Title
Sustaining Rural Livelihoods Amid Changing Agrarian Landscapes in Senegal

Author
Voss, Rachel Charlene

Publication Date
2020

Peer reviewed|Thesis/dissertation

UNIVERSITY OF CALIFORNIA
SANTA CRUZ

SUSTAINING RURAL LIVELIHOODS AMID CHANGING AGRARIAN LANDSCAPES IN SENEGAL

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ENVIRONMENTAL STUDIES

by

Rachel C. Voss

September 2020

The Dissertation of Rachel Voss is approved:

Professor Carol Shennan, Chair

Professor Jeffrey Bury

Professor Adam Millard-Ball

Tim Krupnik, Ph.D.

Quentin Williams
Interim Vice Provost and Dean of Graduate Studies

Table of Contents

List of Tables

List of Figures

Abstract

Sustaining Rural Livelihoods Amid Changing Agrarian Landscapes in Senegal

Rachel C. Voss

The late 20th and early 21st century have wrought drastic change in the lives and livelihoods of smallholder farmers in the Global South. This research evaluates how rural farming households in Senegal are navigating the intersecting pressures of globalization and environmental change while responding to new opportunities, including the arrival of new technologies. First, I assess farmers' perceptions of and responses to changes in climate and socioeconomic circumstances, with attention to the factors shaping their adaptive strategies. Second, I evaluate the impacts of aid projects leveraging information and communication technologies (ICTs) and participatory farm trials to incentivize uptake of seeds and fertilizers among farmers. Finally, I follow up with direct beneficiaries of participatory farm trials to gauge post-project impacts on farmers' production practices, with attention to how new technologies are applied in relation to farm soil fertility gradients. My research shows widespread perceptions of changing weather patterns and shifting socioeconomic circumstances that together undermine the viability of smallholder farming in Senegal. While farmers' adaptive strategies are differentiated based on their access to resources, I find that youth emigration is playing a growing role in sustaining rural households. My findings further point to limitations and gender inequities in using

ICT-enabled extension to disseminate information to rural farmers. Ultimately, farmers in semi-arid parts of Africa face an increasingly risky environment that limits the viability of costly agricultural technologies and increases farmers' focus on resilience-oriented strategies. These findings provide insight into the future of farming under climate change and suggest ways that development efforts can—and cannot—better support rural smallholder farmers in a changing world.

Dedication

I dedicate this dissertation to my parents – my mother, who modeled for me the curiosity, compassion, and wonder of a good scientist, and my father, whose unwavering belief in me carried me here, although he did not get to see me cross the finish line.

I also dedicate this work to the farmers who shared their time, knowledge, and many plates of *thieboudienne*. I especially dedicate it to the twins in Nianing who pushed me to question why and how I have done this research, and what more I can do for the farmers I profess to serve. I know this effort yielded more for me than it did for them, but hope I have done their experiences justice and can pay my debt to them in the coming years and decades.

Acknowledgements

This research would not have been possible without 600+ farmers' generous contributions of their time and knowledge. I am in constant awe of their resilience and resourcefulness and grateful that they were willing to take me on as a student.

Stefan Rhein was by my side through the steps and missteps of this journey and proved to be a more loving and supportive partner than I could have dreamed. Thank you for holding down the fort, taking me on countless airport runs, writing emails and fielding phone calls at all hours, and cooking me so many amazing meals. Thank you also to my wonderful parents and brothers for the unwavering support and willingness to listen and advise.

A brilliant team of research assistants and translators made this project a reality and generated much of the data shared here. I found in them kind-hearted friends and excellent colleagues. My immeasurable gratitude goes to Bacary Mané, Patricia Attiba, Marouane Diallo, Demba Ba, Zoé Daba Gomis, Therèse Senghor, Abdoulaye Sadio, Halie Kampman, and Johnathan George. Thank you also to Aissatou Diagne for handling translation and transcription with professionalism.

The UC Santa Cruz community has provided extensive moral and scholarly support. I'll forever be indebted to officemates and friends Kate Ross, Daniel Hastings, and Juniper Harrower; the Agri-Food Working Group; and many friends and cohortmates, including Colby Anton, John Armstrong, Alicia Calle, Monika Egerer, Ryan Ehlen, Halie Kampman, Andy Kulikowski, James Larkby-Lahet, Josie Lesage, Robin Lovell, Jen Macasek, Allyson Makuch, Flavia Oliveira, Emily

Reisman, Rachel Shellabarger, and Darryl Wong. Invaluable training, guidance, and assistance with soil and labwork came from Dr. Weixin Cheng, Kelsey Forbush, Colin Carney, and the fantastic Shennan Lab staff, including Margie Zavatta, Joji Muramoto, Bella Bolstad, Makena Savidge, Sophia, Nick, and others. The ENVS department, and especially its grad student community, has been a wonderful home. I also send my love to Amanda Hazelwood, Jessica Campbell, and Alvin Rosa for their encouragement from afar.

A wider network of individuals and friends in Senegal contributed support and guidance, including Tony and Elia Jansen, Jon Eldon, Carmel Moran, Giorgia Nicatore, Saidou Sidibeh, Mary Allen, Stephane Boyera, Amy Ndeye Kebé and her superb staff at Jokalanté, and Stephane Contini. Special thanks to partners at COPI (especially Abdoulaye Gassama and Sekou Coly), URIS (Amadou Bassoum), and RESOPP, including Arona Diop, Ousmane Sarr, Saliou Mbacké, and many staff at COOPAM, COOPAKEL, and COOPEDELSI for their kindness and generosity. United Purpose's staff, including their fearless team of drivers, were wonderful colleagues.

I benefited, too, from generous funding support. My research was supported by the UC Santa Cruz Department of Environmental Studies, New Alliance ICT Extension Challenge (USAID Cooperative Agreement No. AID-OAA-A-15-00010), the UC Santa Cruz Blum Center and Department of Sociology (Jessica Roy Memorial Award), Annie's Homegrown, and the National Science Foundation Graduate Research Fellowship Program (Grant No. DGE 1339067). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not reflect the views of the funders.

The text of this dissertation includes reprints of manuscripts under review at *Climate and Development* (Chapter 1) and *World Development* (Chapter 2) at the time of submission. The manuscript *Encouraging technology adoption using ICTs and farm trials in Senegal: lessons for gender equity and scaled impact* includes Tony Jansen, Bacary Mané, and Carol Shennan as co-authors. Carol Shennan secured the grant that funded this research and advised on study design, execution, and analysis, in addition to providing editorial support. Tony Jansen and Bacary Mané were involved in implementation of the project evaluated in the study and aided in data collection, logistical support, and reviewing the manuscript. This study was a central component of my doctoral work, and I held primary responsibility for data collection, analysis, interpretation, and writing.

I take full responsibility for all mistakes and omissions in this research while giving ample credit to my committee for its praise-worthy aspects. Dr. Carol Shennan has been a brilliant advisor, a supportive mentor, and a friend in many ways. Thank you for helping me explore new opportunities and teaching me to believe in my own abilities. I am grateful for Dr. Adam Millard-Ball's kindness, patience, and good humor in guiding a largely qualitative scholar in a vastly different corner of Environmental Studies to understand and conduct quantitative analysis. Dr. Jeff Bury bears much responsibility for my increased understanding of alternative epistemologies and ontologies, which has forced me to rethink my ambitions of being

an ‘expert’ (in a good way). Dr. Tim Krupnik has been a champion mentor from across many time zones, providing thoughtful feedback and career advice even before I arrived at UCSC. Each of you has contributed so much in your own way, and I will be eternally grateful.

