Feed the Future Innovation Lab for Food Security Policy

Research Paper 94 March 2018

INTEGRATING CLIMATE- AND MARKET-SMARTNESS INTO STRATEGIES FOR SUSTAINABLE PRODUCTIVITY GROWTH OF AFRICAN AGRI-FOOD SYSTEMS

By

Nicholas J. Sitko and T.S. Jayne

Food Security Policy *Research Papers*

This *Research Paper* series is designed to timely disseminate research and policy analytical outputs generated by the USAID funded Feed the Future Innovation Lab for Food Security Policy (FSP) and its Associate Awards. The FSP project is managed by the Food Security Group (FSG) of the Department of Agricultural, Food, and Resource Economics (AFRE) at Michigan State University (MSU), and implemented in partnership with the International Food Policy Research Institute (IFPRI) and the University of Pretoria (UP). Together, the MSU-IFPRI-UP consortium works with governments, researchers, and private sector stakeholders in Feed the Future focus countries in Africa and Asia to increase agricultural productivity, improve dietary diversity, and build greater resilience to challenges like climate change that affect livelihoods.

The papers are aimed at researchers, policy makers, donor agencies, educators, and international development practitioners. Selected papers will be translated into French, Portuguese, or other languages.

Copies of all FSP Research Papers and Policy Briefs are freely downloadable in pdf format from the following Web site: www.foodsecuritypolicy.msu.edu

Copies of all FSP papers and briefs are also submitted to the USAID Development Experience Clearing House (DEC) at: http://dec.usaid.gov/

AUTHORS

Sitko is Programme Coordinator, ESA Division, FAO and Jayne is University Foundation Professor and Co-Director of the Alliance for African Partnership, Michigan State University.

Authors' Acknowledgment:

The authors appreciate financial and scholarly support from both the Bureau for Food Security/USAID through the Food Security Policy Innovation Lab and from UKAID through Vuna, a DFID-funded regional climate-smart agriculture programme, implemented by Adam Smith International. However, the views and recommendations contained in this report are those of the authors only; no organization is responsible for, or bound by the recommendations made. The authors also acknowledge the editorial assistance of Patricia Johannes.

This study is made possible by the generous support of the American people through the United States Agency for International Development (USAID) under the Feed the Future initiative. The contents are the responsibility of the study authors and do not necessarily reflect the views of USAID or the United States Government

Published by the Department of Agricultural, Food, and Resource Economics, Michigan State University, Justin S. Morrill Hall of Agriculture, 446 West Circle Drive, Room 202, East Lansing, Michigan 48824, USA.

EXECUTIVE SUMMARY

The Sustainable Agri-Food System Productivity Framework (SAP)

This study develops a novel conceptual framework, the sustainable agri-food system productivity framework (SAP), to develop a comprehensive approach for promoting productivity and resilience of African agri-food systems in the context of climate change. Based on this framework, we identify concrete strategies for consideration by policy makers and development partners.

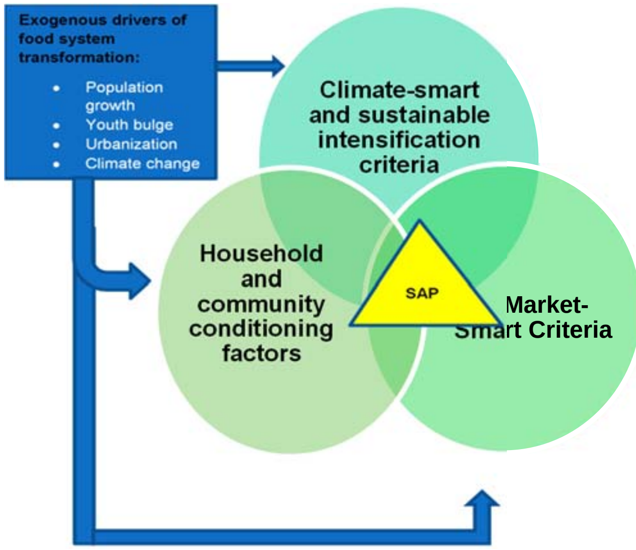
We represent the SAP framework visually in Figure 1a as a Venn diagram with three pillars. The first pillar, shown in the top circle, include the criteria by which climate-smart agricultural (CSA) outcomes are typically assessed. In Sub-Saharan Africa (SSA) CSA actions typically include the promotion of *sustainable intensification* (SI) practices, such as conservation agriculture (CA), agroforestry, irrigation, practices to control erosion, and use of improved seeds and fertilizers. Whether or not these practices contribute to productivity growth or climate resilience depends on whether other practices are also adopted, the duration of adoption, and site-specific agro-ecological characteristics, among other things.

The second pillar of the SAP framework, shown in the bottom right circle of Figure 1, are the criteria for assessing *market-smart* (MS) strategies. We characterize MS approaches as those that enroll the private sector to overcome persistent market failures or strengthen markets to promote long-term market development objectives. Based on this definition, an intervention can be considered MS if it is demand-driven (e.g., promoting practices or technologies with a proven demand by farmers at commercial prices), reduces costs and/or risks for agri-food system actors, and contributes to sustainable forms of food production and distribution.

The third element of the SAP framework draws attention to the highly varied household and community level factors that influence the viability of particular farmer practices, such as farm resource endowments, market access, and agro-ecological conditions. These conditioning factors are represented on the lower left circle of Figure 1. This framework raises the possibility that achieving sustainable intensification and climate-smart agriculture objectives may involve strategies that are outside of farm-level programmes per se (e.g., macro-economic policies, waste management programmes, development of markets for organic compost) but which fundamentally affect the profitability of farm-level adoption of integrated sustainable intensification practices and technologies.

A programme of sustainable and market-smart responses to climate change occurs at the intersection of these three circles of Figure 1. An intervention (i.e., policy, programme, practice) meets the criteria of the SAP framework when it: 1) contributes to long-term productivity growth and stability of the entire agri-food system; 2) strengthens the operation of markets and opens up new opportunities for investment by farmers and others in the agri-food system; and 3) criteria 1 and 2 hold for a sufficient number of households or farmland area to have a meaningful impact on the agri-food system.

Figure 1a. The Sustainable Agri-food System Productivity Framework (SAP)



Source: Authors

The final element of the SAP framework is that it anticipates and accounts for exogenous forces associated with rapidly growing and urbanizing populations and growing climate uncertainty. These forces have exerted extraordinary transformative pressure on agri-food systems in the region over the past decade. An effective climate-smart and sustainable intensification programme will need to anticipate and account for these dynamics of food systems transformation. The study traces out how sustainable agricultural productivity strategies will be affected by forces such as 1) rapid population growth and its effects on the relative costs of labor, land and capital in agricultural production; 2) widespread observed shifts in the labor force from farm to off-farm activities over the past decade in most African countries, driven by youth exit from farming, and associated with chronic low public investment in agriculture; 3) the rapid growth in medium-scale investor farms and associated changes in farm size distributions in the region; 4) rapid investment in agri-food systems by large-scale traders; and 5) increasingly scarce energy and water situations associated with rapid population growth and slow investment responses to date.

Soil Degradation and the Social Trap

Using data from Barbier and Hoachard (2016) we find that in 2000, the number of rural Africans living on degrading agricultural land (DAL) and improving agricultural land (IAL) was virtually the same, with 157 million living on DAL and 154 million on IAL. However, when we look at the pace and direction of change over the period 2000-2010, we find that while the number of Africans living on DAL has increased by 43 million, the number living on IAL has actually declined by 441,901. This finding reinforces the conclusions of other recent studies (e.g., Montpellier Panel 2013) that reversing land degradation in Sub-Saharan Africa is a monumental challenge lying at the heart of a sustainable intensification, climate-smart, and market-smart agricultural programme.

Farmers living on degrading land are highly vulnerable to weather related shocks, because degraded soils lack sufficient soil organic matter to retain moisture and are often unresponsive to inorganic fertilizers. Making African agri-food system more resilient to climate change, therefore, requires policy and investments that can meaningfully improve soil conditions even as population continue to grow.

We argue that a sustainable agricultural productivity strategy requires breaking the social trap in which many land-constrained smallholders find themselves. For millions of poor farmers in SSA, decisions about the allocation of land, labor, and capital are made with the short-term objective of meeting immediate food and livelihoods needs. These rational decisions, however, often prevent them from making long-term investments in their farm that would maintain soil fertility over time. As a result, their farms become less productive and increasingly vulnerable to climate shocks. As the exogenous trends related to population growth, rising land scarcity and climate change continue to unfold, the menu of activities and actions currently being promoted as *climate-smart* will be increasingly insufficient or unprofitable for farmers to adopt unless strategies to restore soil quality across tens of millions of hectares of agricultural land are initiated.

When viewed through the lens of the SAP framework we find that many of the practices and technologies being promoted as climate-smart cannot be feasibly adopted by most farmers mired in this social trap. This highlights the urgent need for more radical and holistic approaches to making African agri-food system productive and resilient in the context of climate change. These approaches must address the social trap affecting millions of small-farmers, while at the same time being responsive to the exogenous trends associated with rapid population growth, which are buffeting African economies.

Recommendations

To cope with and reverse the worrying trend of widespread soil degradation, declining productivity and increased vulnerability of African food systems to climate change requires a holistic approach to sustainable intensification, which recognizes that action is required within the agricultural sector and beyond. This includes approaches that enable farmers to make long-term soil fertility-augmenting investments and more effective public investments that help farmers identify best practices under the wide range of micro-environments in the region. More broadly, it requires developing policies that make labor and financial markets more flexible and supportive of climate-smart outcomes. This may include:

1) substantially increase investments in public agricultural research and participatory extension services in tandem with efforts to identify more effective modes of implementing such programs;
2) prioritize macro-economic stability, with an emphasis on low inflation and borrowing rates, to enable greater investment in the food system and beyond;
3) transform public subsidies in ways that support the development of markets for organic matter, in particular harvest waste from growing urban areas (e.g., livestock production yards, sawdust mills, waste from retail food markets) as sources of organic compost for farm production;
4) Develop policy frameworks to legitimize and strengthen emergent land rental markets;
5) Improve labor market flexibility and foreign direct investment policies, coupled with a social safety net fund; and
6) Substantially reform staple food market policy in order to create a level playing field for alternative crops and livestock systems.

Given the enormity of the challenges facing food systems in the context of rapid population growth and climate change, and the importance of collective action in address them, public sector action and effective use of scarce public expenditures to agriculture will be decisive in achieving sustainable agricultural productivity in the region. Once enacted, the proposals made here will take time to generate their full impacts. That is why there is no time to waste in getting started.

CONTENTS

EXECUTIVE SUMMARY iv

LIST OF TABLES viii

LIST OF FIGURES viii

ACRONYMS ix

1. INTRODUCTION 1

2. SUSTAINABLE AGRI-FOOD SYSTEM PRODUCTIVITY FRAMEWORK (SAP): AN INTEGRATED CONCEPTUAL FRAMEWORK FOR ASSESSING CLIMATE INTERVENTIONS IN AGRI-FOOD SYSTEMS 3

2.1. Population Growth and Heterogeneous Effects on Land/Labor Price Ratios 6
2.2. Land Size Dynamics and the Rise of the Medium Scale Farmer 8
2.3. Energy and Water 9
2.4. Output Market Transformations: The Rise of Large-scale Traders 9
2.5. Agricultural Productivity Growth and the Non-Farm Economy 11

3. UNDERSTANDING THE RELATIONSHIPS BETWEEN POPULATION DENSITY, MARKET ACCESS, AND DEGRADED AGRICULTURAL LAND IN SSA 13

4. ASSESSING THE FEASIBILITY OF FARM-LEVEL ADAPTION AND RESILIENCE TO CLIMATE CHANGE: AN APPLICATION OF THE SAP FRAMEWORK 23

4.1. Conservation Agriculture 23
4.2. Minimum Soil Disturbance: Zero and Minimum Tillage 23
4.3. Crop Rotation and Intercropping 25
4.4. Mulching and Residue Retention 26
4.5. Cover Crops 27
4.6. Agroforestry 27
4.7. Soil Conservation and Erosion Management 28
4.8. Irrigation 29

5. CONCLUSION AND RECOMMENDATIONS: ACHIEVING SAP FRAMEWORK OUTCOMES BY HARNESSING SYSTEM-WIDE TRANSFORMATIONS AND OPPORTUNITIES TO BUILD CLIMATE RESILIENCE 30

5.1. Substantially Increase Investments in Public Agricultural Research and Participatory Extension Services 31
5.2. Prioritize Macro-economic Stability and Low Inflation 32
5.3. Use Subsidies to Support the Development of Markets for Organic Matter 32
5.4. Develop Policy Frameworks to Legitimize Emergent Land Rental Markets 33
5.5. Improve Labor Market Flexibility and Foreign Direct Investment Policies, Coupled With a Social Safety Net Fund 34
5.6. Staple Food Market Policy Reform 34

REFERENCES 36

LIST OF TABLES

1. Population in 2010 and Population Change 2000-2010 on Degrading Agricultural Land (DAL) and Improving Agricultural Land (IAL) in SSA......14
2. Share of Rural Population on All, Remote, and Accessible DAL in 2010......15
3. Unconditional Correlation between Share of Rural Population on DAL (Remote and Accessible) in 2010 and Rural Population Density 2000......17
4. Change in Rural Population on All, Remote, and Accessible DAL, 2000-2010......19
5. Unconditional Correlation between Changes in the Share of Rural Population (Remote and Accessible) DAL between 2000 and 2010 and Rural Population Density 2000......20

LIST OF FIGURES

1. Sustainable Agri-food System Productivity Framework (SAP FRAMEWORK)......4
2. Association between Total Factor Productivity Growth and Change in Share of Labor Force Engaged in Farming in Selected Countries......6
3. Association between Agricultural Total Factor Productivity Growth and Labor Productivity in the Non-agricultural Sector......11
4. Share on Rural Population on Accessible DAL in 2010 by Rural Pop. Density 2000......17
5. Share on Rural Population on Remote DAL in 2010 by Rural Pop. Density 2000......18
6. Change in Share of Rural Population on Remote DAL 2000- 2010 by Rural Pop. Density 2000..21
7. Change in Share of Rural Population on Accessible DAL 2000-2010 by Rural Pop. Density 2000......21

ACRONYMS

CSA	Climate-Smart Agriculture
DFID	Department for International Development
MT	Minimum Tillage
mt	metric tons
ha	hectare
kg	kilograms
CA	Conservation agriculture
SAP FRAMEWORK	Sustainable Agri-Food System Productivity Framework
SSA	Sub-Saharan Africa
MS	Market Smart
SI	Sustainable Intensification
R&D	Research and Development
DAL	Degrading agricultural land
IAL	Improving agricultural land

1. INTRODUCTION

Increasing greenhouse gas levels and associated rises in temperature and climate variability pose major threats to food systems across the globe (IPCC 2013). There is, therefore, urgent need to identify strategies to make food systems more resilient to the effects of a rapidly changing climate. Nowhere is this more important than in Africa, where temperature and rainfall patterns are discernibly changing (Engelbrecht et al. 2015; Hua et al. 2016; Souverijns et al. 2016) and where vulnerability to climate-induced shocks are acute. African countries are particularly vulnerable to climate-related shocks due to the region's reliance on rain-fed production systems, transport systems that often cannot efficiently handle the region's food import needs during years of major food production shortfalls in the region, and the limited coping abilities of a large fraction of the region's population who live in poverty.

Governments, the private sector, civil society and development partners all have important roles to play in supporting climate adaptation and resiliency efforts in Africa. To date, the dominant paradigms of agricultural sector response to climate change are *climate-smart agriculture* (CSA), *market-smart* development (MS), and *sustainable intensification* (SI). Yet despite the increasing prominence of these terms in development programs and government policies, there is a lack of clarity over what they mean in practice, particularly in the context of highly varied and rapidly changing African agri-food systems. Unless farm practices and other actions can be identified that have a proven ability—based on strong evidence—to promote desired outcomes and can be feasibly adopted by farmers and communities across the wide range of micro-climates and conditions found in the region, then terms like CSA, MS, and SI are at risk of becoming slogans that cannot effectively contribute to sustainable development goals.

To date, farmer adoption of practices considered to promote CSA-MS-SI objectives has been mostly disappointing (Arslan et al. 2014; Corbeel et al. 2014; Giller et al. 2009). More importantly, the evidence suggests that most practices currently being promoted as CSA-MS-SI, even if they were adopted, could only marginally stabilize yields in the face of increasingly dramatic climate variability; they could not ensure a harvest in years of increasingly common extreme weather events. These observations may call for a fundamental re-refocus of CSA-MS-SI strategies, in two respects.

First, limited farmer adoption of CSA-SI practices highlights the need for a better understanding of the situation-specific interventions required to change farmers' behaviors in ways that contribute to improved livelihoods and resilience in the context of climate change (Corbeel et al. 2014; Arslan et al. 2014; Umar et al. 2011). This in turn must account for the ways in which broader economic and demographic trends are altering the behaviors of African farmers, urban consumers, and agri-food system actors. Many of these trends relate to rapid population growth, Africa's unique 'youth bulge', urbanization and the accumulation of wealth among a narrow segment of Africans who are changing the face of African agriculture and affecting the behaviors of all actors operating in the agri-food system. By not adequately accounting for these important trends, the current menu of practices being promoted by governments and development partners are in many cases ill-equipped to enhance CSA-MS-SI objectives.

Second, the insufficiency of current practices being promoted as CSA calls for a more holistic approach that views agriculture, water and energy as one interrelated and comprehensive system and that major public policy actions will be required in these three interrelated sectors to respond adequately to changing climates in the region.

