldbank.org/indicator/SP.POP.TOTL. Accessed in May 10.

World Bank. 2017c. Fundamentals of Purchasing Power Parities. http://pubdocs.worldbank.org/en/242881493822925477/PPP-brochure-2017-webformat.pdf. Accessed August 28.

You, L., C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, T. Zhu, G. Nelson, Z. Guo, and Y. Sun. 2011. "What Is the Irrigation Potential for Africa? A Combined Biophysical and Socioeconomic Approach." *Food Policy* 36 (6): 770 –782.

Chapter 6

ACRE (Agriculture and Climate Risk Enterprise Ltd.). 2017. ACRE Africa. https://acreafrica.com/. Accessed August 7.

Assah, F., D. Chemiller-Gendreau, T. Touffut, and A. Sidibe. 2017. "Technology and Insurance: Building Resilient Agriculture in Africa." *The African Reinsurer* 31: 4–9.

Berhane, G., S. Dercon, R. V. Hill, and A. Taffesse. 2015. "Formal and Informal Insurance: Experimental Evidence from Ethiopia." Paper presented at International Conference of Agricultural Economists, Milan, August 8–14.

Bhushan, C., G. Singh, V. Rattani, and V. Kumar. 2016. *Insuring Agriculture in Times of Climate Change.* New Delhi: Centre for Science and Environment.

Ceballos, F., and M. Robles. 2014. *Weather Risks and Insurance Opportunities for the Rural Poor.* 2020 Conference Brief 10. Washington, DC: International Food Policy Research Institute.

———. 2017. "Demand Heterogeneity for Index-Based Insurance: The Case for Flexible Products." Unpublished, Washington, DC: International Food Policy Research Institute.

Clarke, C., O. Mahul, K. N. Rao, and N. Verma. 2012. *Weather-Based Crop Insurance in India*. Policy Research Working Paper 5985. Washington, DC: World Bank.

Clarke, D., and S. Dercon. 2016. *Dull Disasters? How Planning Ahead Will Make a Difference.* New York: Oxford University Press.

Cole, S. A., X. Giné, J. Tobacman, P. B. Topalova, R. M. Townsend, and J. I. Vickery. 2013. "Barriers to Household Risk Management: Evidence from India." *American Economic Journal: Applied Economics* 5 (1): 104–135.

de Janvry, A., V. Dequiedt, and E. Sadoulet. 2014. "The Demand for Insurance against Common Shocks." *Journal of Development Economics* 106:227–238.

Dercon, S., R. V. Hill, D. Clarke, I. Outes-Leon, and A. S. Taffesse. 2014. "Offering Rainfall Insurance to Informal Insurance Groups: Evidence from a Field Experiment in Ethiopia." *Journal of Development Economics* 106: 132–143.

Elabed, G., M. F. Bellemare, M. R. Carter, and C. Guirkinger. 2013. "Managing Basis Risk with Multi-scale Index Insurance." *Agricultural Economics* 44: 419–431.

FAO (Food and Agriculture Organization of the United Nations). 2015. *The Impact of Natural Hazards and Disasters on Agriculture and Food Security and Nutrition: A Call for Action to Build Resilient Livelihoods*. Rome.

———. 2017. FAOSTAT database. Accessed August 1. www.fao.org/faostat/en/#home.

Greatrex, H., J. W. Hansen, S. Garvin, R. Diro, S. Blakeley, M. Le Guen, K. N. Rao, and D. E. Osgood. 2015. *Scaling Up Index Insurance for Smallholder Farmers: Recent Evidence and Insights.* CCAFS Report 14. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Hazell, P., J. Anderson, N. Balzer, A. Hastrup Clemmensen, U. Hess, and F. Rispoli. 2010. *The Potential for Scale and Sustainability in Weather Index Insurance for Agriculture and Rural Livelihoods*. Rome: International Fund for Agricultural Development.

Hazell, P., C. Pomareda, and A. Valdes. 1986. *Crop Insurance for Agricultural Development*. Baltimore: Johns Hopkins University Press.

Hill, V. R. 2010. "Agricultural Insurance in Sub-Saharan Africa: Can It Work?" Paper prepared for Fourth African Agricultural Markets Program policy symposium, Lilongwe, Malawi, September 6–7. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.185.1831&rep=rep1&type=pdf.

Hill, R. V., and M. Robles. 2011. *Flexible Insurance for Heterogeneous Farmers: Results from a Small Scale Pilot in Ethiopia*. Discussion Paper 1092. Washington, DC: International Food Policy Research Institute.

Hill, R. V., L. M. Robles, and F. Ceballos. 2016. "Demand for a Simple Weather Insurance Product in India: Theory and Evidence." *American Journal of Agricultural Economics* 98 (4): 1250–1270.

IFC (International Finance Corporation). 2013. *Kilimo Salama Project Description*. Washington, DC.

ILRI (International Livestock Research Institute). Index-based Livestock Insurance. Accessed August 24, 2017. https://ibli.ilri.org/.

Janzen, S., and M. Carter. 2013. *The Impact of Micro-insurance on Asset Accumulation and Human Capital Investments: Evidence from a Drought in Kenya*. Research Paper 31. Geneva: International Labour Organization.

Kramer, B., F. Ceballos, K. Hufkens, E. Melaas, A. Mishra, M. S. Toor, and M. Robles. 2017. *Picture-Based Crop Insurance: Using Farmers' Smartphone Pictures to Minimize the Costs of Loss Verification.* Project Note. Washington, DC: International Food Policy Research Institute.

Kramer, B., F. Ceballos, M. Krupoff, A. Mishra, M. Robles, and M.S. Toor. 2017. *Picture-Based Insurance: Is It Sustainable? Effects on Willingness to Pay, Adverse Selection and Moral Hazard.* Project Note 1. Washington, DC: International Food Policy Research Institute.

Leftley, R. 2009. *Innovations in Insuring the Poor: Microinsurance for Health and Agricultural Risks*. Vision 2020, Focus 17, Brief 4. Washington, DC: International Food Policy Research Institute.

Lybbert, T., and M. R. Carter. 2015. "Bundling Drought Tolerance and Index Insurance to Reduce Rural Household Vulnerability to Drought." In *Sustainable Economic Development: Resources, Environment, and Institutions*, edited by A. Balisacan, U. Chakravorty, and M.-L. Ravago, 401–414. San Diego, CA, US: Elsevier Academic Press.

Madajewicz, M., A. H. Tsegay, and M. Norton. 2013. *Managing Risks to Agricultural Livelihoods: Impact Evaluation of the HARITA Program in Tigray, Ethiopia, 2009–2012*. Boston: Oxfam America.

Mahul, O., and C. J. Stutley. 2010. *Government Support to Agricultural Insurance: Challenges and Options for Developing Countries*. Washington, DC: World Bank.

Matul, M., A. Dalal, O. De Bock, and W. Gelade. 2013. *Why People Do Not Buy Microinsurance and What We Can Do about It*. Briefing Note 17. Geneva: Microinsurance Innovation Facility.

McIntosh, K. 2015. "Insurance Markets in Rural Uganda: A Case for Government Intervention." *The Public Sphere* 2015: 70–95.

Miranda, M., and F. Mulangu. 2016. "Index Insurance for Agricultural Transformation in Africa." Background paper for *African Transformation Report 2016: Transforming Africa's Agriculture*. Tokyo: Japan International Cooperation Agency.

Mude, A., C. B. Barrett, M. R. Carter, S. Chantarat, M. Ikegami, and J. McPeak. 2010. *Index-Based Livestock Insurance for Northern Kenyan Arid and Semi Arid Land: The Marsabit Pilot.* Project Summary. Nairobi, Kenya: International Livestock Research Institute.

Slim, H. 2012. *IASC Real-Time Evaluation of the Humanitarian Response to the Horn of Africa Drought Crisis in Somalia, Ethiopia and Kenya: Synthesis Report.* Geneva: Inter-agency Standing Committee.

Smith, V. H., and B. K. Goodwin. 2010. "Private and Public Roles in Providing Agricultural Insurance in the United States." In *Public Insurance and Private Markets*, edited by J. R. Brown, 173–210. Washington, DC: American Enterprise Institute.

Townsend, R. M. 1994. "Risk and Insurance in Village India." *Econometrica* 62 (3): 539–591.

UNRCO (United Nations Office of the Resident Coordinator) Mozambique. 2013. *Mozambique: Flooding*. Situation Report 4. Maputo.

Wani, S. P., J. Rockström, and T. Oweis, eds. 2009. *Rainfed Agriculture: Unlocking the Potential.* London: CAB International.

Ward, P. S., D. J. Spielman, D. L. Ortega, N. Kumar, and S. Minocha. 2015. *Demand for Complementary Financial and Technological Tools for Managing Drought Risk*. Discussion Paper 01430. Washington, DC: International Food Policy Research Institute.

WFP (World Food Programme). 2017. "The R4 Rural Resilience Initiative: Building Long-Term Resilience to Climate Change for Food and Income Security." Accessed July 31. www.wfp.org/climate-change/initiatives/r4-rural-resilience-initiative.

WFP and Oxfam America. 2015. *Rural Resilience in Action: Preliminary Results of the Impact Evaluation for the R4 Rural Resilience Initiative in Senegal (2013–2015).* Rome and Boston.