Positionality statement

I approach this study as a white woman and an American. My interest in smallholder farmers' lives and livelihoods stems from years spent working in Washington, DC, where I was involved in efforts to expand agricultural development funding for Africa. Concerns about how U.S. agricultural development funding and programs impact smallholder farmers and their environment, and a desire to better understand those impacts from the perspective of farmers, drew me to this research. The project detailed in Chapter 2 brought me to Senegal for the first time, presenting me with the uncomfortable challenge of thoughtfully and accurately documenting the experiences of a people to whom I was not intimately connected. I have struggled with my role as a foreign researcher in these communities as well as the neocolonial nature of development practices that dictate priorities and pathways. My research, although often critical of this approach to development, makes me part of that system.

As an outsider to the communities I studied, I strove to approach this research with humility, compassion, curiosity, and humanity. I spent much of my first field season in Senegal living in a rural community in Casamance and approached shared meals and cross-country *sept-places* rides as opportunities to discuss culture, politics, and relationships between white development practitioners and Senegalese communities. Although I worked to learn French, basic Wolof, and bits and pieces of Diola, Pular, and Mandika, I never achieved fluency in any local languages, regrettably following in the footsteps of many foreign researchers who came before me.

I frequently worried about data quality, recognizing that my position as a white researcher affiliated with a development project may have impacted farmers' responses to my questions. I suspect that many research participants were motivated by a desire to accommodate me and provide the answers my team and I were looking for, perhaps in the hopes of receiving additional benefits. These dynamics were difficult to navigate, and our lengthy consent process could only do so much to mitigate them. I leaned on qualitative methods that I felt provided space for more honest, unstructured conversations. I also worked with Senegalese colleagues (primarily graduate students from the University of Assane Seck in Ziguinchor) to tailor surveys to avoid topics that I felt would exacerbate harmful power dynamics, allowing them to mediate my interactions with communities as much as possible. Resource and time constraints presented barriers to more extensive use of participatory methods in this research, which I will always regret in looking back on this work.

I was able to make small contributions to local capacity through training and mentorship but feel these efforts were inadequate to compensate for the extraction of knowledge typically involved in this sort of research. I intend to support localized knowledge production and prioritize responsible knowledge co-production practices between communities and foreign researchers in the career this degree will allow me.

Introduction

Twenty-first century poverty alleviation and development efforts in Africa face the challenge of supporting resilient rural livelihoods and improving food security amid significant global changes, including climate change, globalization, growing populations, and increased connectivity. As the international community works toward UN Sustainable Development Goals that encompass food security, environmental protection, economic growth, and gender equity, among other diverse objectives, disputes over preferred development pathways are inevitable.

Agricultural development and food security approaches are often plagued by contradictions and controversies (Blesh, Hoey, Jones, Friedmann, & Perfecto, 2019). How should agricultural research and extension approach trade-offs between productivity, resilience, nutrition security, and equitable food distribution (Blesh et al., 2019; Darnhofer, Bellon, Dedieu, & Milestad, 2010; Ponisio & Ehrlich, 2016)? What are the appropriate roles of Western science, corporate finance, and indigenous knowledge in fostering innovation and setting development agendas (Agrawal, 1995; Biovision Foundation for Ecological Development & IPES-Food, 2020; Caron, Biénabe, & Hainzelin, 2014; Mitchell, 2002; Patel, Bezner Kerr, Shumba, & Dakishoni, 2015)? Should trade liberalization and market integration be fostered or abandoned in favor of greater food sovereignty (Bernstein, 2014; Jansen, 2015; Jayne, Mather, & Mghenyi, 2010)? Is the future of smallholder agriculture in commercialization and consolidation, and will that future achieve greater efficiency and pro-poor growth (Collier & Dercon, 2014; Netting, 1993)? Does rural households' pursuit of off-farm employment undermine rural society or aid farmers in escaping poverty traps (Bryceson, 2002; Collier & Dercon, 2014; Jayne et al., 2010; Rigg, 2006)?

One central debate concerns the agricultural model(s) best suited to African nations populated by large numbers of smallholder farmers. The Green Revolution of the twentieth century, which dramatically increased cereal yields in many parts of the world through expanded use of high-yielding varieties, fertilizers, pesticides, and irrigation technologies (Evenson & Gollin, 2003), is simultaneously viewed as a model on which to structure a new Green Revolution for Africa and a cautionary tale among critics (Patel, 2013). Funding for agriculture and rural development from many major donors, including the United States, United Kingdom, and Bill & Melinda Gates Foundation, backs the 'new Green Revolution' pathway for Africa, with a focus on maximizing yields through resource-intensive models (Biovision Foundation for Ecological Development & IPES-Food, 2020; DeLonge, Miles, & Carlisle, 2016; Pimbert & Moeller, 2018). At the same time, there is growing interest in centering sustainability, natural resource conservation, and agroecology in efforts to increase agricultural production and support livelihoods, both in regions where industrial agriculture is well-established and in sub-Saharan Africa (Altieri, 2002; Bennett & Franzel, 2013; Bernard & Lux, 2017; Cassman, 1999; Godfray et al., 2010; IAASTD, 2009; Pretty et al., 2006; Snapp, Blackie, Gilbert, Bezner-kerr, & Kanyama-phiri, 2010).

The dissertation that follows confronts many of these questions as it explores rural Senegal as a site of change. It offers several important contributions. First, it uses mixed methods to probe relationships between on- and off-farm livelihoods in semi-arid West Africa, building our understanding of how climate change is likely to impact this dynamic in the future. It considers drivers of and constraints to uptake of new Green Revolution technologies promoted using information and communication technologies (ICTs), offering some of the first empirical evidence of the limitations and equity risks associated with this new approach to extension in sub-Saharan Africa. Finally, it provides rare follow-up on a development project to understand farmers' retention and use of improved seeds and soil fertility technologies in the years following initial uptake, underscoring farmers' focus on resilience over optimized productivity.

Fundamentally, this work challenges assumptions that smallholder farmers are a homogenous group that is resistant to change and motivated by a universal economic rationality (Darnhofer, Bellon, et al., 2010). Reality is more complex. Smallholders' farming practices and livelihood strategies are dynamic and diverse, shaped by a diversity of interests, priorities, constraints, and inclinations toward risk and innovation (Netting, 1993) and embedded in complex socioeconomic, political, and environmental histories (Burnham & Ma, 2016; Crane, Roncoli, & Hoogenboom, 2011; Raynaut, 2001; Smit & Wandel, 2006).

In particular, this work builds our understanding of the differentiated experiences of women and men farmers. Women's unique roles in the household, on the farm, and in society shape their perceptions of the environment, their ability to pursue new opportunities, and their options for responding to challenges (Fortmann, 1990; Rocheleau, Thomas-Slayter, & Wangari, 1996). While most development efforts now seek to include women, there has been insufficient attention to the underlying social, economic, and political systems that create and perpetuate inequalities (Harcourt, 2016). This research intentionally seeks to break apart the household and examined gender-differentiated experiences with modern, 'gender-inclusive' development efforts.

Despite decades of investment by the international community and national governments, poverty and food insecurity in Africa persist. This failure demands critical reevaluation of priorities in and approaches to agriculture and rural development that have often been dictated to Africans by foreign governments, experts, and philanthropists. This dissertation offers new empirical evidence to support that reevaluation. While focused on farmer livelihoods and development practices in Senegal, the findings have implications for the broader West African and sub-Saharan African region. Smallholders' experiences in this semi-arid and highly variable environment have particular relevance as climate change threatens to make farming in much of Africa more marginal.