In this context, this report has three main objectives. Our first aim is to put the terms climate-smart and market-smart into a unified conceptual framework that puts sustainable productivity growth of agri-food systems at the centre. Failure to integrate these terms into a coherent framework risks the continuation of agricultural policies that may promote narrow short-term production objectives while impeding other major societal objectives such as sustainable natural resource management, system-wide productivity growth, and minimization of negative externalities associated with conventional forms of agricultural production. The framework developed in this report stresses the importance of (i) identifying approaches that raise and stabilize the returns to family labor in farming in the context of climate change and improve resilience throughout the various stages of the food system, and (ii) views the agricultural, water and energy sectors as one interrelated system. Our second aim is to situate this framework within the context of rapidly changing socio, biophysical, and economic landscapes in SSA. By so doing, we seek to anticipate how the range of feasible strategies to achieve productivity growth within agri-food systems in SSA will change over time, and to consider what a coherent agri-food system strategy would look like in the context of rapid demographic and economic transition. Our final aim is to systematically interrogate the evidence on a range of practices/actions often promoted to enhance climate resilience in order to identify the conditions under which these can contribute to agri-food system productivity growth and resilience now and in the future.

The remainder of this paper is organized as follows. Section II presents a novel conceptual framework for assessing actions to enhance the resilience of African agri-food systems. Section III presents data on the relationships between population density change, market access conditions, and soil quality. Section IV reviews the evidence on a range of practices promoted as climate-smart through the lens of our alternative conceptual framework. Section V concludes by providing concrete recommendation on alternative strategies to achieving a more sustainable and resilient food system than are currently being pursued by governments or donor partners.

2. SUSTAINABLE AGRI-FOOD SYSTEM PRODUCTIVITY FRAMEWORK (SAP): AN INTEGRATED CONCEPTUAL FRAMEWORK FOR ASSESSING CLIMATE INTERVENTIONS IN AGRI-FOOD SYSTEMS

This section presents our conceptual framework, which we refer to as the *sustainable agri-food system productivity framework* (SAP). The SAP framework integrates a range of disparate concepts that currently guide agricultural programs toward climate change into a more unified and forward-looking framework. In particular, the SAP framework draws on evidence from both CSA/SI and MS development approaches, and situates these within the context of Africa's rapidly changing agri-food system. By so doing, the SAP framework draws attention to the ways in which system-wide pressures, including population growth, urbanization, and climate change, affect household and community-level variables, such as land size, market access, and land/labor factor ratios, influence whether or not a potentially climate-smart practice will be adopted and by whom.

Our conceptual framework draws upon the concept of 'Social Traps', pioneered by John Platt (1973). Platt observed many examples in which humans, acting in their own best interests in the short-run, under some conditions produce adverse consequences for themselves in the long-run. The well-known 'tragedy of the commons', overfishing, and other examples of social traps are explained here. A common attribute of social traps is that (i) they involve situations where people prioritize immediate interests (i.e., feeding one's family) over long-run concerns such as maintaining soil in a condition capable of growing food on it productively 10 years from now; (ii) behaviors in the short-term lead to adverse consequences in the long-term; and (iii) collective action may be effective in providing incentives to alter short-term behaviors so as to avoid the adverse long-term consequences.

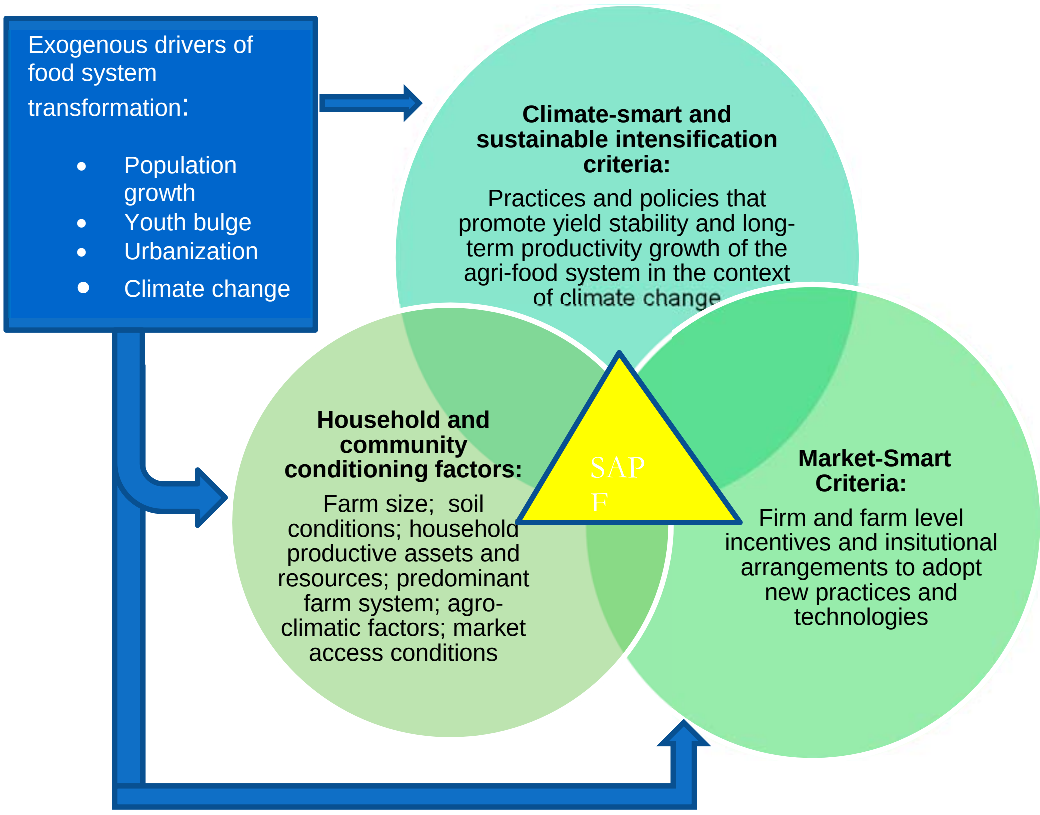
Social traps are particular evident among poor people who must prioritize immediate needs over long-term needs for their survival. In this way, Platt's model explains why food insecure small-scale farmers, especially those with very little land, may utilize their land in ways that maximize their food production in the current year even if it leads to unsustainable land management practices that erode their future productivity. The social trap theory is consistent with observations of low adoption of soil-augmenting practices such as planting basins, ripping, and other conservation farming practices that require major up-front time investments, come at an opportunity cost to other land uses, and tend not to produce clear benefits until at least several years into the future. The fact that soil quality augmentation is a long-term process that requires significant resource investments today leads to under-investment in soil quality, depletes the soil of organic matter and contributes to the phenomenon increasingly noted by soil scientists that some soils are becoming "non-responsive" to inorganic fertilizer application (Tittonell and Giller 2013).

Farm households with relatively abundant land and capital resources face less acute trade-offs. Evidence indicates that they tend to put a higher proportion of their farmland under long-term fallows and can adopt practices that replenish soil nutrients and organic matter (Sheahan and Barrett 2014). The social trap literature suggests that an important role for policy makers is to find ways to effectively reduce the costs, include the perceived risks, incurred by resource constrained farmers to adopt practices that protect their long-run interests. Section 6 seeks to identify potential entry points for government policy to achieve SAP objectives and thereby nudge farming systems toward more ecologically and economically sustainable futures.

We represent the SAP framework visually in Figure 1 as a Venn diagram with three pillars. The first pillar, shown in the top circle, include the criteria by which CSA outcomes are typically assessed. According to FAO (2013), an action would be deemed climate-smart if it achieves some combination of the following objectives: (1) contributes to an increase in food security through changes in agricultural productivity and incomes; (2) supports adaption and resilience to climate change; and (3) reduces and/or removes greenhouse gases emissions, where possible. In SSA, this typically includes the promotion of SI practices such as conservation agriculture (CA), agroforestry, irrigation, and improved seed adoption. Whether or not these practices contribute to productivity growth or climate resilience depends on whether other practices are also adopted, the duration of adoption, and site-specific agro-ecological characteristics, among other things.

The SAP framework is designed to address limitations to the CSA paradigm. While the objectives of CSA are laudable, in practice they can limit our understanding of the range of actions required to achieve sustainable, system-wide resilience to climate change in at least three ways. First, CSA activities often do not acknowledge the temporal nature of the trade-offs involved, e.g., a given intervention might promote achievement of sustainable intensification and productivity in the long-run but work against the achievement of households' food security and income objectives in the short run. Second, CSA strategies are currently limited by their scope: farm production is part of a wider agri-food system that ensures' humans' access to food, including farm input and equipment generation and distribution, on-farm production, storage, transport, assembly, wholesaling, processing, retailing, restaurants and food prepared for those eating away from home, etc. All these stages will be increasingly affected by climate variability and hence issues of climate- and market-smartness are best considered from the standpoint of the entire agri-food system. For example, inorganic fertilizer is widely understood to be an important component of a holistic strategy for maximizing the build-up of biomass in soils but the manufacture of inorganic fertilizer entails substantial greenhouse gas emissions.

Figure 1. Sustainable Agri-food System Productivity Framework (SAP FRAMEWORK)



A third shortcoming of discussions of CSA is that they tend not to consider the ways in which rapidly transforming African economies are circumscribing the range of actions that can be considered climate- or market-smart. Wayne Gretzky quipped that a good hockey player plays where the puck is, but a great hockey player plays where the puck is going to be. As the global economy becomes more complex it behooves African governments and development partners to anticipate and proactively respond to emerging challenges to the sustainability of the region's food systems rather than being whip-sawed by them. To be effective, SAP outcomes, programs need to proactively anticipate these major demographic and economic trends.

We address the weaknesses of CSA/SI in our model through the inclusion of two other pillars. The second pillar of the SAP framework, shown in the bottom right circle, are the criteria by which market-smart strategies are typically assessed. Though not defined in the literature, we can characterize MS approaches as those that enroll the private sector to overcome persistent market failures or strengthen markets to promote long-term market development objectives. Based on this definition, an intervention can be considered MS if it encourages competition, reduce costs and/or risks for agri-food system actors, and contributes to sustainable forms of food production and distribution.

Greater attention to marketing policies and programs is critical for SAP outcomes, as low rates of farmer participation in markets are important correlates of both poverty and limited adoption of sustainable agricultural intensification practices (Place et al. 2003; Barrett and Carter 1999; Reardon et al. 1999). Moreover, low farmer adoption of technologies or management practices deemed to be climate-smart might reveal a lack of market smartness. For example, some input subsidy programs in the region do not allow farmers to acquire their subsidized inputs from private dealers and do not promote the use of some inputs that could promote system-wide intensification, thereby squandering opportunities for subsidy programs to contribute to sustainable intensification and climate-smart objectives (Jayne et al. 2016).

Of course, not all market-smart strategies produce climate-smart outcomes, or vice versa. The SAP framework stresses the intersection between practices that promote productivity growth in the context of climate change and the broader incentives and institutions needed to adopt and sustain these practices.

The third element of the SAP framework draws attention to the highly varied household and community level factors that influence the viability of particular farmer practices, such as farm resource endowments, market access, and agro-ecological conditions. These 'conditioning factors' are represented on the lower left circle of Figure 1.

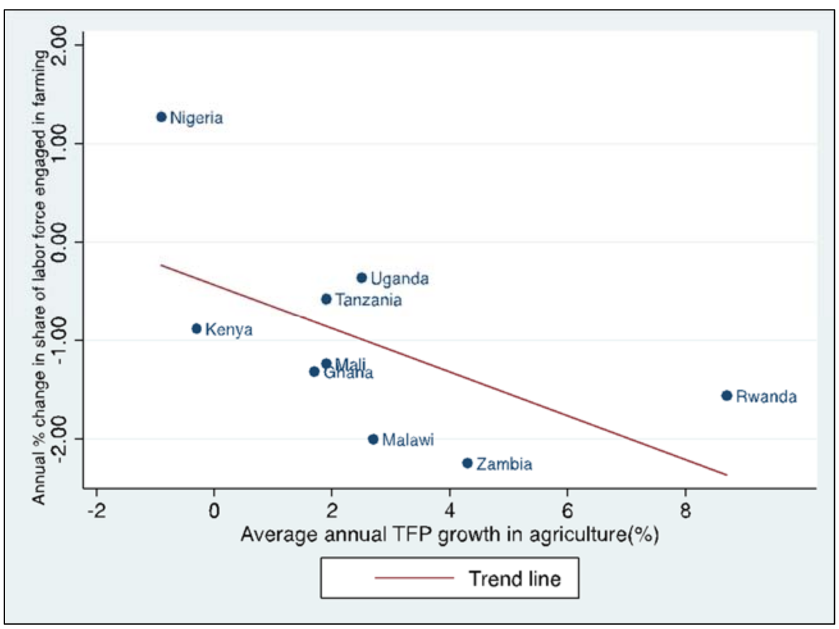
A sustainable and market-smart response to climate change within agri-food systems occur at the intersection of these three circles of Figure 1. An intervention (*i.e.,* policy, program, practice) meets the criteria of the SAP framework when it: 1) contributes to long-term productivity growth (raises long-term yields, or improved net returns to capital and labor at various stages of the system, e.g., commerce, processing, production) and stability (e.g., improves the stability of yields or ease of balancing localized food shortfalls with surplus production through regional trade); 2) strengthens the operation of markets and opens up new opportunities for farmers and others in the agri-food system; and 3) criteria 1 and 2 hold for a sufficient number of households or land area to have a meaningful impact on the agri-food system.

The final element of the SAP framework is that it draws attention to the ways in which exogenous forces, associated with rapidly growing and urbanizing populations, coupled with growing climate uncertainty, are placing extraordinary transformative pressure on agri-food systems. Rural Africa is projected to have 60% more people by 2050 than today, while the total SSA population is projected to quadruple to 4 billion people by 2100 (Gerland et al. 2014). Rapid population growth leading to shifting population densities, and resultant effects on input and output prices, market access conditions, farm sizes, and labor opportunities will have important though regionally heterogeneous effects on the types of technologies and management practices and intensification incentives at the farm-level and in agri-food systems (Pingali 2012). A critical element of the SAP framework is to anticipate how changing factor prices and other evolving market forces will shape the range of feasible strategies to achieve SAP outcomes.

2.1. Population Growth and Heterogeneous Effects on Land/Labor Price Ratios

Sub-Saharan Africa's population is projected to double to 2.1 billion people by 2050 and quadruple to 4.0 million people by 2100. SSA is the only region of the world in which rural population is expected to continue to grow (Figure 2). Population growth will be especially rapid in urban areas. By 2050, about 45% of the population will be urbanized. The pace of population growth in Africa will add greatly to the supply of labor, but the effect on wages will depend on the growth in demand for labor, which will in turn depend on the rate and composition of economic growth.

Figure 2. Association between Total Factor Productivity Growth and Change in Share of Labor Force Engaged in Farming in Selected Countries



Source: Yeboah and Jayne 2016. Changes in the share of the labor force engaged in farming are derived primarily from Living Standards Monitoring Surveys (LSMS) national data sets described in Yeboah and Jayne (2016). Mean annual agricultural TFP growth rates are from United States Department of Agriculture Total Factor Productivity (USDA TFP) dataset (Fuglie 2015); the time periods for computation of TFP growth rates are lagged two years relative to the dates of the LSMS surveys. Spearman Correlation coefficient = -0.69, prob > |t| =0.04.

The direction of labor price movements relative to land and capital will have important implications for the sorts of farm and soil management practices that are likely to be adopted. While labor is plentiful, nutrients may be applied to the soil via a range of practices that make intensive use of household labor. These include manure application, composting, intensive weeding, and non-mechanized reincorporation of weed residues. As non-farm employment opportunities grow, agricultural labor becomes scarcer. This will tend to push up wages, thus incentivizing households to acquire nutrients in the form of chemical fertilizers, shift to mechanized land preparation, and use of herbicides to reduce the labor required for weeding. All of these changes in farming practices occur when the cost of labor rises relative to capital and land. In areas close to dynamically growing towns and cities, SAP outcomes will require markets to enable purchasing of inorganic nutrients and organic matter to add biomass.

Novel approaches to recycling nutrients will likely be essential in relatively densely populated areas. This includes the development of industries to process and market soil amendments made from manure by-products of intensive animal feeding operations and from human waste from urban areas. Some parts of the world are already developing the technologies and practices to close the loops in the cycle from food production to consumption to harvesting human and animal waste for nutrient application back onto crops. Many areas have started to recycle human waste water for subsequent drinking water in cities, thereby freeing up more scarce water resources for agriculture. The working out of the technologies and institutional set up in some parts of the world should hasten their adoption in Africa, where these innovations will be critical in light of such rapid urban population growth.

While the effects of population growth on wages is indeterminate, and will likely vary considerably within and between countries, the effects of rapid population growth on land prices are more straightforward. Rapid population growth will increase the demand for finite arable land and raise land prices, especially in high-potential areas close to cities with good access to markets. We are already seeing agricultural land prices and rental rates rise faster than wages or capital goods in many rural areas, especially those that are relatively densely populated and considered to have favorable access to markets (Jayne and Ameyaw 2016). Theories of induced innovation (Hayami and Ruttan 1971; Binswanger and McIntire 1987) indicate that increased land/capital price ratios will lead to more capital intensive forms of farm production, and not surprisingly, we are starting to see increased use of mechanization, herbicide use, and inorganic fertilizer in areas experiencing rapid increases in land prices.

Relatedly, we predict that farming patterns will become more capital intensive in agricultural areas with favorable market access conditions. Consistent with the von Thunen model of geographic specialization, we anticipate that areas close to cities will experience rising land values, and a consequent movement toward capital-intensive and land-saving forms of agricultural commercialization, e.g., high-value cash crops, fresh fruits and vegetables, dairy/eggs/poultry operations. Conversely, grains will increasingly be concentrated in areas further from cities where land values are lower and which can support lower-value per hectare agriculture and bigger farm sizes. The labor intensity of farming operations will depend largely on the rate of employment growth in the off-farm economy. Rapid employment growth and rising wages in the non-farm economy typically promotes a movement of labor from farming to off-farm jobs, promoting more labor-saving forms of agricultural technologies and management practices. The economically dynamic parts of the region are indeed showing signs of rapid exit of rural labor out of farming (Yeboah and Jayne 2016).