Wiggins, S. 2009. "Can the Smallholder Model Deliver Poverty Reduction and Food Security for a Rapidly Growing Population in Africa?" Paper presented at Expert Meeting on How to Feed the World in 2050, Rome, June 24–26.

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

Chapter 7

Abberton, M., R. Conant, and C. Batello, eds. 2010. *Grassland Carbon Sequestration: Management, Policy and Economics: Proceedings of the Workshop on the Role of Grassland Carbon Sequestration in the Mitigation of Climate Change.* Integrated Crop Management, vol. 11. Rome: Food and Agriculture Organization of the United Nations.

Africom Commodities. 2016. *S.E. du Parc Agro Industriel de Bukanga-Lonzo, Farming: Year-End Report.* Kinshasa, Democratic Republic of the Congo.

Altieri, M. 1999. "Applying Agroecology to Enhance the Productivity of Peasant Farming Systems in Latin America." *Environment, Development and Sustainability* 1 (3–4): 197–217.

Biermacher, J. T., B. W. Brorsen, F. M. Epplin, J. B. Solie, and W. R. Raun. 2009. "The Economic Potential of Precision Nitrogen Application with Wheat Based on Plant Sensing." *Agricultural Economics* 40: 397–407.

Branca, G., L. Lipper, N. Neves, D. Lopa, and I. Mwanjioka. 2011. "Payments for Watershed Services Supporting Sustainable Agricultural Development in Tanzania." *Journal of Environmental Development* 20 (3): 278–302.

Bronick, C. J., and R. Lal. 2005. "Soil Structure and Management: A Review." *Geoderma* 124: 3–22.

Bullock, D. S., M. L. Ruffo, D. G. Bullock, and G. A. Bollero. 2009. "The Value of Variable Rate Technology: An Information-Theoretic Approach." *American Journal of Agricultural Economics* 91: 209–223.

Carr, P. M., G. R. Carlson, J. S. Jacobsen, G. A. Nielsen, and E. O. Skogley. 1991. "Farming Soils, Not Fields: A Strategy for Increasing Fertilizer Profitability." *Journal of Production Agriculture* 4: 57–61.

CIAT (International Center for Tropical Agriculture). 2008. *The Impact of New Bean Technologies on Rural Livelihoods in Seven African Countries.* Highlights: CIAT in Africa 44. Kampala, Uganda.

Colorado State University Extension. 2012. "New Technologies Boost Crop Yield, Save Money, Time and Resources." *Impact*, August. http://extension.colostate.edu/docs/comm/impact/PrecisionAgriculture.pdf.

Conant, R. 2010. *Challenges and Opportunities for Carbon Sequestration in Grassland Systems.* Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/fileadmin/templates/agphome/documents/climate/AGPC_grassland_webversion_19.pdf.

Cook, S. E., M. L. Adams, and R. G. V. Bramley. 2000. "What is Obstructing the Wider Adoption of Precision Agriculture Technology?" In *Proceedings of the 5th International Conference on Precision Agriculture, Bloomington, Minnesota, USA, 16–19 July, 2000,* edited by P. C. Robert, R. H. Rust, and W. E. Larson, 1–7. Madison, WI, US: American Society of Agronomy.

Cook, S., R. O'Brien, R. Corner, and T. Oberthur. 2003. "Is Precision Agriculture Irrelevant to Developing Countries?" Paper presented at fourth European Conference on Precision Agriculture, Berlin, June 15–19.

Daberkow, S. G., and W. D. McBride. 1998. "Socioeconomic Profiles of Early Adopters of Precision Agriculture Technologies." *Agribusiness* 16 (2): 151–168.

Day, W., E. Audsley, and A. R. Frost. 2008. "An Engineering Approach to Modelling, Decision Support and Control for Sustainable Systems." *Philosophical Transactions of the Royal Society B* 363 (1491): 527–541.

Diaz-Zorita, M., G. Duarte, and J. Grove. 2002. "A Review of No-Till Systems and Soil Management for Sustainable Crop Production in the Sub-humid and Semi-arid Pampas of Argentina." *Soil Tillage Resources* 65: 1–18.

FAO (Food and Agriculture Organization of the United Nations). 2005. *The Importance of Soil Organic Matter: Key to Drought-Resistant Soil and Sustained Food Production.* Soils Bulletin 80. Rome. http://www.fao.org/docrep/009/a0100e/a0100e.pdf.

———. 2010. *"Climate-Smart Agriculture": Policies, Practices, and Financing for Food Security, Adaptation and Mitigation.* Rome.

———. 2011. *Socio-economic Analysis of Conservation Agriculture in Southern Africa.* Network Paper 2. Rome.

———. 2013a. *Climate-Smart Agriculture Sourcebook.* Rome.

———. 2013b. *Democratic Republic of the Congo: BEFS Country Brief.* Rome.

———. 2015. "Fertilizer Use to Surpass 200 Million Tonnes in 2018," February 16. www.fao.org/news/story/en/item/277488/icode/.

Farooq, M., K. H. M. Siddique, H. Rehman, T. Aziza, D.-J. Lee, and A. Wahid. 2011. "Rice Direct Seeding: Experiences, Challenges and Opportunities." *Soil Tillage Research* 111 (2): 87–98.

Florax, R. J. G. M, R. L. Voortman, and J. Brouwer. 2002. "Spatial Dimensions of Precision Agriculture: A Spatial Econometric Analysis of Millet Yield on Sahelian Coversands." *Agricultural Economics* 27 (3): 425–443.

Fuglie, K., and D. Bosch. 1995. "Implications of Soil Nitrogen Testing." *American Journal of Agricultural Economics* 77: 891–900.

Geigenberger, P., A. R. Fernie, Y. Gibon, M. Christ, and M. Stitt. 2000. "Metabolic Activity Decreases as an Adaptive Response to Low Internal Oxygen in Growing Potato Tubers." *Journal of Biological Chemistry* 381: 723–740.

Harris, W. G., M. Chrysostome, T. A. Obreza, and V. D. Nair. 2010. "Soil Properties Pertinent to Horticulture in Florida." *HortTechnology* 20: 10–18.

Harvey, C. A., Z. L. Rakotobe, N. S. Rao, R. Dave, H. Razafimahatratra, R. H. Rabarijohn, H. Rajaofara, and J. L. MacKinnon. 2014. "Extreme Vulnerability of Smallholder Farmers to Agricultural Risks and Climate Change in Madagascar." *Philosophical Transactions of the Royal Society B* 369 (1639): 20130089.

Herdeschee, J., K. A. Kaiser, and M. D. Samba, eds. 2012. *Resilience d'un Geant Africain: Accelerer la Croissance et Promouvoir l'emploi en Republique Democratique du Congo. Vol. 1. Synthese, Contexte Historique et Macroeconomique*. Kinshasa: World Bank.

Hine, R., and J. Pretty. 2008. *Organic Agriculture and Food Security in Africa*. Geneva: United Nations Conference on Trade and Development; New York: United Nations Environment Programme.

Hudson, D., and D. Hite. 2003. "Producer Willingness to Pay for Precision Application Technology: Implications for Government and the Technology Industry." *Canadian Journal of Agricultural Economics* 51: 39–53.

IPNI (International Plant Nutrition Institute). n.d.-a *Potassium Chloride*. Nutrition Source Specifics 3. Norcross, GA, US. http://www.ipni.net/publication/nss.nsf/0/8FBD66599EAB433F852579AF00741710/$FILE/NSS-03%20PotassiumChloride.pdf.

———. n.d.-b *Monoammonium Phosphate (MAP)*. Nutrition Source Specifics 9. Norcross, GA, US. https://www.ipni.net/publication/nss.nsf/0/2F200FA9C8C946F0852579AF00762904/$FILE/NSS-09%20Monoammonium%20Phosphate.pdf.

Kassam, A., T. Friedrich, F. Shaxson, and J. Pretty. 2009. "The Spread of Conservation Agriculture: Justification, Sustainability and Uptake." *International Journal of Agricultural Sustainability* 7: 292–320.

Khanna, M., and D. Zilberman. 1997. "Incentives, Precision Technology and Environmental Protection." *Ecological Economics* 23: 25–43.

Kilian, B. 2000. *Economic Aspects of Precision Farming: A German Viewpoint*. Stuttgart, Germany: Department of Farm Economics, University of Hohenheim.

Knox, J., T. Hess, A. Daccache, and T. Wheeler. 2012. "Climate Change Impacts on Crop Productivity in Africa and South Asia." *Environmental Research Letters* 7 (3): 034032.

Lal, R. 2009. "The Plow and Agricultural Sustainability." *Journal of Sustainable Agriculture* 33: 66–84.

Lowenberg-DeBoer, J., and A. Aghib. 1999. "Average Returns and Risk Characteristics of Site Specific P and K Management: Eastern Corn Belt On-Farm Trial Results." *Journal of Production Agriculture* 12 (2): 276–282.

Maohua, W. 2001. "Possible Adoption of Precision Agriculture for Developing Countries at the Threshold of the New Millennium." *Computers and Electronics in Agriculture* 30:45–50.