Study site

A coastal West African country, Senegal sits at the intersection of the semi-arid Sahel and sub-humid tropics, of northern and sub-Saharan African cultures, and of agricultural and pastoral livelihood traditions. In the decades since independence, Senegal has earned a reputation for stability and peaceful democratic elections. However, its lagging progress in addressing poverty and hunger have led its Human Development Index Ranking to drop in recent years, falling to 166 in 2019 (UNDP, 2019). These factors make Senegal a frequent target of development funding in West Africa—it received approximately U.S. $991 million in official development assistance (ODA) in 2018 (World Bank, 2018c), and among Sahelian countries, its per capita ODA is surpassed only by Mali and Mauritania (World Bank, 2018b). As such, Senegal represents a useful bellwether through which to examine rural development processes in the broader West African region.

Senegalese agricultural development

Senegal's agricultural and pastoral traditions have been traced back well into pre-colonial times (e.g., Carney, 2001), but its modern agricultural priorities and policies were heavily shaped by French rule. Senegalese farms became important contributors to the French economy as peanut (groundnut) and peanut oil were heavily promoted by and exported to an industrializing France in the nineteenth and twentieth centuries. The expansion of peanut production encouraged seasonal and permanent migration of wage laborers to central and western Senegal, boosting populations in these regions and across the territory that would become an independent Senegal (Bernards, 2019).

In the post-independence era, Senegalese economic and agricultural policies perpetuated state-centric models adopted under French rule, rebranding them to align with African socialist priorities of centralization and nationalization (Oya, 2006). Economic development priorities under Senegal's first president, Léopold Sédar Senghor, focused largely on the agricultural sector and the peasantry. The 1960s-1970s saw substantial government investment in the sector, including establishment of national agronomic research institutions, cooperatives and extension networks, state marketing boards, a subsidized credit system managed through a national development bank, and input distribution channels. The *Programme Agricole*, officially launched in 1957, promoted mechanization, spatial expansion of cultivation, and increased yields. However, amid the loss of France's preferential prices for groundnuts in the late 1960s and severe droughts in the early 1970s, Senghor's government fought to prop up struggling rural livelihoods through price supports and fertilizer subsidies (Oya, 2006). Expanded rice production in the Senegal River Valley became a priority in the wake of these droughts, drawing substantial investment in irrigation infrastructure and other yield-enhancing Green Revolution technologies (Diagne, Demont, Seck, & Diaw, 2013; Krupnik et al., 2012).

The 1980s marked a decided turn in Senegal's agricultural policies. Fiscal imbalances led Senegal, like many countries in the Global South, to seek assistance from international finance institutions and embark on mandated structural adjustment programs. State involvement in the agricultural sector waned and the *Programme Agricole* ground to a halt, along with associated input distributions, subsidies, and extension and credit services. The *Programme Agricole* was supplanted in 1984 by the more neoliberal *Nouvelle Politique Agricole,* which set goals of increased self-sufficiency in cereal production and led to substantial *dis*investment from the Groundnut Basin (Oya, 2001, 2006). At the same time, austerity measures and massive currency devaluation contributed to several waves of rioting (Oya, 2006) with little measurable impact on poverty alleviation (Weissman, 1990).

The 2000s brought renewed focus on state support to agriculture, including a return to input subsidies. Fertilizer subsidies and certified seed subsidies now constitute substantial state investments in the sector (IPAR, 2015), although the strength and stability of seed systems (Mabaya, Ba, Ndiaye, & Mugoya, 2017) and fertilizer supply chains remain obstacles (Diagne et al., 2013). Agriculture and development policies since 2000, including the *Plan National D'Investissement Dans Le Secteur Agricole* associated with CAADP, *Plan Sénégal Émergent*, and *Stratégie Nationale De Développement Economique et Social* have continued to prioritize the agricultural sector, particularly increased use of inputs, value addition, market access, and increased self-sufficiency in cereal production (Benkahla, Ba, & Ndoye Niane, 2011; Food and Agriculture Organization, 2015). Following the 2007-2008 food price crisis, Senegalese agricultural policy placed added emphasis on rice self-sufficiency, leading to further efforts to expand and improve cultivation in the northern Senegal River Valley (Diagne et al., 2013).

In recent decades, Senegal's agricultural sector has remained central to rural livelihoods. Agriculture continues to disproportionately support poor, rural households in Senegal and engages about 70% of the country's labor force in some capacity (Food and Agriculture Organization, 2015). However, some estimates suggest official agricultural employment as a percentage of total employment has been steadily declining since the 1990s, and stood at only 30% in 2019 (World Bank, 2019a), likely related to urbanization and related livelihood diversification. An estimated 15% of Senegal's population engages in internal migration, which provides an important source of income to rural households (Food and Agriculture Organization, 2020a). International migration is also increasingly common; according to World Bank estimates, personal remittances received in Senegal amount to more than double the country's annual ODA and have risen dramatically in recent years (World Bank, 2019b). However, Senegal lacks a clear and cohesive strategy linking migration and development (Food and Agriculture Organization, 2020a). Instead, much focus remains on the agricultural sector, Senegal's fourth most-funded sector for U.S. foreign aid (USAID, 2020), which is seen as an under-exploited engine for broader economic growth (World Bank Group, 2018).

Agroecological conditions

Like many countries in the Sudano-Sahelian zone, Senegal is only marginally suited to rainfed agriculture due to climatic and soil fertility constraints. A single July-September growing season generally accounts for all annual precipitation, with historic seasonal averages ranging from a sparse 220 mm/year average in the north, where the growing period typically spans 66 days, to a more manageable 850 mm/year in the south, where the growing period lasts an average of 107 days (Eldon & Rapaport, 2017). Growing season temperatures largely mirror rainfall patterns but are also affected by proximity to the coast, with the highest temperatures and least rainfall in the inland Northeast. The narrow window for production necessitates careful planning and a certain degree of risk-taking by farmers, as well as timely delivery of farming information and inputs.

Agricultural systems vary as a function of rainfall and temperature gradients, encompassing lowland rice production in river valleys and the rainy southern regions, cereal and groundnut in the central basin, and agropastoral systems in more arid regions. Outside the Senegal River Valley, production is almost exclusively rainfed. Key crops include pearl millet (*Pennisetum glaucum* L.) and grain sorghum (*Sorghum bicolor* L.) – both well-suited to the climate and soil constraints (S. C. Mason, Maman, & Palé, 2015) – as well as peanut/groundnut (*Arachis hypogaea* L.), rice (primarily *Oryza sativa* L., which has largely replaced *Oryza glaberrima* Steud.), cowpea (*Vigna unguiculate* L.), maize *(Zea mays* L.), various vegetables, and sorrel/roselle (*Hibiscus sabdariffa* L.). Parkland savannah agroecosystems are common, especially in northern Senegal, with fields interspersed with diverse *Acacia* species, baobab (*Adansonia digitate* L.), *Faidherbia albida* ((Del.) A. Chev.), mango (*Mangifera indica* L.), shea (*Vitellaria paradoxa* C. F. Gaertn.), neem (*Azadirachta indica*), locust bean (*Parkia biglobosa* (Jacq.) Benth.), and other trees.

Soils in the region are relatively unproductive, with low inherent fertility, limited water holding capacity, and frequently negative nutrient balances that constrain yields (Bationo & Buerkert, 2001; Diop, 1999; Eswaran, Almaraz, Van Den Berg, & Reich, 1997). Bush fallow systems, which historically replenished soil nutrients over years of non-use, are no longer widely feasible; population pressures and intensive cultivation mean that fallowing is both impractical and unlikely to satisfy crop nutrient needs (Bagayoko, Mason, Traore, & Eskridge, 1996; Schlecht & Buerkert, 2004). Crop rotation, particularly millet-groundnut and millet-cowpea rotations, is used in some regions to increase yields, improve soil fertility, and reduce pest and disease pressures (Diop, 1999), but is not thought to be universally practiced (Schlecht, Buerkert, Tielkes, & Bationo, 2006).