Labor-intensive forms of agriculture will be retained, at least for a while longer, in densely populated rural areas with high labor/land ratios, although here is where migration outflows tend to be greatest. Much of rural Africa's population still live in such areas, but very few households rely exclusively on small-scale farming for their livelihoods (Barrett et al. 2005). Their livelihoods are increasingly diversified, and hence labor may not be as abundant as one might think, particularly if the non-farm economy booms as it has in many areas in recent years.

This suggests that the types of agricultural strategies that meet the criteria for the SAP framework will have distinct geographic elements that are determined by factor market conditions, access to growing urban markets, as well as prevailing agro-ecological conditions. In the absence of carbon payments or other compensation mechanisms, strategies that entail high opportunity costs to land—that take cultivable land out of production—will become less attractive in many area as the demand for land continues to grow rapidly along with rural population growth.

Incentives to adopt labor-intensive practices may seem to be favorable in more densely populated farming regions but this may be changing rapidly as rural youth stream out of farming and look for non-farm jobs, which in most cases provide returns to labor that are greater than in farming on one hectare or less of land (McMillan and Hartgen 2014). This may help to keep wage rates low in destination areas, but will likely drive up labor costs in supply regions, mostly in more remote areas. Mechanization will likely play a growing role in low-density regions, while labor intensive practices such as various forms of minimum tillage or soil conservation structures that are often promoted as climate-smart will make increasingly less economic sense as the cost of labor rises.

2.2. Land Size Dynamics and the Rise of the Medium Scale Farmer

Medium-scale farms (defined here as farms between 5 and 100 hectares) have increased over the last decade to control roughly 20% of total farmland in Kenya, 32% in Ghana, 39% in Tanzania, and over 50% in Zambia (Jayne et al. 2016). The numbers of such farms are still growing very rapidly, except in Kenya. The rapid rise of medium-scale holdings in most cases reflects increased interest in land by urban-based professionals or influential rural people associated with rapidly rising urban population growth and demand for food in Africa. About half of these farmers obtained their land later in life, financed by nonfarm income (Sitko and Jayne 2014). Ironically, well-educated, relatively older urban-based people with access to finance are investing in farming at the same time that much greater numbers of poor rural young people are leaving farming. The combined effect of this two-way flow of labor and capital is a fairly rapid shift in the size distribution of farms, especially in countries experiencing rapid farm to non-farm employment shifts (Jayne et al. 2016).

In areas where farmland consolidation is the result of urban capital influx, a greater share of total farmland will be less constrained by access to capital. We may therefore expect to see an evolution toward more capital-intensive forms of farming in such areas, indicating that SAP framework outcomes may require more capital-intensive intensification practices on somewhat bigger farms over time.

At the same time, the majority of rural Africans will reside on farms under five hectares for at least the next several decades. While small-scale farms will continue to be an important source of food, the livelihoods of small-scale farmers are likely to become increasingly diversified and reliant on non-farm income sources. Growth in non-farm opportunities is likely to continue to pull labor out of farming over time, providing incentives for labor-saving technologies and farming practices. SAP outcomes among such farms is therefore likely to require labor saving (and capital using) technologies.

Agricultural surpluses and incomes will become increasingly concentrated on larger farms. We are already seeing evidence in some countries of increasing concentration of the marketed grain surplus on larger farms (Sitko, Burke, and Jayne 2018). Therefore, agri-food system resilience will become more a function of non-farm labor market improvements, coupled with agricultural productivity intensification on a smaller share of relatively larger farms, although self-provisioning of food for consumption is likely to remain important for millions of rural farm households. Land rental markets are developing in areas with relatively favorable access to markets, which may further promote capital-intensive forms of SAP.

The sorts of intensification strategies that can achieve SAP outcomes in particular regions will be in large measure conditioned by the relative rates of growth in the farm vs. non-farm economy. If non-farm sectors start to grow (e.g., export-oriented manufacturing), then this could suck more labor out of small-scale farming and raise wage rates in agriculture. This, in turn, will encourage a move toward more labor-saving farming techniques; labor intensive forms of farming such as planting basins, intensive weeding, construction on erosion control structure, etc. would face increasing barriers to adoption. Instead, such farms would be likely to become more capital intensive (increased use of fertilizer, mechanization, herbicides)—trends exemplified by southern Ghana, parts of Tanzania, and Rwanda over the past 20 years.

2.3. Energy and Water

As Africa's population booms, the pressure on Africa's water and energy resources will intensify further. As of 2004, 76% of all people living in SSA relied on biomass for cooking fuel (Maes and Verbist 2012). Even in urban areas, erratic power supplies creates substantial demand for biomass energy, mostly in the form of charcoal (Tembo, Mulenga, and Sitko 2015). Without substantial improvements in energy availability and generation, the effects of widespread deforestation on African carbon emissions is likely to off-set any mitigation improvements achieved through changes in farm practices.

Similarly, rapid urbanization increases water demand and elevates the risk of water contamination, which has important implications on the viability and safety of peri-urban agriculture (Cofie and Drechsel 2007). Given that high density, mostly peri-urban agricultural regions will become an increasingly important element of most African agri-food systems, developing legal frameworks for managing competing water demands and for ensuring minimum water safety levels will be critical for achieving SAP framework outcomes in the future.

2.4. Output Market Transformations: The Rise of Large-scale Traders

Rapid population growth and urbanization over the past several decades has contributed to the region's rapidly increasing dependence on global markets for staple foods, especially wheat and rice (Jayne and Ameyaw 2016). Consequently, food prices in most of SSA have trended up to import parity levels (Jayne, Mather, and Mghenyi 2010). The continuation of relatively high import parity food prices will contribute to both greater investor interest in agricultural land and production, thus further stimulating the rise of larger investor farms, as well as greater farm-level incentives for intensification.

Whether or not rising prices in urban markets translates into higher farm gate prices and, thus incentives for intensification, is contingent on market performance. Traditional African grain markets are typically plagued by cumulatively high transaction costs, resulting in part from the numerous levels of aggregators required to move grain from producer to processors (Fafchamps 2001). This leads to a large marketing price wedge that pushes down farm gate prices.

Recent evidence suggests that in some countries, the predominance of very small traders is giving way to larger, more consolidated trading and wholesaling firms. Recent waves of farm household survey data from Zambia and Kenya show that a rapidly growing number of farm-level sales and share of total smallholder grain volumes are sold directly to large-scale traders (LSTs) (Sitko, Burke, and Jayne 2018). In Zambia, nationally representative survey data from 2012 and 2015 show that smallholder sales to LSTs increased from 3% of total maize sales volume, or approximately 40,000 metric tonnes (mt), to 12% of total maize sales by volume, over 240,000 mt. In Kenya, we find virtually no sales to LSTs in 2004, increasing to 21% of all maize sales by volume in 2007, and expanding further to 37% in 2014.

The rise of large-scale traders in food markets in SSA offers opportunities for greater supply chain coordination through the use of contracts (Poulton, Kydd, and Dorward et al 2006; Reardon and Timmer 2012). Large-firms are better able to manage and diffuse the costs and risks associated with input credit and forward delivery contracting, through vertical integration and risk hedging (Sitko and Chisanga 2016). Through a reduction in the number of intermediaries and improved supply chain coordination, the rise of large-scale trading is found to increase farm-gate prices relative to traditional market players (Sitko, Burke, and Jayne 2018). This transformation, therefore, will likely expand opportunities to achieve SAP framework outcomes. However, this will likely be achieved primarily on large and medium farms, which predominantly sell to these traders (ibid).

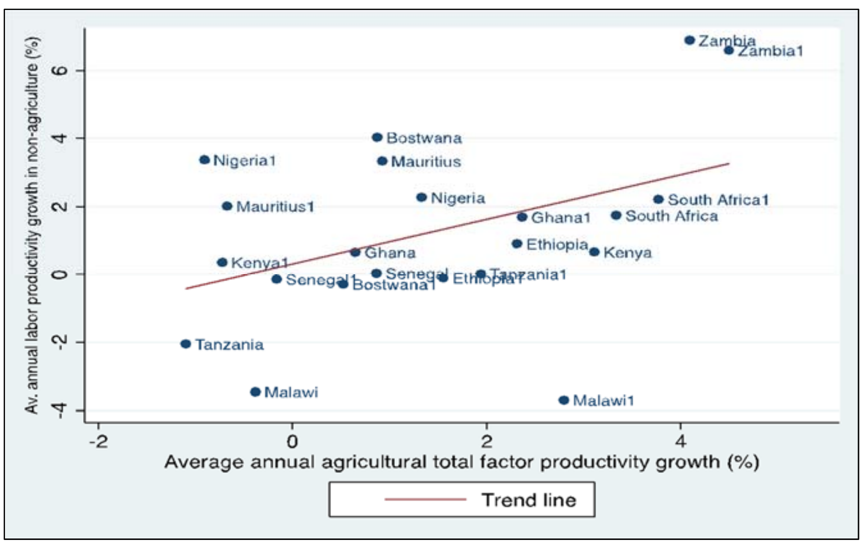
An important implication of the rise of large-scale trading is that it will expand incentives for farm households to grow tradable crops over non-tradable staples. This has important potential implications for the spillover effects of smallholder commercialization. As de Janvry and Sadoulet (2002) argue, for major food crops (e.g. rice), increased productivity and marketed volumes have limited impact on the consumer price, because they are tradable and their price is largely determined by international markets. Thus, the majority of the benefits from commercialization remain in rural areas. By contrast, where major food crops are non-tradable (e.g. cassava, yams, white maize), increased productivity and marketed volumes put downward pressure on prices, thereby passing a share of the benefits onto consumers. Farmers will only end up better off if their rate of productivity growth exceeds the rate of decline in output prices. As several major African food crops are non-tradable and demand is inelastic with respect to price, demand constraints are a non-trivial issue for smallholder commercialization in Africa, ongoing urbanization and growth in incomes notwithstanding (Masters et al. 2013). To the extent that the rise of large-scale trading firms spurs market opportunities for tradable food crops, the implications for commercialization outcomes and spillovers are likely to be important. Large traders tend to provide loans to assembly traders to procure crops from farmers and also provide inputs, extension, and other services to farmers in order to expand their production base and achieve scale economies in distribution. To the extent that farmers' access to inputs and services expand as agricultural commodity value chains continue to develop and grow, we again anticipate greater use of capital in farm production, promoting capital-intensive forms of SAP, even on small farms.

2.5. Agricultural Productivity Growth and the Non-Farm Economy

What might make the non-farm economy boom? Agricultural productivity growth appears to be the most important cause. African agriculture has shown remarkable but geographically uneven improvement compared to its previous state 15 years ago. African governments, including Ghana, Burkina Faso, and Ethiopia, which have invested in their agricultural sectors are reaping the benefits—stronger economic growth, declining poverty rates, and better nutritional status (Badiane and Makombe 2015). Cross-country econometric evidence shows that African countries experiencing the most rapid rates of agricultural productivity growth over the past 15 years have also enjoyed the greatest rates of non-farm labor productivity growth and the most rapid exit of the work force out of farming (Yeboah and Jayne 2016, see also Figures 3 and 4). Such evidence indicates that the expansion of job opportunities in the overall economy will be greatly affected by government policies and programs affecting the rate and inclusivity of productivity growth in farming. Agricultural productivity growth, especially if broadly based, will generate strong multiplier effects that expand job opportunities in the downstream stages of the agri-food system and in the broader non-farm economy.

Burkina Faso provides a striking case highlighting the diverse ways in which productivity gains in staple crops alone can profoundly affect youth livelihoods. Burkina Faso has benefited in recent years from new cereal crop varieties produced by their national agricultural research system and extended to millions of smallholder farmers through extension programs. Cereal yields (mainly maize and rice) doubled between the 1990-1995 and 2010-2014 periods (FAOSTAT 2016). These enabled farmers to produce their households' staple food needs on less land, thereby freeing up land and labor for other income earning activities, including the growing of fodder crops that have over time replaced the transhumance system of sending livestock herds away during the dry season to a more intensive year-round raising of livestock locally.

Figure 3. Association between Agricultural Total Factor Productivity Growth and Labor Productivity in the Non-agricultural Sector



Source: Yeboah and Jayne 2016. Agricultural total factor productivity growth rates derived from USDA TFP dataset (Fuglie 2015) and computed as mean annual rates over 2001-2005 and 2006-2011 periods; labor productivity growth rates (mean annual rates over 2001-2005 and 2006-2011 period) derived from Groningen Global Development Centre (http://www.rug.nl/research/ggdc/) employment data for corresponding periods. NB: two points are shown for each country; the latter period (2006-2011) for each country is denoted with "1" (e.g., Malawi1 represents Malawi 2006-2011). Spearman Correlation coefficient = 0.37, prob > |t| = 0.09.

The ability to integrate fodder crops into the farming system has allowed for more permanent tending of livestock, providing regular dairy income for many households, improved nutrition resulting from the year-round supply of dairy products, and the ability to collect manure for reintegration of organic matter back into the cereal fields, thereby improving soil quality, improving crop response to inorganic fertilizer and contributing further to sustainable agricultural intensification. In these various ways, the success of Burkinabe crop science and associated investments resulting in cereal yield growth has transformed the integrated cereal-legume-livestock systems in ways that have promoted sustainability and resilience, improved nutritional outcomes, greater profit opportunities for youth in farming, and greater multiplier effects from agricultural growth on job growth in the off-farm economy.[1]

In countries where the national economy still depends largely on the performance of agriculture, public investments in support of agricultural productivity growth will remain a crucial component of an effective youth employment strategy and will directly influence the range of feasible strategies that can achieve SAP framework outcomes. Indeed, given the enormity of the challenges facing food systems in the context of rapid population growth and climate change, and the importance of collective action in address them, public sector action and effective use of scarce public expenditures to agriculture will be decisive in influencing the range of actions that can achieve SAP framework outcomes and how changes in welfare are distributed.

[1] According to IFAD (2016), agricultural value added per worker in constant USD rose by 42% between 1990-1994 and 2010-2014 (page 368).

3. UNDERSTANDING THE RELATIONSHIPS BETWEEN POPULATION DENSITY, MARKET ACCESS, AND DEGRADED AGRICULTURAL LAND IN SSA

This section utilizes recently available national-level data on the relationship between population densities, market access, and population changes on degrading and improving agricultural land over the period 2000-2010. These data, published by Barbier and Hochard (2016), are derived from spatially referenced data that estimate changes in Net Primary Productivity (NPP) over the period 1981 to 2000. In this case, NPP is measured as the change in grams of carbon sequestered per square meter over the 1981–2000 time period after subtracting respiration losses (ibid:8). *Degrading agricultural land* (DAL) is defined as a negative change in NPP over this period, while *improving agricultural land* (IAL) is land with non-negative NPP over the same period.[2] The Barbier and Hochard data also disaggregate trends in the population living on degraded and improving agricultural land in areas considered *remote*, defined as areas more than five hours travel time from an urban market of 50,000 people or more.

Using these data we explore three hypotheses of particular relevance for understanding relationships between the exogenous pressures affects agri-food systems in SSA and agricultural land use:

- Increases in population densities in rural Africa are associated with increases in the share of rural populations living on degraded agricultural land;
- The pace of population change on degraded agricultural land is associated with increases in rural population densities; and
- These dynamics are especially pronounced in regions considered accessible to urban markets.

We begin our analysis with Table 1, which presents data for each Sub-Saharan African country on the rural population living on DAL and IAL in 2010, as well as changes over the period 2000-2010. Table 1 shows a remarkable dynamic. In 2000, the number of rural Africans living on DAL and IAL is virtually the same, with 157 million living on DAL and 154 million on IAL. However, when we look at the pace and direction of change over the period 2000-2010, we find that while the number of Africans living on DAL has increased by 43 million, the number living on IAL has actually declined by 441,901. This finding reinforces the conclusions of other recent studies (e.g., Montpellier Panel 2013) that land degradation in Sub-Saharan Africa is a monumental problem, and one that threatens the sustainability of economic growth and resilience to climate change in the region. As this deeply worrying trend unfolds, the challenges facing sustainable land intensification in Africa will intensify. While there is widespread agreement that SAP framework outcomes in Africa will require major increase in the use of inorganic fertilizer, continued soil degradation places limits on land's yield response to inorganic and organic fertilizers and its capacity to retain water (Tittonell and Giller 2013; Paul et al. 2013).

Among the African countries showing the greatest increase in the rural population residing on degrading agricultural land (and/or a decline in the population residing on improving agricultural land) are Benin, Burundi, Democratic Republic of Congo, Cote d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, Ghana, Kenya, Mali, Mozambique, Niger, Nigeria, Rwanda, South Africa, Togo, and Uganda. Countries showing favorable improvements in the share of the population on improving land include Burkina Faso, Chad, The Gambia, Guinea-Bissau, Lesotho, Liberia, Sierra Leone, Zambia, and Zimbabwe.

[2] Unfortunately, these datasets do not include information on the hectares classified as degraded or degrading, only population changes on land categorized as such.