National Research Council. 1997. *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management*. Washington, DC: National Academy Press. https://www.nap.edu/catalog/5491/precision-agriculture-in-the-21st-century-geospatial-and-information-technologies.

NRCS (Natural Resources Conservation Service). n.d. *Soil Organic Matter*. Guides for Educators. Washington, DC: US Department of Agriculture. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053264.pdf.

———. 2007. *Precision Agriculture: NRCS for Emerging Technologies*. Agronomy Technical Note 1. Washington, DC: US Department of Agriculture.

Palapala, V., and M. Nyamolo. 2016. "Effect of Water Logging on Selected Morphological Characteristics in Maize." *Journal of Agricultural Science and Food Technology* 2 (6): 80–92.

Pan, Y., R. A. Birdsey, J. Hom, K. McCoullough, and K. Clark. 2006. "Improved Satellite Estimates of Net Primary Productivity from MODIS Satellite Data at Regional and Local Scales." *Ecological Applications* 16 (1): 125–132.

Plant & Soil Sciences eLibrary. 2017. "Soils–Part 2: Physical Properties of Soil and Soil Water." University of Nebraska–Lincoln. Accessed July 30, 2017. https://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447039&topicorder=10&maxto=10.

Porter, J. R., L. Xie, A. J. Challinor, K. Cochrane, S. M. Howden, M. M. Iqbal, D. B. Lobell, and M. I. Travasso. 2014. "Food Security and Food Production Systems." In *Climate Change: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by C. B. Field, V. R. Barros, D. J. Dokken, et al., 485–533. Cambridge, UK: Cambridge University Press.

Pretty, J. 2000. "Can Sustainable Agriculture Feed Africa?" *Environment Development and Sustainability* 1: 253–274.

Pretty, J. N., A. D. Noble, D. Bossio, J. Dixon, R. E. Hine, F. W. T. Penning de Vries, and J. I. L. Morison. 2006. "Resource-Conserving Agriculture Increases Yields in Developing Countries." *Environmental Science and Technology* 40 (4): 1114–1119.

Ramirez-Villegas, J., and P. K. Thornton. 2015. *Climate Change Impacts on African Crop Production*. Working Paper 199. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Rasmussen, K. J. 1999. "Impact of Ploughless Soil Tillage on Yield and Soil Quality: A Scandinavian Review." *Soil and Tillage Research* 53: 3–14.

Reichardt, M., and C. Jurgens. 2009. "Adoption and Future Perspective of Precision Farming in Germany: Results of Several Surveys among Different Agricultural Target Groups." *Precision Agriculture* 10 (1): 73–94.

Robertson, M. J., R. S. Llewellyn, R. Mandel, R. Lawes, R. G. V. Bramley, L. Swift, N. Metz, and C. O'Callaghan. 2012. "Adoption of Variable Rate Fertiliser Application in the Australian Grains Industry: Status, Issues and Prospects." *Precision Agriculture* 13 (2): 181–199.

Rusinamhodzi, L., M. Corbeels, M. T. van Wijk, M. C. Rufino, J. Nyamangara, and K. E. Giller. 2011. "Long-Term Effects of Conservation Agriculture Practices on Maize Yields under Rain-Fed Conditions: Lessons for Southern Africa." *Agronomy for Sustainable Development* 31 (4): 657–673.

Sain, G., A. M. Loboguerrero, C. Corner-Dolloff, M. Lizarazo, A. Nowak, D. Martinez-Baron, and N. Andrieu. 2017. "Costs and Benefits of Climate-Smart Agriculture: The Case of the Dry Corridor in Guatemala." *Agricultural Systems* 151: 163–173.

Schimmelpfennig, D. 2016. "Precision Agriculture Technologies and Factors Affecting Their Adoption." *Amber Waves,* December 5. www.ers.usda.gov/amber-waves/2016/december/precision-agriculture-technologies-and-factors-affecting-their-adoption/.

Seelan, S. K., S. Laguette, G. M. Casady, and G. A. Seielstad. 2003. "Remote Sensing Applications for Precision Agriculture: A Learning Community Approach." *Remote Sensing of Environment* 88: 157–169.

Silva, C. B., S. M. L. R. do Vale, F. A. C. Pinto, C. A. S. Muller, and A. D. Moura. 2007. "The Economic Feasibility of Precision Agriculture in Mato Grosso do Sul State, Brazil: A Case Study." *Precision Agriculture* 8 (6): 255–265.

Sithole, N. J., L. S. Magwaza, and P. L. Mafongoya. 2016. "Conservation Agriculture and Its Impact on Soil Quality and Maize Yield: A South African Perspective." *Soil and Tillage Research* 162: 55–67.

Stewart, C. M., A. B. McBratney, and J. H. Skerritt. 2002. "Site-Specific Durum Wheat Quality and Its Relationship to Soil Properties in a Single Field in Northern New South Wales." *Precision Agriculture* 3: 155–168.

Summary of Soil Analysis, Parc Agro Industriel de Bukanga-Lonzo, Part 1. n.d. Kinshasa, Democratic Republic of the Congo: 2015.

Swinton, S. M., and J. Lowenberg-DeBoer. 1998. "Evaluating the Profitability of Site-Specific Farming." *Journal of Production Agriculture* 11 (4): 439–446.

———. 2001. "Global Adoption of Precision Agriculture Technologies: Who, When and Why." In *Precision Agriculture: Proceedings of the Third European Conference on Precision Agriculture, Montpellier, France, June 2001,* edited by G. Grenier and S. Blackmore, 557–562. Monticello, IL, US: International Society of Precision Agriculture.

Sylvester-Bradley, R., E. Lord, D. L. Sparkes, R. K. Scott, J. J. Wiltshire, and J. Orson. 1999. "An Analysis of the Potential of Precision Farming in Northern Europe." *Soil Use and Management* 15 (1): 1–8.

Takacs-Gyorgy, K. 2008. "Economic Aspects of Chemical Reduction on Farming: Role of Precision Farming—Will the Production Structure Change?" *Cereal Research Communications* 36: 19–22.

Tey, Y. S., and M. Brindal. 2012. "Factors Influencing the Adoption of Precision Agricultural Technologies: A Review for Policy Implications." *Precision Agriculture* 13: 713–730.

Thierfelder, C., and P. C. Wall. 2009. "Effects of Conservation Agriculture Techniques on Infiltration and Soil Water Content in Zambia and Zimbabwe." *Soil Tillage Research* 105: 217–227.

Thierfelder, C., and P. C. Wall. 2010. "Investigating Conservation Agriculture Systems in Zambia and Zimbabwe to Mitigate Future Effects of Climate Change." *Journal of Crop Improvement 24* (2): 113-121.

Thomas, R. 2008. "Opportunities to Reduce the Vulnerability of Dryland Farmers in Central and West Asia and North Africa to Climate Change." *Agriculture, Ecosystems & Environment* 126 (1–2): 36–45.

Ulimwengu, J. M. 2017. "Can Agricultural Special Economic Zones Drive African Rural and Agricultural Transformation for Sustainable Development?" Unpublished, International Food Policy Research Institute, Washington, DC.

Umar, B., J. Aune, F. Johnsen, and O. Lungu. 2011. "Options for Improving Smallholder Conservation Agriculture in Zambia." *Journal of Agricultural Science* 3 (3): 50–62.

USAID (United States Agency for International Development). 2012. "USAID Helps Improve Livelihoods and Food Security in DRC." Reliefweb, March 20. http://reliefweb.int/report/democratic-republic-congo/usaid-helps-improve-livelihoods-and-food-security-drc.

———. 2014. *DRC: Agriculture and Food Security.* Washington, DC.

———. 2015a. *Democratic Republic of the Congo: Staple Food Market Fundamentals.* Washington, DC.

———. 2015b. *Maize Commodity Assessment and Workplan Related to Maize.* Kinshasa, Democratic Republic of the Congo.

Vallis, I., W. J. Parton, B. A. Keating, and A. W. Wood. 1996. "Simulation of the Effects of Trash and N Fertilizer Management on Soil Organic Matter Levels and Yields of Sugarcane." *Soil and Tillage Research* 38 (1–2): 115–132.

Woodfine, A. 2009. *The Potential of Sustainable Land Management Practices for Climate Change Mitigation and Adaptation in Sub-Saharan Africa*. Rome: Food and Agriculture Organization of the United Nations.

World Bank. 2010. *Project Appraisal Document on a Proposal Grant to the DRC for an Agriculture Rehabilitation and Recovery Support Project.* Report 49169-ZR. Washington, DC.

World Food Programme. 2014. *Comprehensive Food Security and Vulnerability Analysis: Democratic Republic of Congo*. Rome.

World Population Review. 2017. Dr Congo Population 2017. Accessed July 30. http://worldpopulationreview.com/countries/dr-congo-population/.

Chapter 8

Akinnifesi, F. K., O. C. Ajayi, G. Sileshi, P. W. Chirwa, and J. Chianu. 2010. "Fertiliser Trees for Sustainable Food Security in the Maize-Based Production Systems of East and Southern Africa." *Sustainable Agriculture* 2: 129–146.

Akinnifesi, F. K., P. W. Chirwa, O. C. Ajayi, G. Sileshi, P. Matakala, and F. R. Kwesiga. 2008. "Contributions of Agroforestry Research to Livelihood of Smallholder Farmers in Southern Africa: Taking Stock of the Adaptation, Adoption and Impact of Fertilizer Tree Options." *Agricultural Journal* 3 (1): 58–75.