Use of inputs, such as improved seeds, organic and inorganic fertilizers, and pesticides, remains modest. Most farmers save seed year to year rather than obtaining certified or improved varieties from reputable dealers (Ndiaye, Audet-Bélanger, & Gildemacher, 2015). Senegal's system for producing and distributing improved and certified seed is weak and plagued by quality control issues, contributing to low yields and disincentivizing farmer investments (Mabaya et al., 2017). Irrigation, while a critical tool in Senegal River Valley rice production, remains scarce elsewhere, covering only 3% of cultivated land nation-wide (World Bank Group, 2018). Despite these constraints, average cereal yields have charted an upward trajectory since the early 2000s (World Bank, 2017), driven largely by substantial gains in paddy rice production and more modest gains in maize yields (Food and Agriculture Organization, 2020b).

Soil fertility management on the region's poor, sandy soils is challenging. Management of soil organic matter is particularly important to improve soils' nutrient holding capacity, water retention, and physical and biological properties (Lal, 2006). The availability of organic inputs is limited, however. Manure production in West

Africa is inadequate to meet crop needs (Fernandez-Rivera, Williams, Hiernaux, & Powell, 1995). Rainfall and nutrient limitations restrict biomass production while grazing livestock, termites, and the tropical climate ensure rapid consumption and decomposition of what vegetation is produced (Bationo & Buerkert, 2001). Crop residues not used for livestock feed, fuel, and building material (S. C. Mason, Ouattara, et al., 2015) are frequently collected and burned in the fields before planting, contributing to low soil organic carbon content (Bationo & Mokwunye, 1991; Enyong, Debrah, & Bationo, 1999). These constraints on organic matter availability also limit the utility of inorganic fertilizers, which are drastically more efficient when used in combination with organic inputs (Aggarwal, Kumar, & Power, 1997; Yamoah, Bationo, Shapiro, & Koala, 2002). Inorganic fertilizers have frequently failed to achieve intended yield gains without accompanying use of organic inputs (Diop, 1999; Mortimore, 2010), while their misuse risks contributing to rapid soil organic matter decomposition and acidification (particularly in the case of urea) (Bationo & Buerkert, 2001).

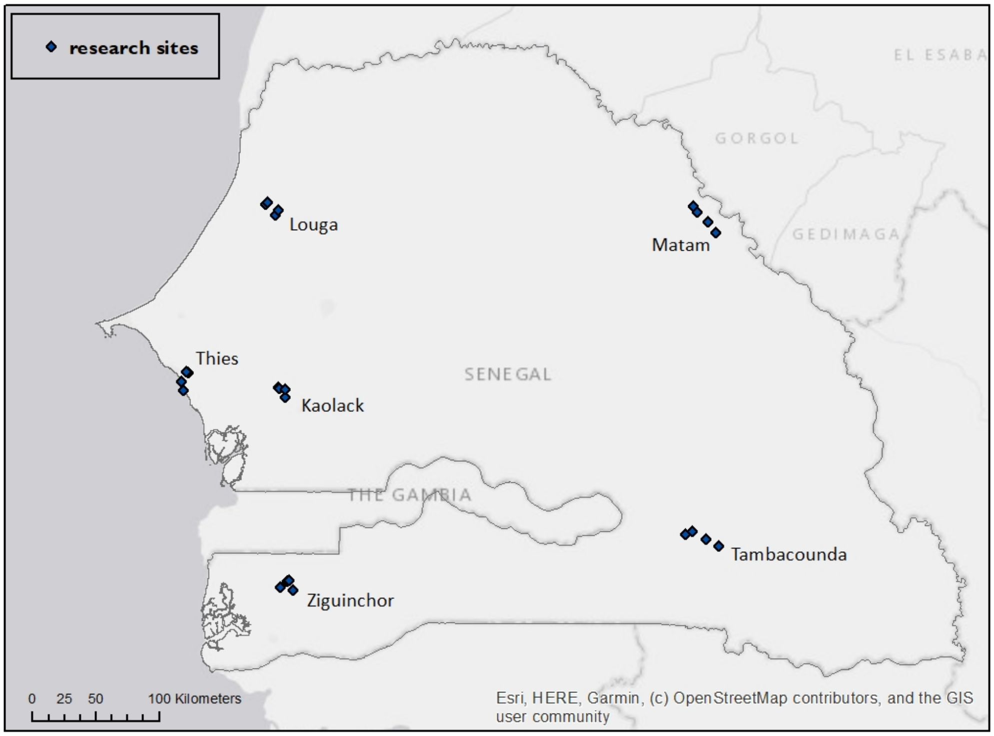

Figure 1. Map of research sites in Senegal.

Data collection for the research that follows was conducted in six regions of Senegal that represent a diversity of agroecosystems (see Figure 1). Kaolack, Thiés, and Louga, populated primarily by Wolof, Serer, and Fula communities, are located in the savannah of central and western Senegal. These regions hosts the greatest concentration of roads and cities in the country (Ross, 2008) and enjoy relatively easy access to Dakar. Matam, Tambacounda, and Ziguichor are more remote. The northeast region of Matam is arguably the most isolated and populated largely by Fula agropastoralists, with relatively little intensively cultivated land (Eldon & Rapaport, 2017). Tambacounda, the least densely populated region in this study and a hub for migrant activity, hosts a relatively large Mandinka population. The final region included in this study, Ziguinchor, is in the southern Casamance region and separated from northern Senegal by The Gambia. While benefitting from more fertile soils and a substantially wetter climate than northern Senegal, Ziguinchor's Diola farmers are impacted by a decades-long regional conflict related to Casamance's autonomy.

Gender dynamics in Senegal

Gender is a key axis of difference that shapes farmers' experiences and behaviors in this setting, making it a central consideration in evaluating differentiated impacts in this study. Senegalese society is predominantly Muslim and often highly patriarchal, even relative to other sub-Saharan African nations; only 14% of Senegalese women aged 15-49 participate in decisions related to their own health care, major household purchases, and visiting family. Roughly 5% of women are estimated to own land, either individually or communally (ANSD/Senegal & ICF, 2017), and nearly half of women farmers surveyed for this study (49%) had received no education, compared to 23% of men.

On the farm, women engage in decision-making primarily for crops grown for household consumption—specifically rice (in regions of Casamance, although men produce rice in the more commercialized Senegal River Valley), cowpea, and vegetables grown at small scale. Men are primary decision-makers for most other crops, including groundnut (often the primary cash crop), millet, sorghum, maize, and large-scale vegetable production. They typically own and control most tools of production (carts, plows, etc.) and in many cases acquire the seeds and farm inputs that women subsequently use. In addition to farming duties, women typically handle the majority of the household work, including cooking, cleaning, carrying water, and childcare. While many women do engage in work outside the home (albeit less commonly than men), their work is more often unpaid (ANSD/Senegal & ICF, 2017).