Table 1. Population in 2010 and Population Change 2000-2010 on Degrading Agricultural Land (DAL) and Improving Agricultural Land (IAL) in SSA

Country	2010 Population on		2000-2010 Change in the Population on	
	DAL	IAL	DAL	IAL
Angola	328,764	3,000,638	90,184	820,828
Benin	2,198,704	1,522,985	628,734	444,345
Botswana	751	524,214	(6)	22,881
Burkina Faso	1,340,142	9,869,294	561,665	3,915,911
Burundi	5,322,220	1,052,280	1,396,710	232,500
Cameroon	2,280,975	3,709,824	517,035	833,504
Central African Republic	64,078	80,906	9,675	12,559
Chad	736,580	1,928,573	202,439	530,034
Congo, Dem. Rep.	13,633,178	2,320,010	3,946,468	661,420
Congo, Rep.	491,228	308,833	128,953	82,889
Cote d'Ivoire	6,432,816	4,805,367	1,557,646	1,001,187
Equatorial Guinea	10,728	8,145	1,947	1,350
Eritrea	225,239	43,698	64,554	12,507
Ethiopia	25,362,813	8,695,590	7,851,213	2,713,890
Gabon	22,334	30,174	4,822	6,592
Gambia, The	303,948	640,274	53,068	195,517
Ghana	8,304,198	4,753,085	2,264,048	1,205,335
Guinea	2,159,985	3,607,146	513,075	888,236
Guinea-Bissau	77,664	275,052	16,950	59,917
Kenya	10,850,937	5,349,616	1,868,797	813,656
Lesotho	61,772	1,276,455	(3,214)	44,910
Liberia	497,217	1,920,189	192,545	742,571
Madagascar	2,591,961	2,165,061	659,201	509,201
Malawi	1,227,683	4,707,049	377,714	1,483,638
Mali	3,042,516	4,289,057	799,366	(1,338,423)
Mauritania	42,591	7,486	12,369	(577,825)
Mozambique	2,344,217	10,284,023	338,367	(3,574,437)
Namibia	1,666	445,710	(423)	(950,175)
Niger	607,307	1,033,867	213,966	(4,939,263)
Nigeria	25,072,929	25,788,795	6,752,629	(17,651,605)

Country	2010 Population on		2000-2010 Change in the Population on	
	DAL	IAL	DAL	IAL
Rwanda	6,742,937	745,546	2,011,427	(260,144)
Senegal	2,185,043	2,999,921	609,873	838,471
Sierra Leone	1,020,892	3,159,149	436,003	1,312,378
Somalia	240,097	1,916,453	83,352	916,428
South Africa	1,734,065	6,409,292	28,745	(139,228)
Sudan	3,080,934	3,410,521	688,394	761,481
Swaziland	45,375	520,890	4,050	29,637
Tanzania	12,523,256	14,041,366	3,664,256	3,632,866
Togo	2,509,008	873,608	595,718	210,448
Uganda	9,486,815	6,522,646	3,475,085	1,999,776
Zambia	1,819,360	3,911,274	453,170	898,134
Zimbabwe	174,824	5,193,805	45,027	1,154,202
Total	157,199,747	154,147,867	43,115,597	(441,901)

Source: Calculated from data in Barbier and Hochard (2016). Note: cells in red highlight signify that the rural population residing on degrading exceeds the population residing on improving land, and where the change in the population on degrading agricultural land exceeds the change in the population on improving land between 2000 and 2010. Countries highlighted red are those where both conditions exist (red highlight in both columns) or where the rural population living on improving agricultural land has declined between 2000 and 2010.

To better understand the factors underlying the rapid increase in populations living on DAL in SSA, Table 2 disaggregates the 2010 data for each country by remote regions and accessible regions, where remote is defined as greater than 5 hours travel time from a urban market of 50,000 people or more (Barbier and Hochard 2016). It shows that in 2010, 130 million rural people in SSA lived on DAL. Of these, 74%, or 96 million, were in areas considered accessible. This suggests that the social challenges of land degradation are largely concentrated in more market-accessible regions, where rural populations typically cluster, and where incentives for land intensification are greatest.

Table 2. Share of Rural Population on All, Remote, and Accessible DAL in 2010

	Rural Population 2010	**All DAL 2010**		**Remote DAL 2010**		**Accessible DAL 2010**	
		Rural population	**% of rural population**	**Rural population**	**% of rural population**	**Rural population**	**% of rural population**
Angola	17,150,900	343,018	2%	343,018	2%	-	0%
Benin	6,810,930	5,488,288	32%	686,036	4%	4,802,252	28%
Botswana	1,545,880	-	0%	-	0%	-	0%
Burkina Faso	14,775,000	1,543,581	9%	686,036	4%	1,029,054	6%
Burundi	8,003,690	11,319,594	66%	1,715,090	10%	9,776,013	57%
Cameroon	17,060,700	2,229,617	13%	686,036	4%	1,543,581	9%

	Rural Population 2010	All DAL 2010		Remote DAL 2010		Accessible DAL 2010	
		Rural population	% of rural population	Rural population	% of rural population	Rural population	% of rural population
Central African Republic	3,752,620	343,018	2%	171,509	1%	171,509	1%
Chad	10,646,700	1,200,563	7%	686,036	4%	514,527	3%
Congo, Dem. Rep.	64,238,200	3,601,689	21%	1,372,072	8%	2,401,126	14%
Congo, Rep.	3,941,970	2,058,108	12%	1,200,563	7%	857,545	5%
Cote d'Ivoire	16,381,200	6,688,851	39%	1,543,581	9%	5,316,779	31%
Equatorial Guinea	575,144	343,018	2%	171,509	1%	171,509	1%
Eritrea	5,022,010	686,036	4%	171,509	1%	514,527	3%
Ethiopia	75,247,200	5,831,306	34%	3,258,671	19%	2,572,635	15%
Gabon	947,745	343,018	2%	343,018	2%	-	0%
Gambia, The	1,063,670	4,973,761	29%	2,401,126	14%	2,401,126	14%
Ghana	18,463,100	7,717,905	45%	1,029,054	6%	6,688,851	39%
Guinea	9,704,590	3,773,198	22%	857,545	5%	2,915,653	17%
Guinea-Bissau	1,283,440	1,029,054	6%	343,018	2%	686,036	4%
Kenya	29,599,100	6,345,833	37%	1,372,072	8%	4,973,761	29%
Lesotho	2,039,140	514,527	3%	343,018	2%	171,509	1%
Liberia	4,479,220	1,886,599	11%	857,545	5%	1,029,054	6%
Madagascar	19,217,500	2,229,617	13%	514,527	3%	1,886,599	11%
Malawi	11,575,900	1,886,599	11%	343,018	2%	1,543,581	9%
Mali	14,855,500	3,430,180	20%	1,029,054	6%	2,572,635	15%
Mauritania	3,325,360	171,509	1%	-	0%	171,509	1%
Mozambique	19,721,300	2,058,108	12%	857,545	5%	1,200,563	7%
Namibia	1,697,180	-	0%	-	0%	-	0%
Niger	15,461,400	686,036	4%	171,509	1%	514,527	3%
Nigeria	123,652,000	3,430,180	20%	343,018	2%	3,087,162	18%
Rwanda	8,822,920	13,034,684	76%	2,572,635	15%	10,633,558	62%
Senegal	8,945,690	4,116,216	24%	514,527	3%	3,601,689	21%
Sierra Leone	5,956,430	2,915,653	17%	171,509	1%	2,744,144	16%
Somalia	12,406,700	343,018	2%	-	0%	343,018	2%
South Africa	16,641,200	1,715,090	10%	514,527	3%	1,200,563	7%
Sudan	36,671,200	1,372,072	8%	686,036	4%	857,545	5%
Swaziland	930,650	857,545	5%	171,509	1%	514,527	3%
Tanzania	41,487,100	5,145,270	30%	2,058,108	12%	3,087,162	18%
Togo	4,763,170	9,089,977	53%	1,372,072	8%	7,717,905	45%
Uganda	29,082,800	5,659,797	33%	857,545	5%	4,802,252	28%
Zambia	11,031,700	2,744,144	16%	1,715,090	10%	1,200,563	7%
Zimbabwe	11,529,700	343,018	2%	171,509	1%	171,509	1%
Total	710,507,549	129,489,295	18%	34,301,800	5%	96,388,058	13%

Source: Calculated from data in Barbier and Hochard (2016).

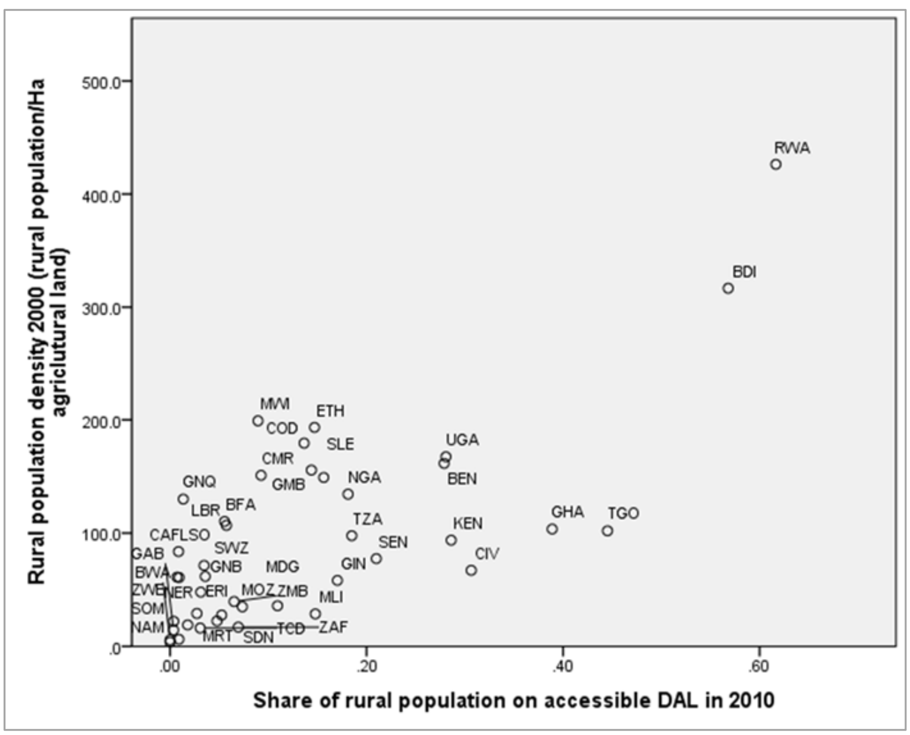
In Table 3, we present regression coefficients on the share of rural populations living on accessible and remote DAL in 2010 against rural population densities in 2000. We find that in SSA, population densities in 2000 are positively associated with the share of the total rural population living on DAL 2010, in both accessible and remote rural regions. We present these relationships visually in Figures 4 and 5. These findings support our first hypothesis, *i.e.,* that as population densities rise, the number of people living on DAL also tends to rise. Moreover, when looking at the size of the coefficient, we see a stronger relationship between population density and share of populations on DAL in accessible regions, which lend support to our third hypothesis that this dynamic is particularly acute in more accessible regions.

Table 3. Unconditional Correlation between Share of Rural Population on DAL (Remote and Accessible) in 2010 and Rural Population Density 2000

	Share of population on remote DAL 2010 (T-statistic)	Share of population on accessible DAL 2010 (T-Statistic)
Rural population density 2000	0.554*** (4.206)	0.730*** (6.753)

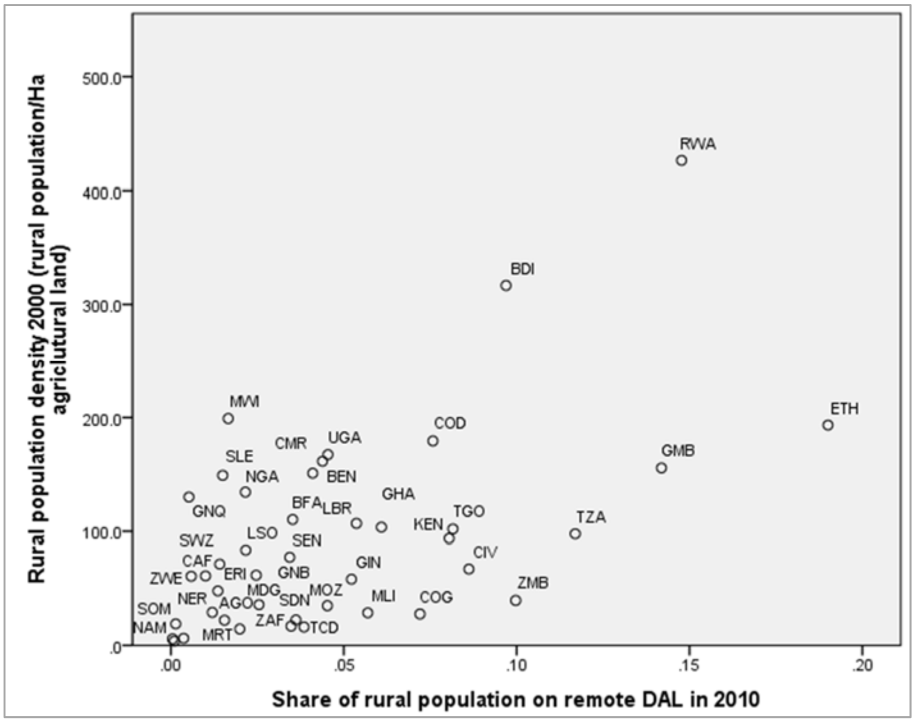
Source: Calculated using World Bank population data and data from Barbier and Hochard (2016).

Figure 4. Share on Rural Population on Accessible DAL in 2010 by Rural Pop. Density 2000



Source: Calculated using World Bank population data and data from Barbier and Hochard (2016).

Figure 5. Share on Rural Population on Remote DAL in 2010 by Rural Pop. Density 2000



Source: Calculated using World Bank population data and data from Barbier and Hochard (2016).

Table 4 examines absolute and relative changes in populations living on DAL over the period 2000-2010, for all, remote, and accessible land. It shows that of the 43 million additional people living on DAL between 2000 and 2010, 30 million of them, or 70%, were residing in accessible DAL. As with our snapshot analysis of 2010, these data indicate that population growth on DAL in SSA is largely occurring in more accessible regions, where smallholder populations typically cluster (Linard et al. 2010). Accessible regions are likely to increase over time in SSA, as population growth and investments in infrastructure spurs improved market access conditions. In the absence of fairly radical changes in land use, this population growth will contribute to degradation of land in regions with the greatest potential for commercialization. This worrying trend risks undermining future prospects for SAPG unless public policies and programs are undertaken to reverse them.

When we regress changes in rural populations on remote and accessible DAL by rural population densities in 2000, we find, in both cases, strong, statistically significant relationships (Table 5). We present these relationships visually for the countries in SSA in Figures 6 and 7. The strong association between rural population densities and the pace of change in populations living on DAL points to a potentially strong correlation between land quality and demographic/population dynamics in Sub-Saharan Africa, and suggest the need for a holistic policy approach toward climate change mitigation, resilience and sustainable agricultural intensification.

Table 4. Change in Rural Population on All, Remote, and Accessible DAL, 2000-2010

	All DAL 2000-2010		Remote DAL 2000-2010		Accessible DAL 2000-2010	
	Population change	Share of total pop. change 2000-2010	Population change	Change in pop. living on Remote DAL 2000-2010/ Rural population 2000	Population change	Change in pop. living on Accessible DAL 2000-2010/Rural population 2000
Angola	90,184	2%	89,438	2%	746	0%
Benin	628,734	38%	82,512	5%	546,223	33%
Botswana	(6)	0%	-	0%	(6)	0%
Burkina Faso	561,665	14%	199,995	5%	361,670	9%
Burundi	1,396,710	67%	209,082	10%	1,187,628	57%
Cameroon	517,035	16%	161,630	5%	355,405	11%
Central African Republic	9,675	2%	6,060	1%	3,615	1%
Chad	202,439	7%	111,568	4%	90,871	3%
Congo, Dem. Rep.	3,946,468	22%	1,464,896	8%	2,481,572	14%
Congo, Rep.	128,953	13%	72,077	7%	56,876	6%
Cote d'Ivoire	1,557,646	48%	450,926	14%	1,106,720	34%
Equatorial Guinea	1,947	1%	-	0%	1,947	1%
Eritrea	64,554	5%	14,146	1%	50,408	4%
Ethiopia	7,851,213	49%	4,470,956	28%	3,380,257	21%
Gabon	4,822	2%	4,089	2%	734	0%
Gambia, The	53,068	26%	22,486	11%	30,582	15%
Ghana	2,264,048	64%	317,052	9%	1,946,996	55%
Guinea	513,075	28%	111,029	6%	402,046	22%
Guinea-Bissau	16,950	6%	5,567	2%	11,383	4%
Kenya	1,868,797	41%	413,802	9%	1,454,995	32%
Lesotho	(3,214)	-4%	(4,234)	-5%	1,020	1%
Liberia	192,545	11%	101,415	6%	91,130	5%
Madagascar	659,201	14%	140,892	3%	518,309	11%
Malawi	377,714	18%	64,705	3%	313,009	15%
Mali	799,366	21%	189,090	5%	610,276	16%

	All DAL 2000-2010		Remote DAL 2000-2010		Accessible DAL 2000-2010	
	Population change	Share of total pop. change 2000-2010	Population change	Change in pop. living on Remote DAL 2000-2010/ Rural population 2000	Population change	Change in pop. living on Accessible DAL 2000-2010/Rural population 2000
Mauritania	12,369	1%	8,495	1%	3,875	0%
Mozambique	338,367	12%	87,216	3%	251,151	9%
Namibia	(423)	0%	-	0%	(423)	0%
Niger	213,966	5%	47,130	1%	166,836	4%
Nigeria	6,752,629	24%	835,068	3%	5,917,561	21%
Rwanda	2,011,427	118%	391,883	23%	1,619,544	95%
Senegal	609,873	31%	78,031	4%	531,842	27%
Sierra Leone	436,003	25%	35,326	2%	400,677	23%
Somalia	83,352	2%	-	0%	83,352	2%
South Africa	28,745	87%	(8,937)	-27%	37,682	114%
Sudan	688,394	10%	287,360	4%	401,034	6%
Swaziland	4,050	7%	1,143	2%	2,907	5%
Tanzania	3,664,256	44%	1,486,728	18%	2,177,528	26%
Togo	595,718	56%	95,434	9%	500,284	47%
Uganda	3,475,085	43%	487,938	6%	2,987,147	37%
Zambia	453,170	21%	320,000	15%	133,171	6%
Zimbabwe	45,027	3%	16,750	1%	28,277	2%
Total	43,115,597	24%	12,868,744	5%	30,246,853	19%

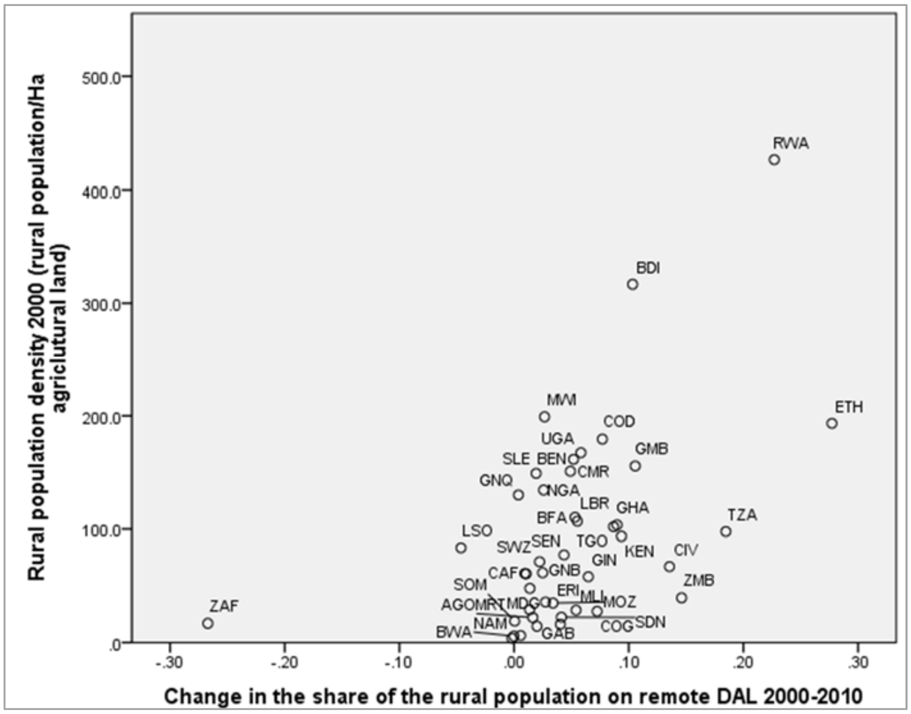
Source: Calculated from data in Barbier and Hochard (2016).