Bationo, A., B. Waswa, J. Kihara, and J. Kimetu, eds. 2007. *Advances in Integrated Soil Fertility Management in Sub-Saharan Africa: Challenges and Opportunities.* New York: Springer Science & Business Media.

Chianu, J. N., J. N. Chianu, and F. Mairura. 2012. "Mineral Fertilizers in the Farming Systems of Sub-Saharan Africa: A Review." *Agronomy for Sustainable Development* 32 (2): 545–566.

CIMMYT (International Maize and Wheat Improvement Center). 2016. *Why Maize?* Texcoco, Mexico.

Druilhe, Z., and J. Barreiro-Hurlé. 2012. *Fertilizer Subsidies in Sub-Saharan Africa.* ESA (Agricultural Development Economics) Working Paper 12-04. Rome: Food and Agriculture Organization of the United Nations.

FAO (Food and Agriculture Organization of the United Nations). 2015. FAOSTAT database. Accessed July 12, 2017. www.fao.org/faostat/en/#home.

FAO. 2013. Zambia Bioenergy and Food Security (BEFS) Country Brief.

Gentile, R., B. Vanlauwe, P. Chivenge, and J. Six. 2008. "Interactive Effects from Combining Fertilizer and Organic Residue Inputs on Nitrogen Transformations." *Soil Biology and Biochemistry* 40 (9): 2375–2384.

Govaerts, B., N. Verhulst, A. Castellanos-Navarrete, K. D. Sayre, J. Dixon, and L. Dendooven. 2009. "Conservation Agriculture and Soil Carbon Sequestration: Between Myth and Farmer Reality." *Critical Reviews in Plant Science* 28 (3): 97–122.

Kang, B. T., and G. F. Wilson, G. F. 1987. "The Development of Alley Cropping as a Promising Agroforestry Technology." In *Agroforestry: A Decade of Development*, edited by H. A. Steppler and P. K. R. Nair, 227-243. Nairobi, Kenya: International Council for Research in Agroforestry.

Lal, R. 2011. "Sequestering Carbon in Soils of Agro-ecosystems." *Food Policy* 36: S33–S39.

Manna, M. C., A. Swarup, R. H. Wanjari, H. N. Ravankar, B. Mishra, M. N. Saha, Y. V. Singha, D. K. Sahi, and P. A. Sarap. 2005. "Long-Term Effect of Fertilizer and Manure Application on Soil Organic Carbon Storage, Soil Quality and Yield Sustainability under Sub-humid and Semi-arid Tropical India." *Field Crops Research* 93 (2): 264–280.

Meijer, S. S., D. Catacutan, O. C. Ajayi, G. W. Sileshi, and M. Nieuwenhuis. 2015. "The Role of Knowledge, Attitudes and Perceptions in the Uptake of Agricultural and Agroforestry Innovations among Smallholder Farmers in Sub-Saharan Africa." *International Journal of Agricultural Sustainability* 13 (1): 40–54.

MIPAD (Market Information System for Agro Dealers). 2017. Fertilizer Price Database. Accessed July 12. http://agromis.mfarms.org/en/prices/fertilizer.

Nandwa, S. M., and M. A. Bekunda. 1998. "Research on Nutrient Flows and Balances in East and Southern Africa: State-of-the-Art." *Agriculture, Ecosystems and Environment* 71 (1): 5–18.

Nkonya, E., C. Azzari, E. Kato, J. Koo, G. Nziguheba, and B. Vanlauwe. 2017. "Mapping Adoption of ISFM Practices Study: The Case of Kenya, Rwanda & Zambia." Unpublished, International Food Policy Research Institute, Washington, DC.

Nkonya, E., T. Johnson, H. Y. Kwon, and E. Kato. 2016. "Economics of Land Degradation in Sub-Saharan Africa." In *Economics of Land Degradation and Improvement—A Global Assessment for Sustainable Development*, edited by E. Nkonya, A. Mirzabaev, and J. von Braun, 215–260. Cham, Switzerland: Springer.

Nkonya, E., J. Koo, and E. Kato. 2017. "Climate Risk Management through SLWM in Sub-Saharan Africa." In *Climate Smart Agriculture: Building Resilience to Climate Change*, edited by D. Zilberman, L. Lipper, N. McCarthy, S. Asfaw, and G. Branca. New York: Springer Science & Business Media, forthcoming.

Rakotoarisoa, M., M. Iafrate, and M. Paschali. 2011. *Why Has Africa Become a Net Food Importer?* Rome: Food and Agriculture Organization of the United Nations.

RATIN (Regional Agricultural Trade Intelligence Network). 2017. Market Prices database. Accessed July 6. http://ratin.net/site/market.

Scoones, I., and J. Thompson. 2011. "The Politics of Seed in Africa's Green Revolution: Alternative Narratives and Competing Pathways." IDS Bulletin 42 (4).

Tilman, D., K. G. Cassman, P. A. Matson, R. Naylor, and S. Polasky. 2002. "Agricultural Sustainability and Intensive Production Practices." Nature 418 (6898): 671–677.

USDA (United States Department of Agriculture). 2016. Fertilizer Use and Price. Accessed July 06, 2017. www.ers.usda.gov/data-products/fertilizer-use-and-price/.

Van Campenhout, B., B. D'Exelle, and E. Lecoutere. 2015. "Equity–Efficiency Optimizing Resource Allocation: The Role of Time Preferences in a Repeated Irrigation Game." Oxford Bulletin of Economics and Statistics 77 (2): 234–253.

World Bank. 2011. Climate-Smart Agriculture Indicators. Report 105162-GLB. Washington, DC.

World Bank. 2017. Carbon Pricing Watch 2017. Accessed July 06. http://carbonpricingdashboard.worldbank.org/.

Chapter 9

Adger, W. N. 2003. "Social Capital, Collective Action, and Adaptation to Climate Change." *Economic Geography* 79 (4): 387–404.

Adger, W. N., S. Dessai, M. Goulden, M. Hulme, I. Lorenzoni, D. R. Nelson, L. O. Naess, J. Wolf, and A. Wreford. 2009. "Are There Social Limits to Adaptation to Climate Change?" *Climatic Change* 93 (3–4): 335–354.

Agrawal, A. 2010. "Local Institutions and Adaptation to Climate Change." In *Social Dimensions of Climate Change: Equity and Vulnerability in a Warming World*, edited by R. Mearns and A. Norton, 173–197. Washington, DC: World Bank.

Agrawal, A., and N. Perrin. 2008. *Climate Adaptation, Local Institutions, and Rural Livelihoods*. Ann Arbor, MI, US: International Forestry Resources and Institutions Program, University of Michigan.

Barrett, C. B., and M. A. Constas. 2014. "Toward a Theory of Resilience for International Development Applications." *Proceedings of the National Academy of Sciences* 111 (40): 14625–14630.

Behrman, J. A., E. Bryan, and A. Goh. 2014. "Gender, Climate Change, and Group-Based Approaches to Adaptation." In *Enhancing Women's Assets to Manage Risk under Climate Change: Potential for Group-Based Approaches*, edited by C. Ringler, A. R. Quisumbing, E. Bryan, and R. Meinzen-Dick, 3–8. Washington, DC: International Food Policy Research Institute.

Béné, C., T. Frankenberger, and S. Nelson. 2015. *Design, Monitoring and Evaluation of Resilience Interventions: Conceptual and Empirical Considerations.* Working Paper 459. Brighton, UK: Institute of Development Studies.

Bernier, Q., R. Meinzen-Dick, P. Kristjanson, E. Haglund, C. Kovarik, E. Bryan, C. Ringler, and S. Silvestri. 2015. *Gender and Institutional Aspects of Climate-Smart Agricultural Practices: Evidence from Kenya*. Working Paper 79. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Bernier, Q., and R. Meinzen-Dick. 2014. "Social Capital and Resilience." In *Resilience for Food and Nutrition Security*, Edited by S. Fan, R. Pandya-Lorch, S. Yosef. Washington, DC: International Food Policy Research Institute.

Beuchelt, T. D. and L. Badstue. 2013. "Gender, Nutrition- and Climate-Smart Food Production: Opportunities and Trade-Offs." *Food Security* 5: 709-721.

Bryan, E., T. T. Deressa, G. A. Gbetibouo, and C. Ringler. 2009. "Adaptation to Climate Change in Ethiopia and South Africa: Options and Constraints." *Environmental Science and Policy* 12 (4): 413–426.

Bryan, E., C. Ringler, B. Okoba, C. Roncoli, S. Silvestri, and M. Herrero. 2013. "Adapting Agriculture to Climate Change in Kenya: Household Strategies and Determinants." *Journal of Environmental Management* 114:26–35.

Burke, M., E. Gong, and K. M. Jones. 2015. "Income Shocks and HIV in Africa." *The Economic Journal* 125 (585): 1157–1189. http://dx.doi.org/10.1111/ecoj.12149.

Carter, M. R., P. D. Little, and T. Mogues. 2007. "Poverty Traps and Natural Disasters in Ethiopia and Honduras." *World Development* 35 (5): 835–856.