Research overview

The chapters that follow explore farmer behavior in response to, and in the context of, changing rural circumstances:

Chapter 1. On- and off-farm adaptation in Senegal: understanding differentiation and drivers of farmer strategies. Variable environmental conditions in Sudano-Sahelian West Africa have spurred rainfed smallholder farmers to develop adaptive cropping systems and livelihood strategies. Today, farmers in this region face a wave of intersecting stressors that includes soil fertility loss, increasingly unpredictable rainfall, and growing socioeconomic pressures associated with globalization and cultural change. This study examines farmers' perceptions of environmental and social change in Senegal and the drivers and constraints on their adaptive responses, with particular attention to the interplay of on- and off-farm livelihood strategies. Semi-structured interviews provide insight into individual lived experiences while large-scale survey data and multinomial regression point to broader patterns in perceptions and adaptive strategies. The findings indicate that most

Senegalese farmers perceive substantial environmental change that is amplifying ongoing processes of agrarian change, increasing reliance on off-farm livelihoods and youth migration in particular. While more resource-constrained farmers rely primarily on prayer—likely an expression of limited alternative strategies—those most concerned about weather changes turn to diversified livelihood strategies. This study illustrates an evolving relationship between farmers and off-farm work amid environmental and socioeconomic change in rural Africa, with implications for development initiatives aimed at supporting farmer adaptation to climate change.

Chapter 2. Encouraging technology adoption using ICTs and farm trials in Senegal: lessons for gender equity and scaled impact. Information and communication technologies (ICTs) are generating substantial interest from aid donors and development practitioners, including as tools for agricultural extension. However, empirical evidence of the impact of ICT-enabled extension on farmers' uptake of introduced technologies remains scarce. This four-year study evaluates an ICT-enabled extension project in Senegal using radio and mobile phone services to encourage rural smallholder farmers' use of certified seeds and organic and inorganic fertilizers across Senegal. Data were collected using large-scale annual surveys in six regions over four years as well as focus groups. The findings suggest that, in general, the forms and format of ICT-enabled extension services deployed failed to significantly contribute to the adoption of promoted technologies. Personal connections to participatory farm trials were consistently associated with adoption, and phone-based voice messaging appears to have potential to increase technology uptake. Gender-based disparities in engagement with ICT services and poorly developed systems for producing and distributing quality seeds emerged as key factors limiting the effectiveness of this project. These findings raise concerns about the equity and effectiveness of ICT-enabled extension in promoting agricultural inputs in contexts like Senegal and have important implications for similar efforts in other countries.

Chapter 3. Post-project decision-making: farmer technology use choices in a risky environment. Efforts toward a new Green Revolution in Africa have focused on expanding smallholder farmers' use of improved seeds, fertilizers, and other inputs. Many of the reasons the first Green Revolution failed to take hold in Africa, including agroecosystem complexity, poorly-suited seed technologies, poor infrastructural and market development, and technology costs (Evenson & Gollin, 2003), remain potential obstacles to uptake and retention of 'new' Green Revolution technologies. This study is a post-intervention follow-up examining farmers' use of and decision-making around introduced seed and fertilizer technologies two years after their participation in farm trials. Using surveys, participatory resource allocation mapping, and soil sampling in three regions of Western Senegal, I explore retention and disadoption of improved seeds and fertilizers in the context of heterogeneous and high-risk farm conditions. Findings suggest that farmer decisions to disadopt seed technologies are often involuntary and related to environmental risk. Additionally, most active farmer decisions were oriented toward risk management rather than maximizing productivity. Both outcomes suggest that promoting seeds through small-scale farm trials may be inadequate to achieve sustained adoption, and that these technologies do not contribute adequately to the resilience of smallholder farms in Senegal.

References

Aggarwal, R. K., Kumar, P., & Power, J. F. (1997). Use of crop residue and manure to conserve water and enhance nutrient availability and pearl millet yields in an arid tropical region. *Soil and Tillage Research*, *41*(1–2), 43–51. https://doi.org/10.1016/S0167-1987(96)01082-3

Agrawal, A. (1995). Dismantling the Divide Between Indigenous and Scientific Knowledge. *Development and Change*, *26*, 413–439.

Altieri, M. A. (2002). Agroecology: The science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems and Environment*, *93*(1–3), 1–24. https://doi.org/10.1016/S0167-8809(02)00085-3

ANSD/Senegal & ICF. (2017). *Senegal: Enquête Démographique et de Santé Continue [Demographic and Health Survey, Senegal]*. Retrieved from https://dhsprogram.com/publications/publication-FR345-DHS-Final-Reports.cfm

Bagayoko, M., Mason, S. C., Traore, S., & Eskridge, K. M. (1996). Pearl millet/cowpea cropping system yields and soil nutrient levels. *African Crop Science Journal*, *4*(4), 453–462. Retrieved from https://tspace.library.utoronto.ca/html/1807/20979/cs96086.html

Bationo, A., & Buerkert, A. (2001). Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, *61*, 131–142.

Bationo, A., & Mokwunye, A. U. (1991). Role of manures and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. *Fertilizer Research*, *29*(1), 117–125. https://doi.org/10.1007/BF01048993

Benkahla, A., Ba, C. O., & Ndoye Niane, A. (2011). *Analyse Du Plan National D'Investissement Dans Le Secteur Agricole Du Senegal*. Retrieved from https://www.ipar.sn/IMG/pdf/ipar-rapport_agriculture-2015-_p_p_.pdf

Bennett, M., & Franzel, S. (2013). Can organic and resource-conserving agriculture improve livelihoods? A synthesis. *International Journal of Agricultural Sustainability*, *11*(January 2015), 193–215. https://doi.org/10.1080/14735903.2012.724925

Bernard, B., & Lux, A. (2017). How to feed the world sustainably: an overview of the discourse on agroecology and sustainable intensification. *Regional Environmental Change*, *17*(5), 1279–1290. https://doi.org/10.1007/s10113-016-1027-y

Bernards, N. (2019). ‘Latent’ surplus populations and colonial histories of drought, groundnuts, and finance in Senegal. *Geoforum*, (August), 0–1. https://doi.org/10.1016/j.geoforum.2019.10.007

Bernstein, H. (2014). Food sovereignty via the ‘peasant way’: a sceptical view. *Journal of Peasant Studies*, *6150*(October), 1–33. https://doi.org/10.1080/03066150.2013.852082

Biovision Foundation for Ecological Development & IPES-Food. (2020). *Money flows: what is holding back investment in agroecological research for Africa?* Retrieved from https://www.agroecology-pool.org/MoneyFlowsreport

Blesh, J., Hoey, L., Jones, A. D., Friedmann, H., & Perfecto, I. (2019). Development pathways toward “zero hunger.” *World Development*, *118*, 1–14. https://doi.org/10.1016/j.worlddev.2019.02.004

Bryceson, D. F. (2002). The scramble in Africa: Reorienting rural livelihoods. *World Development*, *30*(5), 725–739. https://doi.org/10.1016/S0305-750X(02)00006-2

Burnham, M., & Ma, Z. (2016). Linking smallholder farmer climate change adaptation decisions to development. *Climate and Development*, *8*(4), 289–311. https://doi.org/10.1080/17565529.2015.1067180

Carney, J. A. (2001). *Black Rice: The African Origins of Rice Cultivation in the Americas*. Cambridge: Harvard University Press.