Table 5. Unconditional Correlation between Changes in the Share of Rural Population (Remote and Accessible) DAL between 2000 and 2010 and Rural Population Density 2000

	Change in the share of population on remote DAL 2000-2010 (T-statistic)	Change in the share of population on accessible DAL 2000-2010 (T-Statistic)
Rural population density 2000	0.508*** (3.731)	0.514** (3.791)

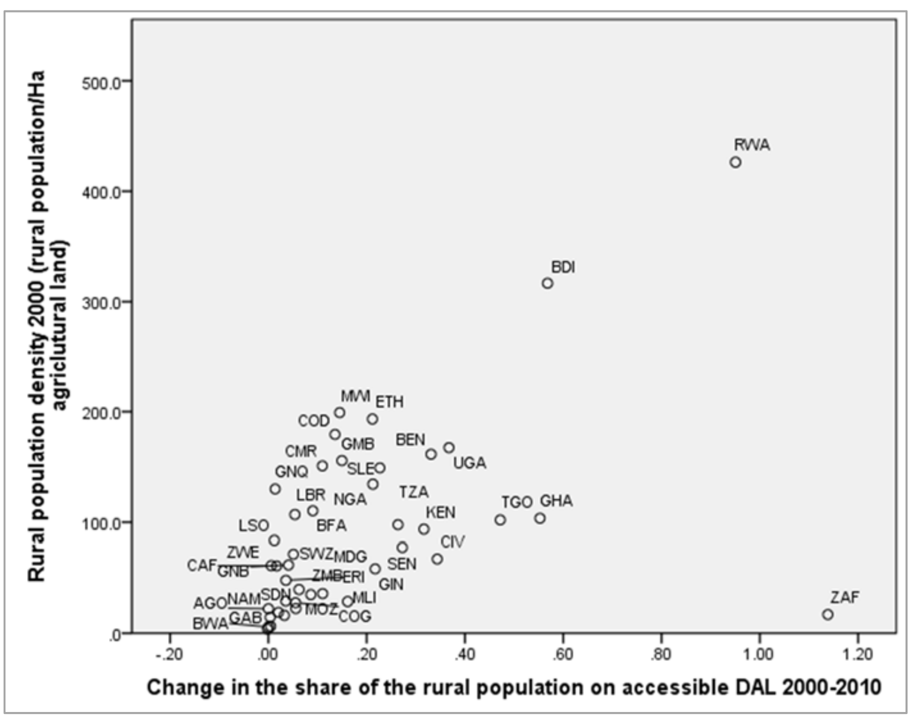
Source: Calculated using World Bank population data and data from Barbier and Hochard (2016).

Figure 6. Change in Share of Rural Population on Remote DAL 2000- 2010 by Rural Pop. Density 2000



Source: Calculated using World Bank population data and data from Barbier and Hochard (2016).

Figure 7. Change in Share of Rural Population on Accessible DAL 2000-2010 by Rural Pop. Density 2000



Source: Calculated using World Bank population data and data from Barbier and Hochard (2016).

Following Platt (1973), we contend that in many high density rural area smallholders face a *social trap*, in which individuals acting in their own best interests in the short-run contribute to potentially adverse long-run outcomes. This, in many ways, runs counter to the induced innovation hypothesis, which has dominated thinking on technology adoption in smallholder systems since Boserup (1981). The induced innovation hypothesis posits that increases in the price of a factor of production induces society to develop and adopt technologies to economize on this production factor. High population densities should put upward pressure on land prices, inducing adoption of technologies and practices to intensify land use.

However, in situations of poverty and food insecurity where people tend to prioritize immediate interests (i.e., feeding one's family) over long-run concerns such as maintaining soil in a condition capable of growing food on it productively 10 years from now. Platt's model helps to explain why food insecure small-scale farmers, especially those in high density areas with limited access to land, may utilize their land in ways that attempt to maximize their food production this year and thereby attend to immediate food security needs, but in ways that lead to soil mining, loss of soil organic carbon, and unsustainable land management practices that erode their future productivity. In particular, we note that such practices may be leading to the phenomenon increasingly noted by soil scientists that some soils are becoming non-responsive to inorganic fertilizer application.

In the absence of novel strategies to support farmers to break free of these social traps, increased population pressures are likely to exacerbate challenges of land degradation in SSA rather than to induce beneficial changes in technology adoption for many small farms.

4. ASSESSING THE FEASIBILITY OF FARM-LEVEL ADAPTION AND RESILIENCE TO CLIMATE CHANGE: AN APPLICATION OF THE SAP FRAMEWORK

The SAP framework stresses the importance of the intersection between the conditions under which an action promotes productivity growth in the agri-food system and the feasibility of sustained adoption under variable and dynamic ecological and economic conditions. In this section, we examine the literature on a range of practices typically promoted to enhance productivity and climate resilience in SSA through the conceptual lens of the SAP framework. We focus most intently on: 1) the practices that make up CA, namely minimal soil disturbance, crop rotation, and crop residue retention; 2) cover crops; 3) agroforestry; 4) soil conservation; and 5) irrigation. These were selected because of their widespread promotion in SSA.

4.1. Conservation Agriculture

Conservation Agriculture (CA) is the most widely promoted farm-level action to achieve productivity growth and resilience to climate change in SSA. It includes three *pillars*: minimum soil disturbance, a legume and cereal-based crop rotation system, and crop residue retention. However, despite widespread promotion, adoption rates remain low (Arslan et al. 2014; Giller et al. 2009). We apply the SAP framework to better understand the limited uptake of CA practices despite significant promotional efforts.

4.2. Minimum Soil Disturbance: Zero and Minimum Tillage

Minimizing soil disturbance through zero or minimum tillage (MT)[3] strategies are frequently promoted in SSA as a means to mitigate soil erosion, increase soil water retention capacity, and to slow the rate of soil organic carbon (SOC) decomposition, and thus achieve yield growth and stability under variable climate conditions (Branca et al. 2011; Chivenge et al. 2007). Despite being widely promoted as a means of improving the climate resilience of small farms in Africa, evidence shows that the yield and soil quality effects of MT are extremely variable, and contingent on soil type and association of MT with other land management practices, while incentives for adoption are often quite limited for small, resource constrained farmers (Giller et al. 2009).

Some studies have shown that soils tilled using MT frequently experience no yield improvement (Hernanz et al. 2002) or in some cases a dramatic drop in yield relative to conventional tillage (CT), particularly in the first years of adoption (Rusinamhodzi et al. 2011; Raimbault and Vyn 1991; Paul et al. 2013). However, in the longer-term MT practices can enhance water availability as a result of improved surface soil structure, with important effects on crop yields in dry years (Fernández-Ugalde et al 2009). Moreover, evidence shows that MT can help to limit the decay of soil organic matter relative to CT, thus improving soil structure and plant nutrient availability (Sisti et al 2004). Beneficial long-run outcomes of MT relative to CT are frequently associated with simultaneous adoption of crop residue retention, legume rotation, and/or nitrogen fertilizer application (Raimbault and Vyn 1991; Govaerts, Sayre, and Deckers 2005; Dalal, Henderson, and Glasby 1991; Triplett et al. 1968). Govaerts, Sayre, and Deckers (2005) estimate that it takes 5 years for the benefits of MT combined with crop residue retention to become evident in terms of yield.

[3] In this section we present evidence on both zero and minimum tillage methods, which we will refer to broadly as minimum tillage (MT).

In a five country study of CA adoption in eastern and southern Africa, Corbeels et al. (2014) finds that CA adopters are on average larger land holders and economically better off than non-adopters. For farmers that do adopt elements of MT, they tend to do so only on 30-40% of their available land. For farmers with limited access to land, the opportunity costs of diverting scare land to an uncertain practice is higher than for farms with greater land access. In places where rapid population growth places pressure on land availability and contributes to declining land size, we would anticipate that the incentives to adopt MT will be low. Indeed, Corbeels et al. (2014) found land access and land ownership to be the main hindering factors to CA adoption in Malawi and Zambia.

Interestingly, one of the principle benefits of adopting minimum or zero tillage practices is a reduction in fuel costs associated with land preparation. This has been critical for promoting adoption of MT in developed country settings (Giller et al. 2009). These benefits are not applicable in most of Africa. The adoption of zero or minimum tillage practices is therefore unlikely to be widely achieved in most African smallholder settings without the development of tractor tillage services that can capture the fuel saving benefits of zero tillage and thus provide tillage services that are competitively priced relative to traditional tillage options. In the context of land consolidation and the potential for rising labor costs in more land abundant regions, farm mechanization is likely to increase. By targeting this segment of the rural population with MT promotion, it is possible to rapidly increase the total area of land under MT, and potentially to create spill-over benefits for neighboring small-scale farms. Yet, focusing on this farm segment will entail foregoing the sorts of direct poverty reduction impact objectives that frequently shape climate spending by international donors.

The recent evidence on commercial tractor hire service development in Ghana, analyzed by Masters et al. 2013, shows how agri –food systems will respond to rising labor costs in other parts of Africa. Ghana is the first country in Sub-Saharan Africa, outside of South Africa, where tractor hire services have become commercially viable, and not surprisingly, this follows 30 years of sustained economic growth, urbanization, and rising rural labor costs, such that rural labor is no longer plentiful. As non-farm economic dynamism occurs elsewhere, we would expect to see similar development of tractor rental markets and the substitution of mechanization for labor even in densely populated smallholder areas. The development of these services will be an important precondition for broader adoption of MT practices in the region.

Of course, not all zero or MT practices require mechanization or animal draught power. Basins and potholes are alternative methods that may be better suited for small farms. However, investment costs associated with acquiring specialized implements, opportunity costs of land, and elevated labor costs limit incentives for adoption by small farms (Giller et al. 2009; Shetto and Owenya 2007; Boahen, Dartey, and Dogbe 2007; Baudron et al. 2014). Elevated labor costs associated with land preparation and increased weeding, where herbicides are not available, are important. In places where the opportunity costs of labor rise due to increased non-farm labor opportunities, the adoption of labor intensive practices such as basin preparation will face considerable barriers.

Applying the SAP framework criteria suggests that the effect of MT promotion on food system outcomes is likely to be marginal at best. In the absence of a systemic change that compensates small-farms for adopting risky climate mitigation practices, such as a through carbon trading, widespread adoption is unlikely to occur in most regions of SSA; for most small farms, high risk of delayed or negligible yield benefits, combined with a lack of labor or capital savings make adoption unlikely. However, in regions experiencing significant farmland consolidation and mechanization, there is scope of adoption. Adoption in these areas would affect large land areas (but few farmers), thereby having a potentially important effect on the overall resilience of the agri-food system, though minimal direct effects on poverty. This adoption will be contingent on capturing fuel savings benefits and access to herbicides, and mitigating adoption risk, potentially through carbon payments or similar environmental incentive mechanisms.

4.3. Crop Rotation and Intercropping

Crop rotation and intercropping, particularly cereal-legume combination, are promoted in order to maximize differential nutrient uptake, enhance soil fertility, enrich soil nutrient supply, thus limiting reliance on inorganic fertilizers, and ultimately increase yields (Branca et al. 2011). Although frequently promoted as similar land management strategies, cereal legume rotation and intercrops have different yield effects and adoption costs, suggesting differing SAP outcomes. As Dakora et al. (1997) show, while intercropping is by far the more dominant practice in SSA, crop rotations are more sustainable due to differing effects on soil quality and nutrient availability. However, Kamanga et al. (2010) show that in Malawi, despite the long-term benefits of rotations, production risk and costs for low income households is lower for legume-maize intercropping than for legume-maize rotations, in part due to limited land availability and the opportunity costs of diverting land away from staple food production. This suggests that the intersection between agronomic benefits and adoption incentives are strongly influenced by land size and resource endowment conditioning factors.

Effects of rotation and intercropping on yield growth, stability, and farm profitability, at least in the short-term, are highly variable (Waddington et al. 2007; Thierfelder, Matemba-Mutasa, and Rusinamhodzi 2015; Snapp et al. 2010). Market conditioning factors strongly influence adoption outcomes. As shown in Corbeels et al. (2014), the promotion of legume/cereal rotations has proved more successful in Malawi than other places, because output market conditions for cereal and legume crops are competitive. Conversely, in more subsistent oriented farm systems, where input and output markets are poorly developed, adoption rates are considerably lower (Corbeels et al. 2014). As Jones, Freeman, and Monaco (2002) show, where intensification of leguminous grains is linked to grain market development, farmers show a greater willingness to invest in these seeds. Thus, dual purpose soybeans, cow peas, or pigeon peas are more likely to be sustainably adopted than varieties that are strictly for soil improvement (Place et al. 2003).

In places where population and economic growth create demand for legumes and improve market access conditions, the promotion of these practices likely meets the SAP framework criteria. Given the relationship between adoption risks and farm size, we anticipate intercropping promotion to be more successful in areas where there is a preponderance of small farms, while rotations are likely to be more widely adopted on larger farms.

Importantly, the scope and scale of adoption is conditioned by the availability of legume seed in the local market. This requires shifting the conceptual focus of most projects, which consider lack of seed access to be a consequence of farm-level capital constraints (and thus address the issue by providing seed to farmers), to a system level. Even when seed provision is carried out with private sector vouchers, this strategy fails to develop effective smallholder market demand for seeds (Place et al. 2003), and thus fails to achieve outcomes that are consistent with SAP framework criteria. An alternative approach is to work at a system-wide level, through large-scale, well capitalized agri-business firms. This alternative approach would stress the need to integrate legume supply chains in ways that strengthen the link between consumer demand, seed supply, and smallholder production. For example, off-setting the costs of input credit default risk (such as through a first loss insurance program for example) may encourage the provision of legume seed input credit to farmers. These contracts would help seed supply companies to better forecast smallholder demand, leading to an increase in legume seed production. These sorts of stable market relationships provide a foundation for sustainable adoption of legumes into smallholder systems, thus more effectively meeting the criteria for the SAP framework.

4.4. Mulching and Residue Retention

Mulching, with animal and crop manures, or field crop residue retention are promoted in order to build up SOC, soil water retention capacity, nutrient utilization, and soil temperatures. The agronomic evidence on mulching and crop residue retention is compelling, yet highly variable. Yamoah et al. (2002) show that residue retention alone raises pearl millet yields 1.2 times relative to clearing residue. When combined with inorganic fertilizer the yield effect is as much as 4 fold, double the effect of fertilizer alone (Yamoah at al. 2002). Similar results were found in Subbarao et al. (2000), Buerkert, Bationo, and Dossa (2000), and Rebafka et al. (1994). In Kenya, Kapkiyai et al. (1999) find that crop yields for maize and beans were substantially improved by crop residue retention in combination inorganic fertilizer application. When residue was removed and without external input maize yields of 1.4 metric ton/hectare (mt/ha) were achieved, when straw was retained and fertilizers and manure applied (120 kilograms [kg] N, 52 kg P and 10 mt/ha manure) yields of 6 mt/ha were achieved. When combined with MT practices, mulching and/or residue retention are routinely shown to increase yields relative to conventional practices of residue removal and conventional ploughing (Triplett et al 1968; Verhulst et al. 2011; Paul et al. 2013).