Carter, M. R., and C. B. Barrett. 2006. "The Economics of Poverty Traps and Persistent Poverty: An Asset-based Approach." *The Journal of Development Studies* 42 (2): 178-199, DOI: 10.1080/00220380500405261.

Codjoe, S. N. A., L. K. Atidoh, and V. Burkett. 2012. "Gender and Occupational Perspectives on Adaptation to Climate Extremes in the Afram Plains of Ghana." *Climatic Change* 110 (1–2): 431–454.

Cole, D. C., C. Levin, C. Loechl, G. Thiele, F. Grant, A. W. Girard, K. Sindi, and J. Low. 2016. "Planning an Integrated Agriculture and Health Program and Designing Its Evaluation: Experience from Western Kenya." *Evaluation and Program Planning* 56: 11–22. http://dx.doi.org/10.1016/j.evalprogplan.2016.03.001.

Constas, M. A., T. R. Frankenberger, J. Hoddinott, N. Mock, D. Romano, C. Béné, and D. Maxwell. 2014. *A Common Analytical Model for Resilience Measurement: Causal Framework and Methodological Options*. Food Security Information Network Technical Series 2. Rome: World Food Programme.

Deere, C. D., and C. R. Doss. 2006. "The Gender Asset Gap: What Do We Know and Why Does It Matter?" *Feminist Economics* 12 (1–2): 1–50.

Deressa, T. T., R. M. Hassan, C. Ringler, T. Alemu, and M. Yesuf. 2009. "Determinants of Farmers' Choice of Adaptation Methods to Climate Change in the Nile Basin of Ethiopia." *Global Environmental Change* 19 (2): 248–255.

Dercon, S. 2004. "Growth and Shocks: Evidence from Rural Ethiopia." *Journal of Development Economics* 74: 309– 329.

Djoudi, H., and M. Brockhaus. 2011. "Is Adaptation to Climate Change Gender Neutral? Lessons from Communities Dependent on Livestock and Forests in Northern Mali." *International Forestry Review* 13 (2): 123–135.

Doss, C. R. 2001. "Designing Agricultural Technology for African Women Farmers: Lessons from 25 Years of Experience." *World Development* 29 (12): 2075–2092.

Doss, C. R., and M. L. Morris. 2001. "How Does Gender Affect the Adoption of Agricultural Innovations? The Case of Improved Maize Technology in Ghana." *Agricultural Economics* 25 (1): 27–39.

Douthwaite, B., and E. Hoffecker. 2017. "Towards a Complexity-Aware Theory of Change for Participatory Research Programs Working within Agricultural Innovation Systems." *Agricultural Systems* 155: 88–102.

Di Falco, S., and E. Bulte. 2013. "The Impact of Kinship Networks on the Adoption of Risk-Mitigating Strategies in Ethiopia." *World Development* 43: 100–110. http://dx.doi.org/10.1016/j.worlddev.2012.10.011.

Emmott, A., 2013. *Market-Led Aflatoxin Interventions: Smallholder Groundnut Value Chains in Malawi*. Focus 20 Brief 8. Washington, DC: International Food Policy Research Institute.

Fanzo, J., R. McLaren, C. Davis, and J. Choufani. 2017. *Climate Change and Variability: What Are the Risks for Nutrition, Diets, and Food Systems?* Discussion Paper 01645. Washington, DC: International Food Policy Research Institute. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131228.

Frankenberger, T., M. Constas, S. Nelson, and L. Starr. 2014. "Current Approaches to Resilience Programming among Non-governmental Organizations. 2020 Conference Paper 7. Washington, DC: IFPRI. http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/128167/filename/128378.pdf

Gillespie, S., J. Harris, and S. Kadiyala. 2012. *The Agriculture-Nutrition Disconnect in India: What Do We Know?* Discussion Paper 01187. Washington, DC: International Food Policy Research Institute.

Glick, P. 2002. *Women's Employment and Its Relation to Children's Health and Schooling in Developing Countries: Conceptual Links, Empirical Evidence, and Policies*. Food and Nutrition Policy Program Working Paper 131. Ithaca, NY, US: Cornell University.

Grothmann, T., and A. Patt. 2005. "Adaptive Capacity and Human Cognition: The Process of Individual Adaptation to Climate Change." *Global Environmental Change* 15 (3): 199–213.

Haas, J. D., E. J. Martinez, S. Murdoch, E. Conlisk, J. A. Rivera, and R. Martorell. 1995. "Nutritional Supplementation during the Preschool Years and Physical Work Capacity in Adolescent and Young Adult Guatemalans." *Journal of Nutrition* 125 (S4): 1078S–1089S. www.ncbi.nlm.nih.gov/pubmed/7722710.

Haddad, L., 2000. "A Conceptual Framework for Assessing Agriculture-Nutrition Linkages." *Food and Nutrition Bulletin* 21 (4): 367–373.

Harwatt, H., J. Sabaté, G. Eshel, S. Soret, and W. Ripple. 2017. "Substituting Beans for Beef as a Contribution toward US Climate Change Targets." *Climatic Change* 143 (1–2): 261–270. doi:10.1007/s10584-017-1969-1.

Herforth, A., and J. Harris. 2014. *Understanding and Applying Primary Pathways and Principles.* Improving Nutrition through Agriculture Technical Brief 1. Arlington, VA, US: Strengthening Partnerships, Results, and Innovations in Nutrition Globally.

Hoddinott, J. 2006. "Shocks and Their Consequences Across and Within Households in Rural Zimbabwe." *Journal of Development Studies* 42 (2): 301–321.

IFPRI (International Food Policy Research Institute). 2015. *Global Nutrition Report 2015: Actions and Accountability to Advance Nutrition and Sustainable Development*. Washington, DC. http://dx.doi.org/10.2499/9780896298835.

———. 2017. *2017 Global Food Policy Report*. Washington, DC. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131085.

Ismail, S., J. Shindano, D. B. Nyirenda, R. Bandyopadhyay, and J. Akello. 2014. "Does Exposure to Aflatoxin Constrain Efforts to Reduce Stunting in Zambia?" *IDS Special Collection*, September, 22–26.

Johnson, N. L., C. Kovarik, R. Meinzen-Dick, J. Njuki, and A. Quisumbing. 2016. "Gender, Assets, and Agricultural Development: Lessons from Eight Projects." *World Development* 83: 295-311.

Jost, C., F. Kyazze, J. Naab, S. Neelormi, J. Kinyangi, R. Zougmore, P. Aggarwal, et al. 2015. "Understanding Gender Dimensions of Agriculture and Climate Change in Smallholder Farming Communities." *Climate and Development* 8 (2): 1–12. www.tandfonline.com/doi/full/10.1080/17565529.2015.1050978.

Juana, J. S., Z. Kahaka, and F. N. Okurut. 2013. "Farmers' Perceptions and Adaptations to Climate Change in Sub-Sahara Africa: A Synthesis of Empirical Studies and Implications for Public Policy in African Agriculture." *Journal of Agricultural Science* 5 (4): 121–135.

Kadiyala, S., J. Harris, D. Headey, S. Yosef, and S. Gillespie. 2014. "Agriculture and Nutrition in India: Mapping Evidence to Pathways." *Annals of the New York Academy of Sciences* 1331: 43–56. doi:10.1111/nyas.12477.

Katungi, E., S. Edmeades, and M. Smale. 2008. "Gender, Social Capital and Information Exchange in Rural Uganda." *Journal of International Development* 20: 35–52.

Kensler, T. W., B. D. Roebuck, G. N. Wogan, and J. D. Groopman. 2011. "Aflatoxin: A 50-Year Odyssey of Mechanistic and Translational Toxicology." *Toxicological Sciences* 120 (1S): S28–S48. http://www.ncbi.nlm.nih.gov/pubmed/20881231.

Khlangwiset, P., G. S. Shephard, and F. Wu. 2011. Aflatoxins and Growth Impairment: A Review. *Critical Reviews in Toxicology* 41 (9): 740–755. www.tandfonline.com/doi/full/10.3109/10408444.2011.575766.

Kiptot, E., and S. Franzel. 2012. "Gender and Agroforestry in Africa: A Review of Women's Participation." *Agroforestry Systems* 84 (1): 35–58.

Komatsu, H., H. J. L. Malapit, and S. Theis. 2015. *How Does Women's Time in Reproductive Work and Agriculture Affect Maternal and Child Nutrition? Evidence from Bangladesh, Cambodia, Ghana, Mozambique, and Nepal.* Discussion Paper 01486. Washington, D.C.: International Food Policy Research Institute.

Kristjanson, P., E. Bryan, Q. Bernier, J. Twyman, R. S. Meinzen-Dick, C. Kieran, C. Ringler, C. Jost, and C. Doss. 2017. "Addressing Gender in Agricultural Research for Development in the Face of a Changing Climate: Where Are We and Where Should We Be Going?" *International Journal of Agricultural Sustainability*. Published electronically June 1. doi:10.1080/14735903.2017.1336411.

Kristjanson, P., H. Neufeldt, A. Gassner, J. Mango, F. B. Kyazze, S. Desta, G. Sayula, B. Thiede, W. Förch, P. K. Thornton, and R. Coe. 2012. "Are Food Insecure Smallholder Households Making Changes in Their Farming Practices? Evidence from East Africa." *Food Security* 4 (3): 381–397.