Caron, P., Biénabe, E., & Hainzelin, E. (2014). Making transition towards ecological intensification of agriculture a reality: The gaps in and the role of scientific knowledge. *Current Opinion in Environmental Sustainability*, *8*, 44–52. https://doi.org/10.1016/j.cosust.2014.08.004

Cassman, K. G. (1999). Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proceedings of the National Academy of Sciences*, *96*(11), 5952–5959. https://doi.org/DOI 10.1073/pnas.96.11.5952

Collier, P., & Dercon, S. (2014). African Agriculture in 50 Years: Smallholders in a Rapidly Changing World? *World Development*, *63*(June 2009), 92–101. https://doi.org/10.1016/j.worlddev.2013.10.001

Crane, T. A., Roncoli, C., & Hoogenboom, G. (2011). Adaptation to climate change and climate variability: The importance of understanding agriculture as performance. *NJAS - Wageningen Journal of Life Sciences*, *57*(3–4), 179–185. https://doi.org/10.1016/j.njas.2010.11.002

Darnhofer, I., Bellon, S., Dedieu, B., & Milestad, R. (2010). Adaptiveness to enhance the sustainability of farming systems. A review. *Agronomy for Sustainable Development*, *30*(3), 545–555. https://doi.org/10.1051/agro/2009053

DeLonge, M. S., Miles, A., & Carlisle, L. (2016). Investing in the transition to sustainable agriculture. *Environmental Science and Policy*, *55*, 266–273. https://doi.org/10.1016/j.envsci.2015.09.013

Diagne, M., Demont, M., Seck, P. A., & Diaw, A. (2013). Self-sufficiency policy and irrigated rice productivity in the Senegal River Valley. *Food Security*, *5*(1), 55–68. https://doi.org/10.1007/s12571-012-0229-5

Diop, A. M. (1999). Sustainable agriculture: New paradigms and old practices? Increased production with management of organic inputs in Senegal. *Environment, Development and Sustainability*, *1*(3–4), 285–296. https://doi.org/10.1023/A:1010026922142

Eldon, J., & Rapaport, P. (2017). *Rural Livelihood Atlas of Senegal, The Gambia and Guinea-Bissau*. Hartford, UK.

Enyong, L. A., Debrah, S. K., & Bationo, A. (1999). Farmers' perceptions and attitudes towards introduced soil-fertility enhancing technologies in western Africa. *Nutrient Cycling in Agroecosystems*, *53*(2), 177–187. https://doi.org/10.1023/A:1009745225465

Eswaran, H., Almaraz, R., Van Den Berg, E., & Reich, P. (1997). An assessment of the soil resources of Africa in relation to productivity. *Geoderma*, *77*(1), 1–8. https://doi.org/10.1016/S0016-7061(97)00007-4

Evenson, R., & Gollin, D. (2003). Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*, *300*(5620), 758–762.

Fernandez-Rivera, S., Williams, T. O., Hiernaux, P., & Powell, J. M. (1995). Faecal excretion by ruminants and manure availability for crop production in semi arid West Africa. In J. M. Powell, S. Fernandez-Rivera, T. O. Williams, & C. Renard (Eds.), *Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of Sub-Saharan Africa* (Vol. 2, pp. 393–409). International Livestock Centre for Africa (ILCA).

Food and Agriculture Organization. (2015). *Country Fact Sheet on Food and Agriculture Policy Trends: Senegal*. https://doi.org/10.1787/g22233cef7-en

Food and Agriculture Organization. (2020a). *Characteristics , patterns and drivers of rural migration in Senegal*. Rome. https://doi.org/https://doi.org/10.4060/ca2510en

Food and Agriculture Organization. (2020b). FAOSTAT. Retrieved August 18, 2020, from http://www.fao.org/faostat/en/#home

Fortmann, L. C. (1990). Women's role in small farm agriculture. In M. A. Altieri & S. B. Hecht (Eds.), *Agroecology and Small Farm Development* (pp. 35–43). CRC Press.

Godfray, H. C. J., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., … Toulmin, C. (2010). Food Security: The Challenge of Feeding 9 Billion People. *Science*, *327*(February), 812–818. https://doi.org/10.4337/9780857939388

Harcourt, W. (2016). Gender Dilemmas in International Development Studies. *European Journal of Development Research*, *28*(2), 167–174.

IAASTD. (2009). *Agriculture at a Crossroads: Executive Summary of the Synthesis Report*. https://doi.org/citeulike-article-id:7871710

IPAR. (2015). *Subventions des intrants agricoles au Sénégal : Controverses et Réalités*. Dakar. Retrieved from https://www.ipar.sn/IMG/pdf/ipar-rapport_agriculture-2015-_p_p_.pdf

Jansen, K. (2015). The debate on food sovereignty theory: agrarian capitalism, dispossession and agroecology. *The Journal of Peasant Studies*, *42*(1), 213–232. https://doi.org/10.1080/03066150.2014.945166

Jayne, T. S., Mather, D., & Mghenyi, E. (2010). Principal Challenges Confronting Smallholder Agriculture in Sub-Saharan Africa. *World Development*, *38*(10), 1384–1398. https://doi.org/10.1016/j.worlddev.2010.06.002

Krupnik, T. J., Shennan, C., Settle, W. H., Demont, M., Ndiaye, A. B., & Rodenburg, J. (2012). Improving irrigated rice production in the Senegal River Valley through experiential learning and innovation. *Agricultural Systems*, *109*(2012), 101–112. https://doi.org/10.1016/j.agsy.2012.01.008

Lal, R. (2006). Enhancing crop yields in the developing countries through restoration of the soil organic carbon pool in agricultural lands. *Land Degradation and Development*, *17*(2), 197–209. https://doi.org/10.1002/ldr.696

Mabaya, E., Ba, M. M. D., Ndiaye, M., & Mugoya, M. (2017). *Senegal Brief 2017 - The African Seed Access Index*. Retrieved from https://tasai.org/wp-content/themes/tasai2016/img/tasai_brief_2017_senegal_final_lr.pdf

Mason, S. C., Maman, N., & Palé, S. (2015). Pearl Millet Production Practices in Semi-Arid West Africa: A Review. *Experimental Agriculture*, *51*(4), 501–521.

https://doi.org/10.1017/S0014479714000441

Mason, S. C., Ouattara, K., Taonda, S. J. B., Palé, S., Sohoro, A., & Kaboré, D. (2015). Soil and cropping system research in semi-arid West Africa as related to the potential for conservation agriculture. *International Journal of Agricultural Sustainability*, *13*(2), 120–134. https://doi.org/10.1080/14735903.2014.945319

Mitchell, T. (2002). *Rule of Experts: Egypt, Techno-politics, Modernity*. Berkeley: University of California Press.

Mortimore, M. (2010). Adapting to drought in the Sahel: Lessons for climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(1), 134–143. https://doi.org/10.1002/wcc.25

Ndiaye, M., Audet-Bélanger, G., & Gildemacher, P. (2015). *Scaling Seeds & Technologies Partnership – Baseline phase II*. Retrieved from www.kit.nl

Netting, R. (1993). *Smallholder, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture*. Stanford: Stanford University Press.

Oya, C. (2001). Large and Middle-scale Farmers in the Groundnut Sector in Senegal in the Context of Liberalization and Structural Adjustment. *Journal of Agrarian Change*, *1*(1), 124–163. https://doi.org/10.1111/1471-0366.00005

Oya, C. (2006). From State Dirigisme to Liberalisation in Senegal: Four Decades of Agricultural Policy Shifts and Continuities. *The European Journal of Development Research*, *18*(2), 203–234. https://doi.org/10.1080/09578810600708163

Patel, R. (2013). The Long Green Revolution. *The Journal of Peasant Studies*, *40*(1), 1–63. https://doi.org/10.1080/03066150.2012.719224

Patel, R., Bezner Kerr, R., Shumba, L., & Dakishoni, L. (2015). Cook, eat, man, woman: understanding the New Alliance for Food Security and Nutrition, nutritionism and its alternatives from Malawi. *The Journal of Peasant Studies*, *42*(1), 21–44. https://doi.org/10.1080/03066150.2014.971767

Pimbert, M. P., & Moeller, N. I. (2018). Absent agroecology aid: On UK agricultural development assistance since 2010. *Sustainability (Switzerland)*, *10*(2). https://doi.org/10.3390/su10020505

Ponisio, L. C., & Ehrlich, P. R. (2016). Diversification, Yield and a New Agricultural Revolution: Problems and Prospects. *Sustainability*, *8*(1118), 1–15. https://doi.org/10.3390/su8111118