However, the optimal amounts of crop residue or mulch needed to achieve positive soil quality outcomes is high. For example, based on an 11-year field trial, Mulumba and Lal (2008) determined that the optimum mulching rate for increased soil porosity is 4 mt/ha and for enhanced water capacity, moisture retention, and aggregate stability it is 8 mt/ha. These application levels are beyond the capacity of most smallholder farms in SSA (Paul et al. 2013). Low rainfall conditions, long-term soil degradation, and limited use of inorganic fertilizer hamper the production of biomass, making it difficult to achieve levels sufficient to measurably improve soil quality (Thierfelder, Matemba-Mutasa, and Rusinamhodzi 2015). Moreover, competition for field residue, as a source of fuel and fodder, is high in many smallholder communities in Africa (Mason et al. 2015). Cultural practices, such as field burning to facilitate mouse hunting in Malawi and Zambia also limit adoption rates of residue retention (Ngwira et al. 2013).

Corbeels et al. (2014) show that the capacity to retain crop residues on small farms is substantially less than on larger farmers due to higher levels of competition, and associated opportunity costs, for crop residues on small farms. The existence of local fodder markets, and the underlying market price of fodder, has been shown to substantially influence the rates of crop residue retention. In Zimbabwe, for example, the lack of locally available fodder on the market significantly increases the opportunity cost of crop residue retention and thus limits adoption rates (Corbeels et al. 2014). Conversely, in the Lake Alaotra region of Madagascar, where forage markets for dairy animals have been established, crop residue retention has become widespread (ibid).

Taken together, the scope for achieving SAP framework outcomes through the promotion of residue retention or mulching is fairly low and contingent on the development input and fodder markets, and adequate biomass production. Given the scope of these challenges, alternative strategies may be considered for building soil organic matter.

4.5. Cover Crops

The use of cover crops is promoted in order to increase soil nitrogen, soil organic matter (when incorporated into the soil), decrease soil erosion, nutrient leaching, and grain losses from pest attacks (Branca et al. 2011). Carsky, Oyewole, and Tian (1999) find in Nigeria, legume cover crop rotation with maize increased soil total nitrogen, maize growth, and dry matter and nitrogen accumulation of maize. The mean nitrogen fertilizer replacement value of the cover crops was 6 to 16 kg/ha, depending on the site. Without application of additional nitrogen, maize yields following cover crops were 235 to 365 kg/ha higher than natural grass fallow (ibid). Similarly, Kaumbutho and Kienzle (2007) showed that maize yield increased from 1.2 to 1.8-2.0 t/ha in Kenya with the use of mucuna cover crop. Pretty (1999) showed that farmers who adopted mucuna cover cropping benefited from higher yields of maize (3-4 mt/ha without inorganic fertilizer) with less labor input for weeding. Altieri (2011) reported that maize yields in Brazil increased by 20-250% with the use of cover crops (cited in Branca et al. 2011). Despite these benefits, the incidence of cover crop rotations in Africa is low, due to both limited availability of planting material and limited capacity of small-farms to dedicate scarce land to non-food crop production.

Promotion strategies for cover crops typically focus on constraints to planting material access by freely distributing seeds to farmers in order to promote adoption (Place et al. 2003). Little effort is made to address what is likely the more pressing constraint of the opportunity and risk costs of diverting scare land to alternative uses. Even when promotion strategies engage private sector market channels to distribute seed material, the costs to farmers is frequent well below market rates or free. As a consequence, these approaches decrease farmers' willingness to pay for seeds, thus stunting the development of private sector markets once project support is withdrawn (Place et al. 2003). These strategies may produce some climate resilience benefits, but would not meet the criteria for achieving SAP framework outcomes.

Interestingly, while cover cropping is typically promoted as a practice to limit soil erosion and improve soil organic matter, benefits in terms of weed suppression are important (McCarthy, Lipper, and Branca 2011). Indeed, in places where cover crop adoption rates are high, weed suppression is seen as the primary benefit by farmers (Tarawali et al. 1999; Erenstein 1999). This is an important consideration in places where labor prices are being bid up by growing returns to farm and non-farm labor. Attention to labor market dynamics can help to identify both appropriate farm practices for a given region, as well as potentially more effective promotion strategies.

4.6. Agroforestry

Agroforestry captures a range of practices involving the deliberate integration of woody perennial with agricultural crops. Practices include alley cropping with leguminous tree, live fencing, and wind breaks. Broadly speaking, agroforestry practices seek to improve the resilience of smallholder farmers through more efficient water utilization, improved microclimates, enhanced soil productivity, and nutrient cycling, control of pests and diseases, and diversified farm income (Lasco, Delfino, and Espaldon 2014; Rosenstock et al. 2014). Agroforestry practices are also seen as a way of reducing farm inorganic nutrient requirements (Schroth and Sinclair 2002).

Analyses on the use of leguminous *fertilizer trees* in smallholder farm systems provides compelling evidence on the productivity and yield stabilizing benefits of agroforestry. Akinnifesi et al. (2008) show that sequential and simultaneous planting of leguminous trees with maize increases maize yields from 1 to over 2 mt/ha in Malawi, Zambia, Tanzania, and Zimbabwe, roughly comparable to yields achieved on fields fertilized with inorganic fertilizer. In Malawi, Verchot et al. (2007) finds similar results, with maize yields of 1.5 mt/ha on agroforestry plots compared to 0.7 on unfertilized maize plots. In Ethiopia, maize and sorghum planted underneath *faidherbia albida* trees achieved yields 56 percent higher than those crops planted in the open (Poschen 1986). Yield stability is enhanced when leguminous perennials planting is combined with inorganic fertilizer application (Sileshi, Debusho, and Akinnifesi 2012; Snapp et al. 2010). Nasielski et al. (2015) also found beneficial effects of agroforestry on soybean yield stability under drought conditions.

Despite the potential benefits of agroforestry practices, adoption rates are low in SSA. Akinnifesi et al. (2008) attribute this to both a lack of available germplasm and limited knowledge on agroforestry practices. Mitigating sapling losses resulting from moisture stress in the dry season and grazing animal damage are also particularly challenging (Bannister and Nair 1990). As a consequence, promotion projects in Eastern and Southern Africa typically provide training accompanied by seeds or seedlings for free to project participants (Franzel et al. 2004). It is therefore difficult to assess the extent to which seedling availability and investment costs constraint adoption of agroforestry. However, given the significant lag between when trees are planted and when benefits accrue, typically in the range of 10 years for *faidherbia albida*, it is unlikely that small, resource constrained farm households are capable of effective agro-forestry adoption, even when seedling costs are off-set.

What is clear is that markets for seedling multiplication and sale are rare in Africa (Place et al. 2003). This is due in large measure to a lack of demand among a broad segment of the smallholder population. Like many other practices being promoted to achieve productivity growth in the context of climate change, the adoption of agroforestry practices is constrained by opportunity costs of removing land from crop production and capital constraints (McCarthy, Lipper, and Branca 2011). As a result, empirical studies show that larger land holdings and higher income status are significant explanatory variables for agroforestry adoptions (McCarthy, Lipper, and Branca 2011; Kuntashula and Mafongoya 2005; Place et al. 2004; Franzel 1999).

In places where rapid population growth is driving land fragmentation and pushing up land prices, the costs of diverting land to agroforestry practices with uncertain and delayed benefits is high, particularly among poorer smallholders with a high time preference for money. In these regions, agroforestry strategies are unlikely to meet SAP framework criteria. However, where ancillary markets for wood-based cooking fuel is high, including high density areas with poor power supplies, the economic incentives for agro-forestry systems that produce fuel wood and charcoal may be significant. This is particularly the case in regions close to urban areas, where charcoal demand is high due to chronic electric deficits. Identifying and leveraging these sorts of ancillary markets is likely an important, though underappreciated, element of agro-forestry promotion.

4.7. Soil Conservation and Erosion Management

Water management and harvesting practices seek to capture rainfall, improve water availability for crops and livestock, and increase the use efficiency of water Rockström and Barron 2007). Specific practices include bunds and tied ridge systems, terracing and contour farming, water tank storage, and irrigation. Proper water management is critical for enhancing soil properties and farm system resilience to rainfall stress. In particular, effective water management is found to enhance biomass production, increase the amount of above-ground and root biomass returned to the soil, and improve soil organic C concentration, by increasing available water in the root zone (Kimmelshue, Gilliam, and Volk 1995).

Evidence on tied ridge systems and bunds suggest that by enhancing water holding capacity and permitting more time for water infiltration, smallholder yields are improved. These systems have increased maize yields by 1800 kg/ha in Burkina Faso at high DAP fertilizer application and 1000 kg/ha under low fertilizer rates relative to yields without ridges (Rodriguez 1986). On alfisol soils in East Africa, maize yields under tied ridge systems were 800 kg/ha greater than flat cultivation (Dagg and Macartney 1968). The benefits of these systems are highest when moisture is a major constraint to production (Lal 1987). However, as shown by Posthumus and De Graaff (2005) while terracing can increase yields, the overall benefits in terms of household production are negligible due to the land area lost due to terracing (roughly 20%). This points to an important adoption constraint for small farms.

In addition to being land intensive, adoption of soil conservation and erosion control measures can be labor intensive. Where adoption has been widespread, evidence suggests that two interrelated factors have been important. The first is widespread knowledge about the importance of controlling soil erosion (Knowler and Bradshaw 2007). This knowledge stimulates demand by farmers for soil erosion control technologies. The second is the emergence of service markets dedicated to the construction of soil conservation structures. In Burkina Faso, for example, groups of young men have responded to local demand for tassas and zai planting pits by forming labor groups that specialize in the construction of these structures and move from village to village offering their services to local farmers (Pretty et al. 2011). As a result of this market-driven approach, more than 3 million hectares of degraded land in Burkina Faso has been rehabilitated. Achieving sustained adoption needed to produce SAP FRAMEWORK outcomes, therefore, is likely to occur in regions where incentives enable a co-evolution of farmer demand and services market development.

4.8. Irrigation

Insufficient and erratic water supplies is likely the most important factor governing soil productivity and hindering crop productivity growth and stability in SSA (Lal 1987). Thus, improving access to and utilization of irrigation technologies by smallholders is critical. Moreover, access to irrigation enables the cultivation of a wide range of crops, including fruits and vegetables, which cannot be feasibly grown under rain-fed conditions (Burney and Naylor 2012). Despite the potential benefits of irrigation, numerous efforts to promote *appropriate* irrigation technologies among African smallholders have met with limited success. High dis-adoption rates of drip and treadle pump irrigation systems have been found in Kenya (Kulecho and Weatherhead 2005), Malawi (Mangisoni 2008), Zimbabwe (Belder et al. 2007), and Ghana (Adeoti et al. 2007).

Frequent barriers to sustained adoption included technical failure and a lack of technical support, as well as limited economic returns under low value crop production. Burney and Naylor (2012) suggest that to support greater adoption, emphasis should be placed on identifying crop mixes that allow irrigation systems to improve returns to land, such as high value crop production. Thus, a SAP framework strategy around irrigation would focus on areas where land prices are being increased by population growth and urban expansion, and where incentives for land intensification are high. In addition, promotion strategies that leverage private sector incentives to drive sales through technical support services are likely to be more effective at sustaining adoption than donor-led approaches that by-pass market intermediaries.

5. CONCLUSION AND RECOMMENDATIONS: ACHIEVING SAP FRAMEWORK OUTCOMES BY HARNESSING SYSTEM-WIDE TRANSFORMATIONS AND OPPORTUNITIES TO BUILD CLIMATE RESILIENCE

This study develops a novel conceptual lens, the Sustainable Agricultural Productivity (SAP) framework, for identifying how to make agri-food systems more resilient and productive in the context of climate change. The main premises of the SAP framework are that the concepts of climate-smart, market-smart and sustainable intensification need to be integrated into a holistic framework for identify promising public programs and policies, and that we need to take account of the ways in which African economies are transforming as a result of rapid population growth and urbanization to identify effective policies and investments that can meaningfully improve the climate resilience of the region's agri-food systems.

We present evidence that the SSA's rural population living on degrading agricultural land has increased by 43 million over the 2000 to 2010 period. That an additional 8% of the region's rural population is residing on land designated as degrading over such a short time period warrants major policy attention. We also show that changes in number of rural people living on degrading land is strongly correlated with rural population densities. Farmers living on degrading land are more vulnerable to weather related shocks, because degraded soils tend to lack sufficient soil organic matter to retain moisture and crops grown on such soils are often less responsive to inorganic fertilizers. Making African agri-food system more resilient to climate change, therefore, requires policy and investments that can meaningfully improve soil conditions under conditions of rising rural population density and associated land scarcity.

Promoting sustainable agricultural productivity and resilience in the face of increasing climate variability will require breaking the social trap in which millions of smallholders in the region find themselves. For millions of farmers in SSA, decisions about the allocation of land, labor, and capital are made with the short-term objective of meeting immediate food and livelihoods needs. These decisions, while eminently rational for poor people, often prevent them from making long-term soil-enhancing investments that would maintain the productive potential of their farms over time. In particular, fallows are declining and, as a result, their farms become less productive as soil quality declines over time and increasingly vulnerable to climate shocks. As the exogenous trends identified in this paper related to population growth, rising land scarcity and climate change continue to unfold, the menu of activities and actions currently being promoted as climate-smart will be increasingly inadequate or unprofitable for farmers to adopt unless strategies to restore soil quality across tens of millions of hectares of agricultural land are initiated.

Our SAP framework highlights the need for more radical approaches to making African agri-food system productive and resilient in the context of climate change. These approaches must address the high time-preferences for money and other resources that underlie the social trap affecting millions of small-scale farmers, while at the same time anticipating and being responsive to the economy-wide trends associated with rapid population growth, urbanization and climate change.

The SAP framework suggests that to address the challenges posed to African agri-food systems by climate change requires focusing attention on the interplay between farm level decision–making and system-wide incentives. To a large extent, enabling farmers to make long-term soil investments will come from more effective policies and programs that generate improved *best practices*, drive down the costs borne by farmers of adopting these best practices, and change incentives and opportunities at other stages of the system.

To this end, we identify five concrete policy recommendation for consideration by African policy-makers and development partners to nudge African agri-food systems towards a more sustainable and productive future.

5.1. Substantially Increase Investments in Public Agricultural Research and Participatory Extension Services

Over the last four decades, African governments have allocated a very small fraction of their agricultural expenditures to crop and livestock research and extension services. Yet, of all types of agricultural expenditures, spending on research and development is among the most crucial to growth (Pardey et al. 2006). Indeed, the weaknesses of Africa R&D and extension constrain the pace of agricultural productivity growth (Fuglie and Rada 2013). Asian farmers benefit from the fact that their governments spend over 8 times more annually on agricultural R&D on average than African governments. Not surprisingly, the pace of agricultural productivity growth in Asia has eclipsed that of Africa over the last several decades.

While advances in ICTs are making it increasingly feasible to provide information to farmers even in the most remote areas, the binding constraint is increasingly an inability to provide farmers with proven best practices due to decades of neglect of agricultural research and development under localized conditions, not the ability to effectively communicate with farmers in remote areas. International R&D cannot fully substitute for local R&D because agricultural technologies, especially seed varieties, which must be locally adapted, tested, and refined to suit Africa's highly varied agro-ecological conditions.

Building African R&D capacity requires sustained investments in people, facilities, lab equipment, budgets for field trials, and other recurrent costs. And because the benefits of most agricultural R&D investments accrue broadly and cannot be captured by firms investing in them, there is a strong role for sustained support for public R&D. Building the capacity of strong African public agricultural R&D and extension systems should be a priority area for international development assistance.

Yet, spending on R&D alone is likely insufficient to have a meaningful impact on productivity outcomes. Extension systems also need to be reformed. To cope with the socio-economic and agro-ecological diversity of farm systems in SSA, R&D must be integrated with a participatory extension model that enables a bi-directional flow of information out to farmers and information into agricultural research stations (Snapp, Blackie, and Donovan 2003; Kerr et al. 2007). As large agri-business firms invest in African agri-food systems, opportunities for private extension services will expand. However, given the scope and scale of the challenges facing African agri-food systems, and the geographic clustering of most private agri-business investments in areas of high-potential and market accessible areas, revitalizing public extension will be critical for breaking the social traps affecting millions of farmers.

As shown in Section 3, some countries such as Burkina Faso are on an upward soil quality trajectory. Burkina is one of the few countries in the region in which a large proportion of the rural population is residing on land that is improving in quality. Burkina's success is in large part due to the effectiveness of crop science research and extension systems and associated investments resulting in cereal yield growth in the 1990s that has transformed the integrated cereal-legume-livestock systems and promoted sustainability and resilience.

Given the enormity of the challenges facing food systems in the context of rapid population growth and climate change, stronger and more sustained support for innovative crop science R&D and farm extension programs will be needed to effectively meet the major challenges being posed by climate change.

5.2. Prioritize Macro-economic Stability and Low Inflation

Macro-economic stability and low inflation levels are essential for pushing down commercial lending rates and encouraging private investment. Until recently, many countries in the region made tremendous strides in controlling inflation, which in turn contributed to dramatic declines in lending rates (Jayne, Mather, and Mghenyi 2010).

Macro-economic stability and low lending rates stimulate private investment. Private investment in agri-food systems are critical for improving input and output market performance, and thus providing farmers with the technologies and price incentives needed for intensification. In addition, low lending rates encourage private firms to profitably store crops and make additional investments in storage facilities. This, in turn, helps to stabilize food supplies within and between years, while also limiting post-harvest losses. These are critical elements of a more resilient and productive food system.

Yet, for millions of very small farms, improvements in the non-farm economy are likely to be of even greater importance. As the non-farm economy grows, wage opportunities are created that pull people out of low-productivity farming into more remunerative non-farm livelihoods that are substantially more resistant to climate vagaries than agriculture. For many farmers faced with limited land access and increasingly degraded and unproductive soils, exit into the non-farm economy is the most effective path out of poverty and a powerful contributor to resilience. Therefore, attention to the macroeconomic policy environment, the availability of rural finance, and the interest rates at which finance is available are among the most powerful determinants of community resilience to climate variability through their system-wide effects on sustainable agricultural productivity.