Kurukulasuriya, P. 2006. "Will African Agriculture Survive Climate Change?" *World Bank Economic Review* 20 (3): 367–388. http://wber.oxfordjournals.org/cgi/doi/10.1093/wber/lhl004.

Lahai, B. A. N., P. Goldey, and G. E. Jones. 1999. "The Gender of the Extension Agent and Farmers' Access to and Participation in Agricultural Extension in Nigeria." *Journal of Agricultural Education and Extension* 6 (4): 223–233. doi:10.1080/13892240085300051.

Lipper, L., P. Thornton, B. M. Campbell, T. Baedeker, A. Braimoh, M. Bwalya, P. Caron, et al. 2014. "Climate Smart Agriculture for Food Security." *Nature Climate Change* 4: 1068–1072. doi:10.1038/nclimate2437.

Malapit, H. J. L., K. Sproule, C. Kovarik, R. Meinzen-Dick, A. Quisumbing, F. Ramzan, E. Hogue, and S. Alkire. 2014. *Measuring Progress Toward Empowerment: Women's Empowerment in Agriculture Index: Baseline Report*. Washington, DC: International Food Policy Research Institute.

Malapit, H. J. L., and A. R. Quisumbing. 2015. "What Dimensions of Women's Empowerment in Agriculture Matter for Nutrition in Ghana?" *Food Policy* 52: 54–63. doi:10.1016/j.foodpol.2015.02.003.

Meinzen-Dick, R., J. Behrman, P. Menon, and A. Quisumbing. 2012. "Gender: A Key Dimension Linking Agricultural Programs to Improved Nutrition and Health." In *Reshaping Agriculture for Nutrition and Health*, edited by S. Fan and R. Pandya-Lorch, 135–144. Washington, DC: International Food Policy Research Institute.

Müller, C., W. Cramer, W. L. Hare, and H. Lotze-Campen. 2011. "Climate Change Risks for African Agriculture." *Proceedings of the National Academy of Sciences* 108 (11): 4313–4315.

Murphy, S. P., and L. H. Allen. 2003. "Nutritional Importance of Animal Source Foods." *Journal of Nutrition* 133 (11 S2): 3932S–3935S. www.ncbi.nlm.nih.gov/pubmed/14672292.

Myers, S. S., M. R. Smith, S. Guth, C. D. Golden, B. Vaitla, N. D. Mueller, A. D. Dangour, and P. Huybers. 2017. "Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition." *Annual Review of Public Health* 38 (1): 259–277. www.ncbi.nlm.nih.gov/pubmed/28125383.

Naab, J. B., and H. Koranteng. 2012. *Using a Gender Lens to Explore Farmers' Adaptation Options in the Face of Climate Change: Results of a Pilot Study in Ghana*. Working Paper 17. Nairobi, Kenya: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Nabikolo, D., B. Bashaasha, M. N. Mangheni, and J. G. M. Majaliwa. 2012. "Determinants of Climate Change Adaptation among Male and Female Headed Farm Households in Eastern Uganda." *African Crop Science Journal* 20 (S2): 203–212.

Nelson, G. C., H. Valin, R. D. Sands, P. Havlík, H. Ahammad, D. Deryng, J. Elliott, et al. 2014. "Climate Change Effects on Agriculture: Economic Responses to Biophysical Shocks." *Proceedings of the National Academy of Sciences* 111 (9): 3274–3279. www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3948295&tool=pmcentrez&rendertype=abstract.

Nelson, V., and T. Stathers. 2009. "Resilience, Power, Culture, and Climate: A Case Study from Semi-arid Tanzania, and New Research Directions." *Gender & Development* 17 (1): 81–95. http://dx.doi.org/10.1080/13552070802696946.

Nhemachena, C., and R. Hassan. 2008. "Determinants of African Farmers' Strategies for Adapting to Climate Change: Multinomial Choice Analysis." *African Journal of Agricultural and Resource Economics* 2 (1): 83–104.

Niang, I., O. C. Ruppel, M. A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart. 2014. "Africa." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by C. B. Field, V. R. Barros, D. J. Dokken, M. D. Mastrandrea, K. J. Mach, T. E. Bilir, M. Chatterjee, et al., 1199–1265. Cambridge, UK: Cambridge University Press.

Nielsen, J. Ø., and A. Reenberg. 2010. "Cultural Barriers to Climate Change Adaptation: A Case Study from Northern Burkina Faso." *Global Environmental Change* 20 (1): 142–152.

Njuki, J., E. Waithanji, B. Sakwa, J. Kariuki, E. Mukewa, and J. Ngige. 2014. "A Qualitative Assessment of Gender and Irrigation Technology in Kenya and Tanzania." *Gender, Technology and Development* 18 (3): 303–340.

Noble, I. R., S. Huq, Y. A. Anokhin, J. Carmin, D. Goudou, F. P. Lansigan, B. Osman-Elasha, and A. Villamizar. 2014. "Adaptation Needs and Options." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, M. Chatterjee, et al., 833–868. Cambridge, UK: Cambridge University Press.

Oloukoi, G., M. Fasona, F. Olorunfemi, V. Adedayo, and P. Elias. 2014. "A Gender Analysis of Perceived Climate Change Trends and Ecosystems-Based Adaptation in the Nigerian Wooded Savannah." *Agenda: Empowering Women for Gender Equity* 28 (3): 16–33.

Owens, S., R. Gulati, A. J. Fulford, F. Sosseh, F. C. Denison, B. J. Brabin, and A. M. Prentice. 2015. "Periconceptional Multiple-Micronutrient Supplementation and Placental Function in Rural Gambian Women: A Double-Blind, Randomized, Placebo-Controlled Trial." *American Journal of Clinical Nutrition* 102 (6): 1450–1459.

PACA (Partnership for Aflatoxin Control in Africa). 2014. *The Relationship between Aflatoxins and Stunting: A Summary of Current Research*. Addis Ababa, Ethiopia. http://aflatoxinpartnership.org/uploads/PACA Stunting Policy Brief.pdf.

Patz, J. A., A. K. Githeko, J. P. McCarty, S. Hussain, U. Confalonieri, and N. de Wet. 2003. "Climate Change and Infectious Diseases." In *Climate Change and Human Health: Risks and Responses*, edited by A. J. McMichael, D. H. Campbell-Lendrum, C. F. Corvalán, K. L. Ebi, A. K. Githeko, J. D. Scheraga, and A. Woodward, 103–132. Geneva: Word Health Organization.

Perez, C., E. Jones, P. Kristjanson, L. Cramer, P. Thornton, W. Förch, and C. Barahona. 2014. *How Resilient Are Farming Households, Communities, Men and Women to a Changing Climate in Africa?* Working Paper 80. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Peterman, A., J. A. Behrman, and A. R. Quisumbing. 2014. "A Review of Empirical Evidence on Gender Differences in Nonland Agricultural Inputs, Technology, and Services in Developing Countries." In *Gender in Agriculture: Closing the Knowledge Gap*, edited by A. R. Quisumbing, R. Meinzen-Dick, T. L. Raney, A. Croppenstedt, J. A. Ehrman, and A. Peterman, 145–186. New York: Springer.

Peterman, A., A. Quisumbing, J. Behrman, and E. Nkonya. 2011. "Understanding the Complexities Surrounding Gender Differences in Agricultural Productivity in Nigeria and Uganda." *Journal of Development Studies* 47 (10): 1482–1509.

Phalkey, R. K., C. Aranda-Jan, S. Marx, B. Höfle, and R. Sauerborn. 2015. "Systematic Review of Current Efforts to Quantify the Impacts of Climate Change on Undernutrition." *Proceedings of the National Academy of Sciences* 112 (33): E4522–E4529. www.ncbi.nlm.nih.gov/pubmed/26216952.

Quisumbing, A. R., ed. 2003. *Household Decisions, Gender, and Development: A Synthesis of Recent Research*. Washington, DC: International Food Policy Research Institute.

Quisumbing, A. R., N. Kumar, and J. A. Behrman. 2011. *Do Shocks Affect Men's and Women's Assets Differently? A Review of Literature and New Evidence from Bangladesh and Uganda*. Discussion Paper 01113. Washington, DC: International Food Policy Research Institute.

Quisumbing, A. R., and J. Maluccio. 2003. "Resources at Marriage and Intrahousehold Allocation: Evidence from Bangladesh, Ethiopia, Indonesia, and South Africa." *Oxford Bulletin of Economics and Statistics* 65 (3): 283–327. http://doi.org/10.1111/1468-0084.t01-1-00052.

Ranganathan, J., D. Vennard, R. Waite, P. Dumas, B. Lipinski, T. Searchinger, and GlobAgri-WRR model authors. 2016. *Shifting Diets for a Sustainable Food Future*. Creating a Sustainable Food Future 11. Washington, DC: World Resources Institute. www.wri.org/sites/default/files/Shifting_Diets_for_a_Sustainable_Food_Future_1.pdf.