Pretty, J. N., Noble, A. D., Bossio, D., Dixon, J., Hine, R. E., Penning de Vries, F. W. T., & Morison, J. I. L. (2006). Resource-Conserving Agriculture Increases Yields in Developing Countries. *Environmental Science & Technology*, *40*(4), 1114–1119. https://doi.org/10.1021/es051670d

Raynaut, C. (2001). Societies and nature in the Sahel: Ecological diversity and social dynamics. *Global Environmental Change*, *11*(1), 9–18. https://doi.org/10.1016/S0959-3780(00)00041-8

Rigg, J. (2006). Land, Farming, Livelihoods, and Poverty: Rethinking the Links in the Rural South. *World Development*, *34*(1), 180–202. https://doi.org/10.1063/1.2756072

Rocheleau, D. E., Thomas-Slayter, B., & Wangari, E. (1996). Gender and Environment: A feminist political ecology perspective. In D. E. Rocheleau, B. Thomas-Slayter, & E. Wangari (Eds.), *Feminist Political Ecology: Global Issues and Local Experience* (pp. 3–26). New York: Routledge. https://doi.org/10.1017/CBO9781107415324.004

Ross, E. S. (2008). *Culture and Customs of Senegal*. Westport, CT: Greenwood Press.

Schlecht, E., & Buerkert, A. (2004). Organic inputs and farmers' management strategies in millet fields of western Niger. *Geoderma*, *121*(3–4), 271–289. https://doi.org/10.1016/j.geoderma.2003.11.015

Schlecht, E., Buerkert, A., Tielkes, E., & Bationo, A. (2006). A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, *76*(2–3), 109–136. https://doi.org/10.1007/s10705-005-1670-z

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, *16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-kerr, R., & Kanyama-phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences*, *107*(48), 20840–20845. https://doi.org/10.1073/pnas.1007199107

UNDP. (2019). 2019 Human Development Index Ranking. Retrieved July 16, 2020, from http://hdr.undp.org/en/content/2019-human-development-index-ranking

USAID. (2020). Foreign Aid Explorer - Senegal. Retrieved July 11, 2020, from https://explorer.usaid.gov/cd/SEN

Weissman, S. R. (1990). Structural adjustment in Africa: Insights from the experiences of Ghana and Senegal. *World Development*, *18*(12), 1621–1634. https://doi.org/10.1016/0305-750X(90)90059-7

World Bank. (2017). Cereal yield (kg per hectare) - Senegal. Retrieved July 11, 2020, from https://data.worldbank.org/indicator/AG.YLD.CREL.KG?locations=SN-ZG-1W-XM

World Bank. (2018a). Net ODA received per capita (current US$) - Senegal, Mauritania, Chad, Niger, Nigeria, Mali, Burkina Faso. Retrieved August 18, 2020, from https://data.worldbank.org/indicator/DT.ODA.ODAT.PC.ZS?locations=SN-MR-TD-NE-NG-ML-BF

World Bank. (2018b). Net official development assistance received (current US$) - Senegal. Retrieved July 11, 2020, from https://data.worldbank.org/indicator/DT.ODA.ODAT.CD?contextual=region&locations=SN

World Bank. (2019a). Employment in agriculture (% of total employment) - Senegal. Retrieved July 11, 2020, from https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=SN

World Bank. (2019b). Personal remittances, received (current US$) - Senegal.

World Bank Group. (2018). *Systematic Country Diagnostic of Senegal*. https://doi.org/10.1596/30852

Yamoah, C. F., Bationo, A., Shapiro, B., & Koala, S. (2002). Trend and stability analyses of millet yields treated with fertilizer and crop residues in the Sahel. *Field Crops Research*, *75*(1), 53–62. https://doi.org/10.1016/S0378-4290(02)00008-4

Chapter 1. On- and off-farm adaptation in Senegal: understanding differentiation and drivers of farmer strategies

Abstract

Variable environmental conditions in Sudano-Sahelian West Africa have spurred rainfed smallholder farmers to develop adaptive cropping systems and livelihood strategies. Today, farmers in this region face a wave of intersecting stressors that includes soil fertility loss, increasingly unpredictable rainfall, and growing socioeconomic pressures associated with globalization and cultural change. This study examines farmers' perceptions of environmental and social change in Senegal and the drivers and constraints on their adaptive responses, with particular attention to the interplay of on- and off-farm livelihood strategies. Semi-structured interviews provide insight into individual lived experiences while large-scale survey data and multinomial regression point to broader patterns in perceptions and adaptive strategies. The findings indicate that most Senegalese farmers perceive substantial environmental change that is amplifying ongoing processes of agrarian change, increasing reliance on off-farm livelihoods and youth migration in particular. While the most resource-constrained farmers rely primarily on prayer—likely an expression of limited alternative strategies—those most concerned about weather changes turn to diversified livelihood strategies. This study illustrates an evolving relationship between farmers and off-farm work amid environmental and socioeconomic change

in rural Africa, with implications for development initiatives aimed at supporting farmer adaptation to climate change.

Keywords

livelihoods, adaptation, climate change, rainfall variability, farmer perceptions, gender

Introduction

The late 20th and early 21st century have wrought drastic change in the lives and livelihoods of smallholder farmers in the Global South. Globalization and policy liberalization have pulled rural farmers into global markets, reshaped local production practices, and restructured livelihood priorities. Meanwhile, climate change threatens to exacerbate the vulnerabilities of smallholder systems in Africa (Niang et al., 2014) as expanded educational opportunities and physical mobility broaden non-agricultural career possibilities for rural youth. In combination, these pressures on rural livelihoods motivate continuous adaptation of smallholder farming systems.

Adaptation is frequently associated with the growing threat of climate change but is not a novel concept for rural households, whose dynamic farming practices and livelihood strategies are embedded in complex socioeconomic, political, and environmental histories (Burnham & Ma, 2016; Crane et al., 2011; Raynaut, 2001; Smit & Wandel, 2006). This is especially true in Sudano-Sahelian West Africa, where historic climate variability has driven the development of unique cropping arrangements and flexible livelihood systems, including integrated livestock systems and dry-season migration traditions (Crane et al., 2011; Mortimore, 2010; Mortimore & Adams, 2001; Reenberg, 2009).

While ongoing and projected climate change is not the sole instigator of adaptation in such a dynamic system, it provides a compelling reason to study farmers' ongoing adaptive efforts. Efforts to support farmer adaptation are most effective when grounded in an understanding of past and current adaptative processes (Below, Artner, Sieber, & Stefan, 2010; Crane et al., 2011; Mortimore, 2010). Particularly informative are farmer practices in dryland regions like Sudano-Sahelian West Africa, where a harsh and variable environment has accelerated rainfed farmers' adaptive processes. This study examines adaptation in Senegal, with particular attention to the interplay of on- and off-farm strategies, in order to help align policies and programs with farmers' needs and priorities as climate change pushes existing systems to their limit.

Theory

Characterizing and classifying adaptations

Although scholars acknowledge the intersecting impacts of environmental change, globalization, and resulting socioeconomic change (O'Brien & Leichenko, 2000; Thomas, Twyman, Osbahr, & Hewitson, 2007), climate change remains the primary locus around which adaptation is studied and adaptation funding is allocated. Thus, this study uses the IPCC's definition of climate change adaptation in human systems as a baseline: “the process of adjustment to actual or expected *climate* and its effects, in order to moderate harm or exploit beneficial opportunities” (2018). This definition is expanded to include adjustments to actual or expected *non-climate* impacts, as socioeconomic and market conditions are often found to be of greater concern to individuals and households than weather and climate (Berrang-Ford, Ford, & Paterson, 2011; Mertz, Mbow, Reenberg, & Diouf, 2009; Ostwald & Chen, 2006; Tucker, Eakin, & Castellanos, 2010). Such adaptation occurs at a range of scales, but this study focuses on the household and individual level.