5.3. Use Subsidies to Support the Development of Markets for Organic Matter

While driving down lending rates is critical for the development of farm and non-farm industries and services, it is likely insufficient to induce millions of farmers mired in the social trap of land degradation and under investment in long-term soil improvements. To incentivize these farmers to make long-term investments today in improving soil quality will require innovative strategies to drive down the cost of these investments.

Input subsidy programmes (ISPs) are commonly used in SSA to lower the cost of fertilizer to farmers. In the case of basal fertilizer, which are predominantly potassium, these subsidies are important because the yield effects of potassium only begin to accrue in the second year of application. Given small farmers high time preference for money, these farmers would be unlikely to use basal fertilizer in the absence of a subsidy.

There is a strong argument to support the use of subsidies in order to develop markets for soil amendments that can help to regenerate degrading and increasingly unresponsive soils, such as organic compost. Governments can consider modifying current input subsidy programs to promote the use of make organic fertilizer, lime, and a range of other soil-augmenting inputs that can help restore soil productivity on degraded land. In this way, input subsidy programs could transition from programs that encourage monocropping and continuous cultivation of the same crops year after year to ones that promote rotations, intercropping, bio-diversity, and building up soil capital.

However, because composting industries are not widely developed in SSA, this subsidy programme would need to both induce demand from farmers and create incentives for industries to develop organic matter supply chains.

With rapid urbanization and dietary shift toward greater animal protein consumption, the challenges of disposing of huge amounts of animal and human waste are likely to become increasingly acute. The production of organic waste from urban settlements and animal feeding operations offers new opportunities to produce quantities of organic matter that, if processed and applied to agricultural fields, could meaningfully improve soil quality conditions in Africa. Indeed, there is evidence that in some parts of Africa this is already happening (see for example Dajopen waste management in Kenya). Closing the loops between food production and consumption will be of interesting importance for sustainable productivity growth as population expansion places mounting pressure on resource availability.

5.4. Develop Policy Frameworks to Legitimize Emergent Land Rental Markets

Policy reform to enable land market development in Africa has been stymied by fears that the development of land markets would result in massive rural landlessness and land consolidation. These views persist in spite of growing evidence that land rental and sales markets provide open up opportunities for rural people, especially women, and promote agricultural productivity growth and equity (Holden, Deininger, and Ghebru 2009; Jin and Jayne 2013; Chamberlin and Ricker-Gilbert 2016). African governments may promote rural community resilience and SAPG by removing the obstacles to and actively promoting the development of land sales and rental market development in rural areas.

Despite a lack of policy clarity, rural land markets in SSA are developing organically in response to population pressures. Evidence on these markets suggest that the outcomes are largely beneficial from both a welfare and efficiency standpoint (Jin and Jayne 2013; Chamberlin and Ricker-Gilbert 2016). Land markets provide capital for households to exit unprofitable farming and enter the non-farm economy (Holden and Otsuka 2014). This is critical for limiting destitution migration.

For households that remain in farming, land securitization that accompanies land market formalization enables and incentivizes the adoption of intensification practices through land collateralization and tenure security (Sitko et al. 2014; Holden, Deininger, and Ghebru 2009). For example, in Ethiopia, Holden, Deininger, and Ghebru (2009) found that after seven years, receipt of land certificates in the Tigray region resulted in better maintenance of soil conservation structures and more planting of trees. They also found a 40-45% increase in productivity on certified land, a sign of land use intensification. However, because of their often clandestine nature, participation in land markets imposes unnecessary transactions costs on participants (Sitko 2010). Moreover, land tenure systems that create uncertainty about personal property rights reduce the degree of long-term soil-augmenting investments made on such land.

Ministries of Agriculture and Land may consider setting up committees to address the potential reforms of land tenure systems as a means to promote SAP in the face of rising climate variability. Of particular importance is generating policies that legitimize agricultural land rentals. Functional and illegitimate rental markets can enable longer-term leases of land, which can limit incentives for short-term soil mining by renters, while providing income to landlords. Prioritizing policy support for rental markets also helps to mitigate concerns of elite capture and speculative land acquisitions that often plague nascent sales markets in Africa.

5.5. Improve Labor Market Flexibility and Foreign Direct Investment Policies, Coupled With a Social Safety Net Fund

Movements in wage rates can have a profound effect on land use patterns and the range of technologies and farm practices that can be feasibly adopted. Of particular importance is the ratio between wages and output prices for agricultural products. In Ghana, for example, a decline in wage rates and/or an increase in farm product prices led to an increase in cultivated farm area, achieved primarily through decreasing fallow rates and converting forested land to fields (Lopez 1997; Barbier 2000). As population growth pushes domestic agricultural prices toward import parity, incentives to expand areas under cultivation or to unsustainably intensify production will increase. How wage rates behave will likely influence how farmers respond to these incentives.

This suggests that labor market policies can have a profound, though unappreciated, effect on the capacity of agri-food systems to achieve SAP outcomes. Improving the capacity of labor markets to respond to natural disasters and to incentivize more sustainable land use is a matter of improving labor market flexibility and capital entry and exit. Collier and Goderis (2009) find that disasters have less severe macroeconomic consequences if employment legislation permits greater flexibility, enabling easier hiring, and releasing of workers. This flexibility is critical for the pace of economic recovery following a disaster. Moreover, labor market flexibility combined with open foreign direct investment (FDI) regulations help to increase the absorption capacity of non-farm employment sectors and thus improve wages, all critical outcomes to achieving sustained agri-food system resilience to climate change (Collier, Conway, and Venables 2008).

Yet labor market flexibility brings with it risks of widespread unemployment during periods of economic decline. Given the volatility of most African economies, developing a robust social safety net fund should be considered in tandem with labor market and foreign direct investment policy reforms. In many countries, these funds can be developed using tax revenue on major commodity exports, such as copper, gold, or natural gas. These funds would be built up during years of high prices and solid economic performance and drawn down through cash transfers during period of economic decline.

5.6. Staple Food Market Policy Reform

Achieving SAP outcomes will also require public policy reforms influencing food market performance. Agricultural policies in many African countries encourage staple food production, often through a combination of input subsidies and above-market producer prices for staple grains. Throughout the region, therefore, government policies elevate the returns to the production of staple cereals compared to legumes and pulses (Barbier 2000). This has three important implications in terms of SAPF outcomes. First, the relatively poor returns to legumes and pulses restricts the income of farmers who practice rotations involving one or more legumes and discourages rotations. Second, when grown in mono-crop, staple cereals tend to expose large areas of soil surface to erosion, contributing to a faster rate of erosion than would be the case if returns to dual purpose legumes were higher (ibid). Finally, for food deficit rural households, policies that push up staple food prices, such as pan-territorial maize market subsidies, affect them as consumers rather than producers. As such, these policies depress the capacity of poor farm households to invest in farm improvements and land managements as higher food prices further constrain incomes (Mason and Myers 2013). Agricultural policies may promote SAP by promoting the cultivation of crops that raise soil fertility, such as bushy legumes. In parts of the region, export markets for pigeonpea are developing, thereby providing great opportunities to expand production of this soil fertility-augmenting crop. Ministries of Agriculture can consider ways of promoting the cultivation of such crops and encouraging the development of Asian export markets.

Containing food price volatility is another entry point for governments to promote SAP. Semi-subsistence producers tend to make decisions about the crops they produce jointly with consumption decisions. Where markets are highly volatile, these farmers will tend to focus production on meeting staple food needs (Fafchamps 1992). Public policy has an important role to play here. In many parts of the region, government routinely use policy instruments such as trade bans, price controls, and output market subsidies to influence prices and availability of staple foods. Contrary to their intent, these policies typically contribute to higher levels of price volatility than would be the case otherwise (Chapoto and Jayne 2009). Governments may re-evaluate the effects of these restrictive trade policies and thereby encourage more diversified agricultural production patterns resulting from being able to rely more on markets to obtain staple food.

Given the enormity of the challenges facing food systems in the context of rapid population growth and climate change, and the importance of collective action in address them, public sector action and effective use of scarce public expenditures to agriculture will be decisive in achieving sustainable agricultural productivity in the region. Once enacted, the proposals made here will take time to generate their full impacts. That is why there is no time to waste in getting started.

REFERENCES

Adeoti, A., B. Barry, R.E. Namara, A. Kamara, and A. Titiati. 2007. *Treadle Pump Irrigation and Poverty in Ghana*. IWMI Research Report No. 117. Colombo, Sri Lanka: International Water Management Institute.

Akinnifesi, F.K., P.W. Chirwa, O.C. Ajayi, G. Sileshi, P. Matakala, F.R. Kwesiga … and W. Makumba. 2008. Contributions of Agroforestry Research to Livelihood of Smallholder Farmers in Southern Africa: 1. Taking Stock of the Adaptation, Adoption, and Impact of Fertilizer Tree Options. *Agricultural Journal* 3.1: 58-75.

Altieri, M.A., M.A. Lana, H.V. Bittencourt, A.S. Kieling, J.J. Comin, and P.E. Lovato. 2011. Enhancing Crop Productivity via Weed Suppression in Organic No-Till Cropping Systems in Santa Catarina, Brazil. *Journal of Sustainable Agriculture* 35.8: 855-869.

Arslan, A., N. McCarthy, L. Lipper, S. Asfaw, and A. Cattaneo. 2014. Adoption and Intensity of Adoption of Conservation Farming Practices in Zambia. *Agriculture, Ecosystems, and Environment* 187: 72-86.

Badiane, O. and T. Makombe. 2014. *The Theory and Practice of Agriculture, Growth, and Development in Africa.* WIDER Working Paper 2014/061. Helsinki: UNU-WIDER.

Bannister, M.E. and P.K.R. Nair. 1990. Alley Cropping as a Sustainable Agricultural Technology for the Hillsides of Haiti: Experience of an Agroforestry Outreach Project. *American Journal of Alternative Agriculture* 5.2: 51-59.

Barbier, E.B. 2000. The Economic Linkages between Rural Poverty and Land Degradation: Some Evidence from Africa. *Agriculture, Ecosystems, and Environment* 82.1-3: 355-370.

Barbier, E.B. and J.P. Hochard. 2016. Does Land Degradation Increase Poverty in Developing Countries? *PloS ONE* 11.5: e0152973. https://doi.org/10.1371/journal.pone.0152973.

Barrett, C.B. and M.R. Carter. 1999. Microeconomically Coherent Agricultural Policy Reform in Africa. In *African Economies in Transition Volume 2: The Reform Experience,* ed. Jo Ann Paulson. London: Palgrave Macmillan.

Barrett, C.B., M.B. Clark, D.C. Clay, and T. Reardon. 2005. Heterogeneous Constraints, Incentives, and Income Diversification Strategies in Rural Africa. *Quarterly Journal of International Agriculture* 44.1: 37-60.

Baudron, F., M. Jaleta, O. Okitoi, and A. Tegegn. 2014. Conservation Agriculture in African Mixed Crop-livestock Systems: Expanding the Niche. *Agriculture, Ecosystems, and Environment* 187: 171-182.

Belder, P., D. Rohrbach, S. Twomlow, and A. Senzanje. 2007. *Can Drip Irrigation Improve the Livelihoods of Smallholders? Lessons Learned from Zimbabwe: Global Theme on Agroecosystems.* Report No. 33. Monograph. Bulawayo, Zimbabwe: International Crops Research Institute for the Semi-Arid Tropics.

Binswanger, H.P. and J. McIntire. 1987. Behavioral and Material Determinants of Production Relations in Land-Abundant Tropical Agriculture. *Economic Development and Cultural Change* 36.1: 73-99.

Boahen, P., B.A. Dartey, and G.D. Dogbe, G. Delali, E. Boadi, B. Triomphe, S. Daamgard-Larsen, and J. Ashburner. 2007. Conservation Agriculture as Practiced in Ghana. Nairobi: African Conservation Tillage Network, *Centre de Coopération Internationale de Recherche Agronomique pour le Développemen*t, Food and Agriculture Organization of the United Nations.

Branca G, N. McCarthy, L. Lipper, and M.C. Jolejole. 2011. Climate-Smart Agriculture: A Synthesis of Empirical Evidence of Food Security and Mitigation Benefits from Improved Cropland Management. Mitigation of Climate Change in Agriculture Series 3. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO).

Buerkert, A., A. Bationo, and K. Dossa. 2000. Mechanisms of Residue Mulch-Induced Cereal Growth Increases in West Africa. *Soil Science Society of America Journal* 64.1: 346-358.

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.

Carsky, R.J., B. Oyewole, and G. Tian. 1999. Integrated Soil Management for the Savanna Zone of W. Africa: Legume Rotation and Fertilizer N. *Nutrient Cycling in Agroecosystems* 55.2: 95-105.

Chamberlin, J.and J. Ricker-Gilbert. 2016. Participation in Rural Land Rental Markets in Sub-Saharan Africa: Who Benefits and by How Much? Evidence from Malawi and Zambia. *American Journal of Agricultural Economics* 98.5: 1507-1528.

Chapoto, A. and T.S. Jayne. 2009. *The Impacts of Trade Barriers and Market Interventions on Maize Price Predictability: Evidence from Eastern and Southern Africa.* MSU Working Paper No. 102. East Lansing: Michigan State University.

Chivenge, P.P., H.K. Murwira, K.E. Giller, P. Mapfumo, and J. Six. 2007. Long-term Impact of Reduced Tillage and Residue Management on Soil Carbon Stabilization: Implications for Conservation Agriculture on Contrasting Soils. *Soil and Tillage Research* 94.2: 328-337.

Cofie, O.O. and P. Drechsel. 2007. Water for Food in the Cities: The Growing Paradigm of Irrigated (Peri)-Urban Agriculture and Its Struggle in Sub-Saharan Africa. *African Water Journal* 1.1: 26-50.

Collier, P. and B. Goderis. 2009. Structural Policies for Shock-Prone Commodity Exporters. *Oxford Economic Papers* 61.4: 703-726.

Collier, P., G. Conway, and T. Venables. 2008. Climate Change and Africa. *Oxford Review of Economic Policy* 24.2: 337-353.

Corbeels, M., J. de Graaff, T.H. Ndah, E. Penot, F. Baudron, K. Naudin, ... and L. Rusinamhodzi. 2014. Understanding the Impact and Adoption of Conservation Agriculture in Africa: A Multi-Scale Analysis. *Agriculture, Ecosystems, and Environment* 187: 155-170.

Dagg, M. and J.C. Macartney. 1968. The Agronomic Efficiency of the NIAE Mechanized Tied Ridge System of Cultivation. *Experimental Agriculture* 4.04: 279-294.

Dakora, F.D. and S.O. Keya. 1997. Contribution of Legume Nitrogen Fixation to Sustainable Agriculture in Sub-Saharan Africa. *Soil Biology and Biochemistry* 29.5: 809-817.

Dalal, R.C., P.A. Henderson, and J.M. Glasby. 1991. Organic Matter and Microbial Biomass in a Vertisol after 20 Yr of Zero-Tillage. *Soil Biology and Biochemistry* 23.5: 435-441.

De Janvry, A. and E. Sadoulet. 2002. World Poverty and the Role of Agricultural Technology: Direct and Indirect Effects. *Journal of Development Studies* 38.4: 1-26.

Engelbrecht, F., J. Adegoke, M-J. Bopape, M. Naidoo, R. Garland, M. Thatcher, ….. and C. Ichoku. 2015. Projections of Rapidly Rising Surface Temperatures over Africa under Low Mitigation. *Environmental Research Letters* 10.8. http://iopscience.iop.org/article/10.1088/1748-9326/10/8/085004.

Erenstein, O.C. 1999. *The Economics of Soil Conservation in Developing Countries: The Case of Crop Residue Mulching, Vol. 14*. Wageningen: Wageningen University.

FAO. 2013. *Climate-Smart Agriculture Sourcebook*. Rome, Italy: FAO.

FAOSTAT 2016. http://www.fao.org/faostat/en/

Fafchamps, M. 1992. Solidarity Networks in Preindustrial Societies: Rational Peasants with a Moral Economy. *Economic Development and Cultural Change.* 41.1: 147-174.

Fafchamps, M. 2001. Networks, Communities, and Markets in Sub-Saharan Africa: Implications for Firm Growth and Investment. *Journal of African Economies* 10.Suppl 2: 109-142.

Fernández-Ugalde, O., I. Virto, P. Bescansa, M.J. Imaz, A. Enrique, and D.L. Karlen. 2009. No-tillage Improvement of Soil Physical Quality in Calcareous, Degradation-Prone, Semiarid Soils. *Soil and Tillage Research* 106.1: 29-35.

Franzel, S. 1999. Socioeconomic Factors Affecting the Adoption Potential of Improved Tree Fallows in Africa. *Agroforestry Systems* 47.1-3: 305-321.

Franzel, S., G.L. Denning, J.P.B. Lillesø, and A.R. Mercado. 2004. Scaling Up the Impact of Agroforestry: Lessons from Three Sites in Africa and Asia. *Agroforestry Systems* 61.1-3: 329-344.

Fuglie, K.O. and N.E. Rada. 2013. Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa. Economic Research Report No. 145. Washington, DC: U.S. Department of Agriculture, Economic Research Service. Online at: https://www.ers.usda.gov/mediaImport/1037838/err145.pdf

Fuglie, K. 2015. Accounting for Growth in Global Agriculture. *Bio-based and Applied Economics* 4.3: 201.

Gerland, P., A.E. Raftery, H. Ševčíková, N. Li, D. Gu, T. Spoorenberg ... and G. Bay. 2014. World Population Stabilization Unlikely This Century. *Science* 346.6206: 234-237.

Giller, K.E., E. Witter, M. Corbeels, and P. Tittonell. 2009. Conservation Agriculture and Smallholder Farming in Africa: The Heretics' View. *Field Ccrops Research* 114.1: 23-34.