Rao, S., A. Kanade, B. M. Margetts, C. S. Yajnik, H. Lubree, S. Rege, B. Desai, A. Jackson, and C. H. D. Fall. 2003. "Maternal Activity in Relation to Birth Size in Rural India: The Pune Maternal Nutrition Study." *European Journal of Clinical Nutrition* 57 (4): 531–542. doi:10.1038/sj.ejcn.1601582.

Ringler, C., A. Quisumbing, E. Bryan, and R. S. Meinzen-Dick, eds. 2014. *Enhancing Women's Assets to Manage Risk under Climate Change: Potential for Group-Based Approaches*. Washington, DC: International Food Policy Research Institute. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/128599.

Rivera, J. A., R. Martorell, M. T. Ruel, J. P. Habicht, and J. D. Haas. 1995. "Nutritional Supplementation during the Preschool Years Influences Body Size and Composition of Guatemalan Adolescents." *Journal of Nutrition* 125 (S4): 1068S–1077S. www.ncbi.nlm.nih.gov/pubmed/7722709.

Rodima-Taylor, D. 2012. "Social Innovation and Climate Adaptation Local Collective Action in Diversifying Tanzania." *Applied Geography* 33: 128–134.

Ruel, M. T., H. Alderman, and the Maternal and Child Nutrition Study Group. 2013. "Nutrition-Sensitive Interventions and Programmes: How Can They Help to Accelerate Progress in Improving Maternal and Child Nutrition?" *The Lancet* 382 (9891): 536–551. http://linkinghub.elsevier.com/retrieve/pii/S0140673613608430.

Seo, S., and R. Mendelsohn. 2008. "Measuring Impacts and Adaptations to Climate Change: A Structural Ricardian Model of African Livestock Management." *Agricultural Economics* 38: 151–165.

Smith, L. C., U. Ramakrishnan, A. Ndiaye, L. Haddad, and R. Martorell. 2003. *The Importance of Women's Status for Child Nutrition in Developing Countries*. Research Report 131. Washington, DC: International Food Policy Research Institute. http://www.ifpri.org/publication/importance-womens-status-child-nutrition-developing-countries.

Smithers, J., and B. Smit. 1997. "Human Adaptation to Climatic Variability and Change." *Global Environmental Change* 7 (2): 129–146.

SPRING (Strengthening Partnerships, Results, and Innovations in Nutrition Globally). 2014. *Understanding the Women's Empowerment Pathway*. Improving Nutrition through Agriculture Technical Brief 4. Arlington, VA, US: SPRING.

Springmann, M., D. Mason-D'Croz, S. Robinson, T. Garnett, H. C. J. Godfray, D. Gollin, M. Rayner, P. Ballon, and P. Scarborough. 2016a. "Global and Regional Health Effects of Future Food Production under Climate Change: A Modelling Study." *The Lancet* 387 (10031): 1937–1946. www.thelancet.com/article/S0140673615011563/fulltext.

Springmann, M., D. Mason-D'Croz, S. Robinson, K. Wiebe, H. C. J. Godfray, M. Rayner, and P. Scarborough. 2016b. "Mitigation Potential and Global Health Impacts from Emissions Pricing of Food Commodities." *Nature Climate Change* 7:69–74.

Tall, A., P. Kristjanson, M. Chaudhury, S. McKune, and R. Zougmore. 2014. *Who Gets the Information? Gender, Power and Equity Considerations in the Design of Climate Services for Farmers*. Working Paper 89. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Theis, S., N. Lefore, R. Meinzen-Dick, and E. Bryan. 2017. *What Happens After Technology Adoption? Gendered Aspects of Small-Scale Irrigation Technologies in Ethiopia, Ghana, and Tanzania*. Discussion Paper 01672. Washington, DC: International Food Policy Research Institute.

Twyman, J., M. Green, Q. Bernier, P. Kristjanson, S. Russo, A. Tall, E. Ampaire, M. Nyasimi, J. Mango, S. McKune, C. Mwongera, and Y. Ndourba. 2014. *Adaptation Actions in Africa: Evidence That Gender Matters*. Working Paper 83. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security.

Udry, C. 1996. "Gender, Agricultural Production, and the Theory of the Household." *Journal of Political Economy* 104 (5): 1010–1046.

van den Bold, M., A. R. Quisumbing, and S. Gillespie. 2013. *Women's Empowerment and Nutrition: An Evidence Review*. Discussion Paper 1294. Washington, DC: International Food Policy Research Institute.

Vetter, S. H., T. B. Sapkota, J. Hillier, C. M. Stirling, J. I. Macdiarmid, L. Aleksandrowicz, R. Green, E. J. Joy, A. D. Dangourand, and P. Smith. 2017. "Greenhouse Gas Emissions from Agricultural Food Production to Supply Indian Diets: Implications for Climate Change Mitigation." *Agriculture, Ecosystems & Environment* 237: 234–241. www.ncbi.nlm.nih.gov/pubmed/28148994.

Victora, C. G., L. Adair, C. Fall, P. C. Hallal, R. Martorell, L. Richter, and H. S. Sachdev. 2008. "Maternal and Child Undernutrition: Consequences for Adult Health and Human Capital." *The Lancet* 371 (9609): 340–357.

Chapter 10

AfDB (African Development Bank), OECD (Organisation for Economic Co-operation and Development), UNDP (United Nations Development Programme), and ECA (Economic Commission for Africa). 2013. *African Economic Outlook 2013: Structural Transformation and Natural Resources*. Rome: OECD Publishing. www.undp.org/content/dam/rba/docs/Reports/African%20Economic%20Outlook%202013%20En.pdf.

African Union. 2003. *Maputo Declaration on Agriculture and Food Security*. Maputo, Mozambique.

African Union and NEPAD (New Partnership for Africa's Development). n.d. *Implementing the Comprehensive Africa Agriculture Development Programme and Restoring Food Security in Africa: "The Roadmap."* Midrand, South Africa: NEPAD. Accessed June 14, 2017. ftp://ftp.fao.org/TC/TCA/CAADP%20TT/Background%20%20documents/Main%20document/Roadmap%20of%20implementing%20CAADP.pdf.

African Union Commission. 2014. *Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods*. Addis Ababa, Ethiopia. https://au.int/sites/default/files/documents/31006-doc-malabo_declaration_2014_11_26-.pdf.

———. 2015. *Agenda 2063 Framework Document: The Africa We Want*. Addis Ababa, Ethiopia. www.un.org/en/africa/osaa/pdf/au/agenda2063-framework.pdf.

Agbor, J., O. Taiwo, and J. Smith. 2012. "Sub-Saharan Africa's Youth Bulge: A Demographic Divide or Disaster." In *Foresight Africa: Top Priorities for the Continent in 2012*, edited by J. O. Adeoti, J. Agbor, M. Diene, R. Joseph, A. Kamau, S. N. Karingi, M. S. Kimenyi, et al., 9–11. Washington, DC: Africa Growth Initiative at Brookings. www.brookings.edu/wp-content/uploads/2016/06/01_youth_bulge_agbor_taiwo_smith.pdf.

Bafana, B. 2014. "Denting Youth Unemployment through Agriculture." Special issue on agriculture, *Africa Renewal*, 8–9. www.un.org/africarenewal/magazine/special-edition-agriculture-2014/denting-youth-unemployment-through-agriculture.

Bradbear, N. 2009. "The Value of Bees for Crop Pollination." In *Bees and Their Role in Forest Livelihoods*, 69–79. Rome: Food and Agriculture Organization of the United Nations. ftp://ftp.fao.org/docrep/fao/012/i0842e/i0842e09.pdf.

Calestos, J. 2011. *The New Harvest: Agricultural Innovation in Africa*. New York: Oxford University Press.

De Schutter, O. 2011. "Promotion and Protection of all Human Rights, Civil, Political, Economic, Social and Cultural Rights, Including the Right to Development." Report A/HRC/16/49 presented at the 16th session of the United Nations Human Rights Council, New York, March 8. www.srfood.org/images/stories/pdf/officialreports/20110308_a-hrc-16-49_agroecology_en.pdf.

FAO (Food and Agriculture Organization of the United Nations). 2010. FAO/World Bank workshop on Reducing Post-harvest Losses in Grain Supply Chains in Africa. Lessons Learned and Practical Guidelines. Accessed July 14, 2017. Rome. http://www.fao.org/fileadmin/user_upload/ags/publications/FAO_WB_ph_web.pdf.

FAO. n.d. *Food Wastage Footprints*. Accessed July 14, 2017. Rome. www.fao.org/fileadmin/templates/nr/sustainability_pathways/docs/Factsheet_FOOD-WASTAGE.pdf.

Formo, R. K., H. Jørstad, C. Nellemann, C. Mafuta, R. Munang, J. Andrews, and J. N. Hval (eds). 2014. *Food Wasted, Food Lost: Food Security by Restoring Ecosystems and Reducing Food Loss*. Nairobi, Kenya: United Nations Environment Programme; Arendal, Norway: GRID-Arendal.

Imhoff, D. 2015. "Will the World Bank Get Truly Climate Smart?" Bretton Woods Project, March 31. www.brettonwoodsproject.org/2015/03/will-the-world-bank-get-truly-climate-smart/.

INRA (French National Institute for Agricultural Research). 2016. "World Food Security Affected by a Shortage of Pollinating Insects." Press release. http://presse.inra.fr/en/Press-releases/World-food-security-affected-by-a-shortage-of-pollinating-insects.