Govaerts, B., K.D. Sayre, and J. Deckers. 2005. Stable High Yields with Zero Tillage and Permanent Bed Planting? *Field Crops Research* 94.1: 33-42.

Hayami, Y. and V. Ruttan. 1971. *Induced Innovation in Agricultural Development.* Discussion Center for Economics Research Paper No. 3. Minneapolis, Minnesota: University of Minnesota. Online at: https://conservancy.umn.edu/bitstream/handle/11299/54243/1/1971-03.pdf.

Hernanz, J.L., R. López, L. Navarrete, and V. Sanchez-Giron. 2002. Long-Term Effects of Tillage Systems and Rotations on Soil Structural Stability and Organic Carbon Stratification in Semiarid Central Spain. *Soil and Tillage Research* 66.2: 129-141.

Holden, S.T., K. Deininger, and H. Ghebru. 2009. Impacts of Low-Cost Land Certification on Investment and Productivity. *American Journal of Agricultural Economics* 91.2: 359-373.

Holden, S.T.and K. Otsuka. 2014. The Roles of Land Tenure Reforms and Land Markets in the Context of Population Growth and Land Use Intensification in Africa. *Food Policy* 48: 88-97.

Hua, W., L. Zhou, H. Chen, S. Nicholson, A. Raghavendra, and Y. Jiang. 2016. Possible Causes of the Central Equatorial African Long-term Drought. *Environmental Research Letters* 11.12. http://iopscience.iop.org/article/10.1088/1748-9326/11/12/124002

International Fund for Agricultural Development. IFAD. 2016. Rural Development Report: Fostering Inclusive Rural Transformation. Rome: IFAD.

IPCC. 2013. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Ed. T. Stocker, D. Qin, G.-K. Plattner et al. United Kingdom and New York, NY: Cambridge University Press. http://www.climatechange2013.org/images/report/WG1AR5_TS_FINAL.pdf

Jayne, T.S. and D. Ameyaw. 2016. Africa's Emerging Agricultural Transformation: Evidence, Opportunities and Challenges. Chapter 1. In *Africa Agriculture Status Report – 2016.* Nairobi, Kenya: Alliance for a Green Revolution in Africa.

Jayne, T.S., J. Chamberlin, L. Traub, N. Sitko, M. Muyanga, F.K. Yeboah, W. Anseeuw, A. Wineman, and R. Kachule. 2016. Africa's Changing Farm Size Distribution Patterns: The Rise of Medium-Scale Farms. *Agricultural Economics* 47.S1: 197-214.

Jayne, T.S., D. Mather, and E. Mghenyi. 2010. Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa. *World Development* 38.10: 1384-1398.

Jin, S. and T.S. Jayne. 2013. Land Rental Markets in Kenya: Implications for Efficiency, Equity, Household Income, and Poverty. *Land Economics* 89.2: 246-271.

Jones, R., H.A. Freeman, and G.L. Monaco. 2002. *Improving the Access of Small Farmers in Eastern and Southern Africa to Global Pigeonpea Markets.* Agricultural Research and Extension Network Paper No. 120. London: Agricultural Research and Extension Network.

Kamanga, B.C.G., S.R. Waddington, M.J. Robertson. and K.E. Giller. 2010. Risk Analysis of Maize-Legume Crop Combinations with Smallholder Farmers Varying in Resource Endowment in Central Malawi. *Experimental Agriculture* 46.01: 1-21.

Kapkiyai, J.J., N.K. Karanja, J.N. Qureshi, P.C. Smithson, and P.L. Woomer. 1999. Soil Organic Matter and Nutrient Dynamics in a Kenyan Nitisol under Long-Term Fertilizer and Organic Input Management. *Soil Biology and Biochemistry* 31.13: 1773-1782.

Kaumbutho, P. and J. Kienzle. 2007. *Conservation Agriculture as Practised in Kenya*. Rome: African Conservation Tillage Network; Food Agriculture Organization of the United Nations.

Kerr, R.B., 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* 43.04: 437-453.

Kimmelshue, J.E., J.W. Gilliam, and R.J. Volk. 1995. Water Management Effects on Mineralization of Soil Organic Matter and Corn Residue. *Soil Science Society of America Journal* 59.4: 1156-1162.

Knowler, D. and B. Bradshaw. 2007. Farmers' Adoption of Conservation Agriculture: A Review and Synthesis of Recent Research. *Food Policy* 32.1: 25-48.

Kulecho, I.K. and E.K. Weatherhead. 2005. Reasons for Smallholder Farmers Discontinuing with Low-Cost Micro-Irrigation: A Case Study from Kenya. *Irrigation and Drainage Systems* 19.2: 179–188.

Kuntashula, E. and P.L. Mafongoya. 2005. Farmer Participatory Evaluation of Agroforestry Trees in Eastern Zambia. *Agricultural Systems* 84.1: 39-53.

Lal, R. 1987. Managing the Soils of Sub-Saharan Africa. *Science* 236.4805: 1069-1076.

Lasco, R.D., R.J.P. Delfino, and M.L.O. Espaldon. 2014. Agroforestry Systems: Helping Smallholders Adapt to Climate Risks While Mitigating Climate Change. *Wiley Interdisciplinary Reviews: Climate Change* 5.6: 825-833.

Linard, C., M. Gilbert, R.W. Snow, A.M. Noor, and A.J. Tatem. 2012. Population Distribution, Settlement Patterns and Accessibility across Africa in 2010. *Plos One* 7.2: e31743.

Lopez, R. 1997. Environmental Externalities in Traditional Agriculture and the Impact of Trade Liberalization: The Case of Ghana. *Journal of Development Economics* 53.1: 17-39.

Maes, W.H. and B. Verbist. 2012. Increasing the Sustainability of Household Cooking in Developing Countries: Policy Implications. *Renewable and Sustainable Energy Reviews* 16.6: 4204-4221.

Mangisoni, J. 2008. Impact of Treadle Pump Irrigation Technology on Smallholder Poverty and Food Security in Malawi: A Case Study of Blantyre and Mchinji Districts. *International Journal of Agricultural Sustainability* 6.4: 248-266.

Mason, N.M. and R.J. Myers. 2013. The Effects of the Food Reserve Agency on Maize Market Prices in Zambia. *Agricultural Economics* 44.2: 203-216.

Mason, N.M., A. Wineman, L. Kirimi, and D.L. Mather. 2015. *The Effects of Kenya's 'Smarter' Input Subsidy Program on Crop Production, Incomes, and Poverty*. Tegemeo WPS No. 56. Njoro, Kenya: Tegemeo Institute of Agricultural Policy and Development.

Masters, W. A., A.A. Djurfeldt, C. De Haan, P. Hazell, T. Jayne, M. Jirström, and T. Reardon. 2013. Urbanization and Farm Size in Asia and Africa: Implications for Food Security and Agricultural Research. *Global Food Security* 2.3: 156–165.

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 (FAO).

McMillan, M.S. and K. Harttgen. 2014. *What's Driving the 'African Growth Miracle'?* NBER Working Paper No. 20077. Cambridge, MA: The National Bureau of Economic Research.

Montpellier Panel, The. 2013. *Sustainable Intensification: A New Paradigm for African Agriculture*. London: Agriculture for Impact.

Mulumba, L.N. and R. Lal. 2008. Mulching Effects on Selected Soil Physical Properties. *Soil and Tillage Research* 98.1: 106-111.

Nasielski, J., J.R. Furze, J. Tan, A. Bargaz, N.V. Thevathasan, and M.E. Isaac. 2015. Agroforestry Promotes Soybean Yield Stability and N2-Fixation under Water Stress. *Agronomy for Sustainable Development* 35.4: 1541-1549.

Ngwira, A.R., C. Thierfelder, N. Eash, and D.M. Lambert. 2013. Risk and Maize-Based Cropping Systems for Smallholder Malawi Farmers using Conservation Agriculture Technologies. *Experimental Agriculture* 49.04: 483-503.

Pardey, P.G., N.M. Beintema, S. Dehmer, and S. Wood. 2006. *Agricultural Research: A Growing Global Divide?* (Vol. 17). Washington, DC: International Food Policy Research Institute.

Paul, B.K., B. Vanlauwe, F. Ayuke, A. Gassner, M. Hoogmoed, T.T. Hurisso, ... and M. Pulleman. 2013. Medium-Term Impact of Tillage and Residue Management on Soil Aggregate Stability, Soil Carbon, and Crop Productivity. *Agriculture, Ecosystems and Environment* 164: 14-22.

Pingali, P.L. 2012. Green Revolution: Impacts, Limits, and the Path Ahead. *Proceedings of the National Academy of Sciences 109*.31: 12302-12308.

Place, F., C.B. Barrett, H.A. Freeman, J.J. Ramisch, and B. Vanlauwe. 2003. Prospects for Integrated Soil Fertility Management Using Organic and Inorganic Inputs: Evidence from Smallholder African Agricultural Systems. *Food Policy* 28.4: 365-378.

Platt, J. 1973. Social Traps. *American Psychologist* 28.8: 641.

Poschen, P. 1986. An Evaluation of the Acacia Albida-based Agroforestry Practices in the Hararghe Highlands of Eastern Ethiopia. *Agroforestry Systems* 4.2: 129-143.

Posthumus, H. and J. De Graaff. 2005. Cost-Benefit Analysis of Bench Terraces: A Case Study in Peru. *Land Degradation and Development* 16.1: 1-11.

Poulton, C., J. Kydd, and A. Dorward. 2006. Overcoming Market Constraints on Pro-Poor Agricultural Growth in Sub-Saharan Africa. *Development Policy Review* 24.3: 243-277.

Pretty, J. 1999. Can Sustainable Agriculture Feed Africa? New Evidence on Progress, Processes and Impacts. *Environment, Development and Sustainability* 1: 253-274.

Raimbault, B.A. and T.J. Vyn. 1991. Crop Rotation and Tillage Effects on Corn Growth and Soil Structural Stability. *Agronomy Journal* 83.6: 979-985.

Reardon, T., C. Barrett, V. Kelly, and K. Savadogo. 1999. Policy Reforms and Sustainable Agricultural Intensification in Africa. *Development Policy Review* 17.4: 375-395.

Reardon, T. and C.P. Timmer. 2012. The Economics of the Food System Revolution. *Annual Review of Resource Economics* 4.1: 225-264.

Rebafka, F.P., A. Hebel, A. Bationo, K. Stahr, and H. Marschner. 1994. Short-and Long-Term Effects of Crop Residues and of Phosphorus Fertilization on Pearl Millet Yield on an Acid Sandy Soil in Niger, West Africa. *Field Crops Research* 36.2: 113-124.

Rockström, J. and J. Barron. 2007. Water Productivity in Rainfed Systems: Overview of Challenges and Analysis of Opportunities in Water Scarcity Prone Savannahs. *Irrigation Science* 25.3: 299-311.

Rodriguez, M. 1986. Water Holding Capacity and Fertilizer Response Rates: Maize Yield Effects in Burkina Faso. Paper presented at the International Drought Symposium, May 19-23. Nairobi, Kenya.

Rosenstock, T.S., K.L. Tully, C. Arias-Navarro, H. Neufeldt, K. Butterbach-Bahl, and L.V. Verchot. 2014. Agroforestry with N_2-fixing Trees: Sustainable Development's Friend or Foe? *Current Opinion in Environmental Sustainability* 6: 15-21.

Rusinamhodzi, L., M. Corbeels, M.T. van Wijk, M.C. Rufino, J. Nyamangara, and K.E. Giller. 2011. A Meta-Analysis of Long-Term Effects of Conservation Agriculture on Maize Grain Yield under Rain-Fed Conditions. *Agronomy for Sustainable Development* 31.4: 657-673.

Schroth, G. and F.L. Sinclair. 2002. Impacts of Trees on the Fertility of Agricultural Soils Chapter 1. In Trees, Crops and Soil Fertility: Concepts and Research Methods, ed. G. Schroth and F.L. Sinclair. Wallingford, UK: CABI.

Sheahan, M. and C.B. Barrett. 2014. *Understanding the Agricultural Input Landscape in Sub-Saharan Africa: Recent Plot, Household, and Community-Level Evidence*. Policy Research Working Papare No. 7014. Washington, DC: The World Bank.

Shetto, R. and M. Owenya. 2007. Conservation Agriculture as Practised in Tanzania: Three Case Studies: Arumeru District, Karatu District, Mbeya District. Nairobi, Kenya: African Conservation Tillage Network (ACT).

Sileshi, G.W., L.K. Debusho, and F.K. Akinnifesi. 2012. Can Integration of Legume Trees Increase Yield Stability in Rainfed Maize Cropping Systems in Southern Africa? *Agronomy Journal* 104.5: 1392-1398.

Sisti, C.P., H.P. dos Santos, R. Kohhann, B.J. Alves, S. Urquiaga. and R.M. Boddey. 2004. Change in Carbon and Nitrogen Stocks in Soil under 13 Years of Conventional or Zero Tillage in Southern Brazil. *Soil and Tillage Research* 76.1: 39-58.

Sitko, N.J. and B. Chisanga. 2016. *How Is Multinational Investment in Grain and Oilseed Trading Reshaping the Smallholder Markets in Zambia?* Indaba Agricultural Policy Research Institute Working Paper No. 104. Lusaka, Zambia: IAPRI.

Sitko, N.J, W. Burke, and T.S. Jayne.2018. The Quiet Rise of Large-Scale Trading Firms in East and Southern Africa, *The Journal of Development Studies* 1.20: DOI: 10.1080/00220388.2018.1430773

Sitko, N. J., J. Chamberlin, and H. Hichaambwa. 2014. Does Smallholder Land Titling Facilitate Agricultural Growth? An Analysis of the Determinants and Effects of Smallholder Land Titling in Zambia. *World Development* 64: 791-802.

Sitko, N.J. and T.S. Jayne. 2014. Structural Transformation or Elite Land Capture? The Growth of "Emergent" Farmers in Zambia. *Food Policy* 48: 194-202.

Sitko, N.J. 2010. Fractured Governance and Local Frictions: The Exclusionary Nature of a Clandestine Land Market in Southern Zambia. *Africa* 80.01: 36-55.

Snapp, S.S., M.J. Blackie, R.A. Gilbert, R. Bezner-Kerr, and G.Y. Kanyama-Phiri. 2010. Biodiversity Can Support a Greener Revolution in Africa. *Proceedings of the National Academy of Sciences* 107.48: 20840-20845

Snapp, S.S., M.J. Blackie, and C. Donovan. 2003. Realigning Research and Extension to Focus on Farmers' Constraints and Opportunities. *Food Policy* 28.4: 349-363.

Souverijns, N., W. Thiery, M. Demuzere, and N.P.M. Van Lipzig. 2016. Drivers of Future Changes in East African Precipitation. *Environmental Research Letters* 11.11.

Subbarao, G.V., N.H. Nam, N.H., Y.S. Chauhan, and C. Johansen. 2000. Osmotic Adjustment, Water Relations, and Carbohydrate Remobilization in Pigeonpea under Water Deficits. *Journal of Plant Physiology* 157.6: 651-659.

Tarawali, G., V.M. Manyong, R.J. Carsky, P.V. Vissoh, P. Osei-Bonsu, and M. Galiba. 1999. Adoption of Improved Fallows in West Africa: Lessons from Mucuna and Stylo Case Studies. *Agroforestry Systems* 47.1–3: 93–122.

Tembo, S.T., B.P. Mulenga, and N. Sitko. 2015. *Cooking Fuel Choice in Urban Zambia: Implications on Forest Cover* Iapri Working Paper No. 94. Lusaka, Zambia: IAPRI.

Thierfelder, C., R. Matemba-Mutasa, and L. Rusinamhodzi. 2015. Yield Response of Maize (Zea Mays L.) to Conservation Agriculture Cropping System in Southern Africa. *Soil and Tillage Research* 146: 230-242.

Tittonell, P. and K.E. Giller. 2013. When Yield Gaps Are Poverty Traps: The Paradigm of Ecological Intensification in African Smallholder Agriculture. *Field Crops Research* 143: 76-90.

Triplett, G.B., D.M. Van Doren, and B.L. Schmidt. 1968. Effect of Corn (Zea mays L.) Stover Mulch on No-Tillage Corn Yield and Water Infiltration 1. *Agronomy Journal* 60.2: 236-239. 20.

Umar, B.B., J.B. Aune, F.H. Johnsen, O.I. and Lungu. 2011. Options for Improving Smallholder Conservation Agriculture in Zambia. *Journal of Agricultural Science* 3.3: 50.

Verchot, L.V., M. Van Noordwijk, S. Kandji, T. Tomich, C. Ong, A. Albrecht, ... and C. Palm. 2007. Climate Change: Linking Adaptation and Mitigation through Agroforestry. *Mitigation and Adaptation Strategies for Global Change*, 12.5: 901-918.

Verhulst, N., V. Nelissen, N. Jespers, H. Haven, K.D. Sayre, D. Raes... and B. Govaerts. 2011. Soil Water Content, Maize Yield, and Its Stability as Affected by Tillage and Crop Residue Management in Rainfed Semi-Arid Highlands. *Plant and Soil* 344.1-2: 73-85.

Waddington, S.R., M. Mekuria, S. Siziba, and J. Karigwindi. 2007. Long-Term Yield Sustainability and Financial Returns from Grain Legume–Maize Intercrops on a Sandy Soil in Subhumid North Central Zimbabwe. *Experimental Agriculture* 43.04: 489-503.

Yamoah, C.F., A. Bationo, B. Shapiro, and S. Koala. 2002. Trend and Stability Analyses of Millet Yields Treated with Fertilizer and Crop Residues in the Sahel. *Field Crops Research* 75.1: 53-62.

Yeboah, F.K. and T.S. Jayne. 2016. *Africa's Evolving Employment Structure.* MSU International Development Working Paper No. 148. E. Lansing, MI: Michigan State University.

World Bank. Population Data. Accessed September 2016 at https://data.worldbank.org/