Kanu, B. S., A. O. Salami, and K. Numasawa. 2014. *Inclusive Growth: An Imperative for Africa Agriculture*. Tunis, Tunisia: African Development Bank Group. www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/Inclusive_Growth_-_An_imperative_for_African_Agriculture.pdf.

Kirsten, B., and P. M. Jens. 2001. "Organic Agriculture: Does It Enhance or Reduce the Nutritional Value of Plant Foods?" In "Nutritional Enhancement of Plant Foods," special issue, *Journal of the Science of Food and Agriculture* 81 (9): 924–931.

Marks, A. 2016a. "Agriculture Is in Every SDG: Part 1." Can We Feed the World, January 14. https://canwefeedtheworld.wordpress.com/2016/01/14/agriculture-is-in-every-sdg-part-1/.

———. 2016b. "Agriculture Is in Every SDG: Part 2." Can We Feed the World, January 21. https://canwefeedtheworld.wordpress.com/2016/01/21/agriculture-is-in-every-sdg-part-2/.

Montpellier Panel. 2014a. *No Ordinary Matter: Conserving, Restoring and Enhancing Africa's Soils*. Dakar Almadies, Senegal. http://ag4impact.org/wp-content/uploads/2014/12/MP_0106_Soil_Report_LR1.pdf.

———. 2014b. *Small and Growing Entrepreneurship in African Agriculture: A Montpellier Panel Report*. Dakar Almadies, Senegal. https://workspace.imperial.ac.uk/africanagriculturaldevelopment/Public/Small%20and%20Growing.pdf.

Mubila, M., and M. B. Aissa. 2011. *The Middle of the Pyramid: Dynamics of the Middle Class in Africa*. Market Brief. Abidjan, Côte d'Ivoire: African Development Bank. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/The%20Middle%20of%20the%20Pyramid_The%20Middle%20of%20the%20Pyramid.pdf.

Munang, R., and J. Andrews. 2014. "Despite Climate Change, Africa Can Feed Africa." Special issue on agriculture, *Africa Renewal*, 6–7. www.un.org/africarenewal/magazine/special-edition-agriculture-2014/despite-climate-change-africa-can-feed-africa.

Munang, R., R. Mgendi, K. Alverson, M. O'Brien-Onyeka, C. Ochieng, E. Molua, W. Ottichilo, et al. 2015. *Ecosystem-Based Adaptation (EbA) for Food Security in Africa: Towards a Comprehensive Strategic Framework to Upscale and Out-scale EbA-Driven Agriculture in Africa*. Nairobi, Kenya: United Nations Environment Programme.

Nomathemba, M. , E. Seidler, D. Njie, and S. Gallat. 2010. *FAO / World Bank Workshop on Reducing Post-harvest Losses in Grain Supply Chains in Africa: Lessons Learned and Practical Guidelines*. Washington, DC: World Bank; Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/fileadmin/user_upload/ags/publications/FAO_WB_ph_web.pdf.

Olivier, J., K. Probst, I. Renner, and K. Riha. 2012. *Ecosystem-Based Adaptation (EbA): A New Approach to Advance Natural Solutions for Climate Change Adaptation across Different Sectors*. Eschborn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit. www.giz.de/expertise/downloads/giz2013-en-ecosystem-based-adaptation.pdf.

Pietersen, K., H. Beekman, A. Abdelkader, H. Ghany, A. Opere, E. Odada, T. Ayenew, et al. 2006. "Freshwater." In *Africa Environment Outlook 2: Our Environment, Our Wealth*, edited by J. C. Mohamed-Katerere, 119–154. Nairobi, Kenya: United Nations Environment Programme. http://staging.unep.org/DEWA/Africa/docs/en/aeo-2/chapters/aeo-2_ch04_FRESHWATER.pdf.

REEEP (Renewable Energy and Energy Efficiency Partnership). 2015. "Solar-Powered Irrigation in Kenya: Futurepump." www.reeep.org/projects/solar-powered-irrigation-kenya-futurepump.

Reid, H., N. Seddon, E. Barrow, C. Hicks, X. Hou-Jones, V. Kapos, A. R. Rizvi, D. Roe, and S. Wicander. 2017. Ecosystem-Based Adaptation: Question-Based Guidance for Assessing Effectiveness. London: International Institute for Environment and Development. www.international-climate-initiative.com/fileadmin/Dokumente/2017/170516_EbA_IIED.pdf.

Rohit, J., S. Brent, and K. John. 2006. *Status of Carbon Sequestration Projects in Africa: Potential Benefits and Challenges to Scaling Up*. Nairobi, Kenya: World Agroforestry Centre.

Schaeffer, M., F. Baarsch, G. Balo, K. de Bruin, R. Calland, F. Fallasch, M. E. Melkie, et al. 2015. *Africa's Adaptation Gap 2 Technical Report: Bridging the Gap—Mobilising Sources*. Nairobi, Kenya: United Nations Environment Programme. http://apps.unep.org/redirect.php?file=/publications/pmtdocuments/-Africa%E2%80%99s_Adaptation_Gap_2__.pdf.

Talberth, J., and C. Hanson. 2012. "Green vs. Gray Infrastructure: When Nature Is Better than Concrete." World Resources Institute blog. http://www.wri.org/blog/2012/06/green-vs-gray-infrastructure-when-nature-better-concrete.

UNCCD (United Nations Convention to Combat Desertification). 2017. "What Is Ecosystem-Based Adaptation?" Paris. www.unccd.int/en/programmes/Event-and-campaigns/WDCD/Pages/What-is-Ecosystem-Based-Adaptation.aspx.

UNEP (United Nations Environment Programme). 2015. *The Emissions Gap Report 2015*. Nairobi, Kenya.

UNESCO. 2017. *Regional Conference on Higher Education and Research: Quality and Future Challenges for Eastern Africa*. Harare, Zimbabwe: UNESCO Regional Office for Eastern Africa. www.unesco.org/new/fileadmin/MULTIMEDIA/FIELD/Nairobi/sciencesclimatechange_01.pdf.

United Nations. 2016. *The Sustainable Development Goals Report 2016*. New York. https://unstats.un.org/sdgs/report/2016/The%20Sustainable%20Development%20Goals%20Report%202016.pdf.

World Bank. 2015. "Agriculture Finance". Accessed August 29, 2017. http://www.worldbank.org/en/topic/financialsector/brief/agriculture-finance.

World Bank. 2013. "Africa's Food Markets Could Create One Trillion Dollar Opportunity by 2030." March 4. www.worldbank.org/en/news/press-release/2013/03/04/africas-food-markets-could-create-one-trillion-dollar-opportunity-2030.

World Economic Forum. 2015. *The Africa Competitiveness Report 2015*. Geneva.

Chapter 11 and Annex Tables

AfDB (African Development Bank). 2017. AFDB Socio Economic Database, 1960–2016. http://dataportal.opendataforafrica.org/xedzxdg/afdb-socio-economic-database-1960-2016.

AUC and NPCA (African Union Commission and the NEPAD Planning and Coordinating Agency). 2015. *The CAADP Results Framework 2015–2025*. Midrand, South Africa: NPCA.

Benin, S., M. Johnson, and B. Omilola. 2010. *Monitoring and Evaluation (M&E) System for the Comprehensive African Agriculture Development Program (CAADP)*. ReSAKSS Working Paper 6. Washington, DC: International Food Policy Research Institute.

FAO (Food and Agriculture Organization of the United Nations). 2017. FAOSTAT. http://www.fao.org/faostat/en/#data

OECD (Organisation for Economic Co-operation and Development). 2017. Creditor Reporting System (CRS). http://stats.oecd.org/index.aspx?DataSetCode=CRS1.

International Food Policy Research Institute (IFPRI); Welthungerhilfe (WHH) ; Concern Worldwide, 2016, "2016 Global Hunger Index Data", doi:10.7910/DVN/LU8KRU, Harvard Dataverse, V1.

International Food Policy Research Institute (IFPRI). 2015. Statistics on Public Expenditures for Economic Development (SPEED). Dataverse, V2. https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/INZ3QK.

International Monetary Fund (IMF). 2016. *Regional Economic Outlook: Sub-Saharan Africa: Multispeed Growth.* Washington, DC. http://www.imf.org/external/pubs/ft/reo/2016/afr/eng/pdf/sreo1016.pdf.

ILO (International Labour Organization). 2017. Statistics and databases. http://ilo.org/global/statistics-and-databases/lang--en/index.htm.

NEPAD (New Partnership for Africa's Development). 2015. Countries with Compacts /Investment Plans – Nov 2015. http://www.nepad.org/resource/countries-compacts-investment-plans-%E2%80%93-nov-2015.

United Nations Conference on Trade and Development (UNCTAD). 2017. UNCTADSTAT. http://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx.

World Bank. 2017. World Development Indicators (WDI). http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#.

Regional Strategic Analysis and Knowledge Support System
International Food Policy Research Institute
1201 Eye Street NW
Washington, DC 20005 USA
Tel.: + 1 202.862.5600
Fax: +1 202.862.5606
Email: resakss-africa@cgiar.org
www.resakss.org

ISBN: 978-0-89629-294-9