Farmer responses to perceived changes are studied using a range of frameworks. Many scholars distinguish between coping strategies, defined as short-term, typically reversible responses to immediate threats, and adaptations, which reflect long-term and more permanent responses to change (Brockhaus, Djoudi, & Locatelli, 2013; Tucker et al., 2010). The coping-adaptation dichotomy is contested, however, in large part because the boundary is typically fluid; farmers themselves rarely distinguish between the two, particularly in dynamic livelihood contexts like the Sahel (Agrawal, 2009; Burnham & Ma, 2016; Mortimore, 2010). Similarly blurred are distinctions between proactive (*ex ante*) and reactive (*ex post*) strategies—the former theoretically oriented toward building individual or household resilience in anticipation of shocks, and the latter describing more immediate, short-term responses (Brockhaus et al., 2013; Cooper et al., 2008; Shiferaw et al., 2014). Of greater use, perhaps, are the Intergovernmental Panel on Climate Change’s definitions of incremental and transformational adaptation (2018), which distinguish between adaptations that maintain the integrity of existing systems and those that fundamentally reshape them, while acknowledging that incremental adaptation measures may become transformational.

In order to support policy and programmatic decision-making aimed at facilitating adaptation, this study characterizes adaptive strategies according to the sectors and resources farmers rely on. Of particular interest are the relative importance of on- and off-farm adaptive strategies, as on-farm measures are the principal focus of climate resilience efforts. While rural households in the developing world often structure their livelihood portfolios around agriculture, diversified livelihoods, including those facilitated by migration, are common (Scoones, 1998). The merits of livelihood diversification are debated—in some contexts, migration and pursuit of off-farm livelihoods are seen as involuntary responses to failing agrarian livelihood systems and as markers of vulnerability (Davies, 1996; Warner & Afifi, 2014). In others, livelihood diversification is an important adaptive tool, enabling rural households to build resilience, manage risk, and/or achieve transformative adaptation in a changing world (A. Dorward et al., 2009; Hampshire & Randall, 1999; Radel, Schmook, Carte, & Mardero, 2017; van der Geest & Dietz, 2004). This study explores the importance of on- and off-farm adaptive strategies in this context, with attention to whether livelihood diversification supports or undermines agricultural livelihoods and rural household wellbeing.

Factors shaping farmer response strategies

Beyond the nature of adaptive strategies themselves, this study seeks to characterize the farmers who employ them in order to identify determinants of farmer choices. Farmers' responses to stressors are known to be shaped by a range of factors, including perceptions of the hazard. Risk perceptions are influenced not only by individuals' exposure to a hazard, but their understanding of that risk and individual and collective attitudes toward it (Cullen, Anderson, Biscaye, & Reynolds, 2018). Spiritual and religious beliefs, for example, have been found to play a role in both perceptions and farmers' determination of appropriate adaptive responses (Artur & Hilhorst, 2012; Schipper, 2010; Smith, Liu, Safi, & Chief, 2014).

Prior research establishes that farmers in many parts of Africa perceive increased variability in climate and weather, including temperature maximums, the timing and intensity of rainfall, and the frequency of droughts, floods, and mid-season dry spells (Bryan, Deressa, Gbetibouo, & Ringler, 2009; Bryan et al., 2013; Thomas et al., 2007). Several studies suggest that perceptions of climate risk and uncertainty are more heavily shaped by recent experiences with variability and extreme events than by long-term trends and averages (Berrang-Ford et al., 2011; Bryant et al., 2000; Ostwald & Chen, 2006; Thomas et al., 2007). Even where farmer perceptions of climate and weather are well-aligned with meteorological data, these perceptions do not necessarily correlate with adaptation decisions—or decisions to adapt at all (Bryan et al., 2009; Bryant et al., 2000; Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009). This underscores that constraints on decision-making are potentially more influential than perceptions of risk in shaping adaptive decisions (Tucker et al., 2010).

Constraints on adaptation are typically measured in terms of adaptive capacity, which describes the ability of actors to mitigate risks, cope with and recover from losses, and benefit from adaptations (Kelly & Adger, 2000). This is shaped by a range of determinants: the availability of technical solutions, distribution of resources and decision-making authority, human capital (such as education), social capital, economic institutions including property rights, and perceptions of exposure to a stressor (Yohe & Tol, 2002). Adaptive capacity is the clearest embodiment of the social and structural conditions underlying vulnerability, as it considers how political economy, resource distribution, and entitlements and capabilities enable or constrain adaptive choices and livelihood decisions (Bebbington, 1999; Bohle, Downing, & Watts, 1994; Kelly & Adger, 2000).

Access to resources and entitlements heavily influences adaptation decisions, necessitating consideration of not only personal wealth, but access to credit, land, government support, and knowledge about climate change and adaptation options (Bryan et al., 2009; Deressa et al., 2009; Downing et al., 2005; Kelly & Adger, 2000; Ziervogel, Bharwani, & Downing, 2006). Micro-level studies in West Africa have illustrated their significance. Yegbemey et al. (2013), working in Benin, found maize farmers' choice of adaptive strategies to be tied to gender, years of farming experience, contact with extension, access to credit, and degrees of land tenure; Brokhaus et. al found links between adaptive strategies and gender, age, and ethnicity in Mali (2013). In South Africa, poor farmers have been shown to lean toward risk-spreading strategies like crop diversification or staggered planting, while better resourced farmers can instead strategize for profit maximization, including through investments in inputs or infrastructure (Ziervogel et al., 2006).

This study adds to the literature on farmer adaptation in several ways. First, it combines large-scale survey data and rich qualitative data to probe two poorly understood areas of adaptation: the intersecting impacts of environmental and socioeconomic change, and evolving relationships between agricultural and non-agricultural livelihoods, including migration, in the context of climate change (Antwi-Agyei, Stringer, & Dougill, 2014; Campbell, 1999; Wiederkehr, Beckmann, & Hermans, 2018). Second, this study analyses perceptions and adaptive strategies during a period of heightened rainfall variability in Senegal. Prior research in this area following several years of average or above-average rainfall underscored that livelihood shifts are linked to multiple stressors, but that farmers attribute these shifts primarily to social, economic, and political factors rather than climate change (Mertz et al., 2009). By examining these interactions in a period of more immediate environmental stress, this study aims to inform the sectoral directions of climate change adaptation efforts, particularly in the semi-arid tropics.

Methods

Study site

Senegal provides a useful bellwether for forecasting the impacts of multiple, intersecting pressures on rural lives and livelihoods in Africa. Agriculture in the West African Sudano-Sahelian zone is relatively marginal due to limited rainfall, which decreases as one moves northward, and soil fertility constraints (Bationo & Buerkert, 2001; Eswaran et al., 1997). The region is also prone to intra- and inter-annual rainfall variability, which present challenges to rainfed farmers who make up the vast majority of Senegal's agricultural base. However, farmers have adapted to this variability over individual lifetimes and across generations (Mortimore & Adams, 2001; Reenberg, 2009). Specialized cropping systems vary as a function of rainfall and temperature, encompassing lowland rice production in river valleys and the rainy southern regions; cultivation of groundnut and drought- and heat-tolerant cereal crops (including pearl millet and sorghum) in the central basin; and agropastoralism in northern arid regions.

Despite environmental constraints, agricultural production demands are substantial and growing in Senegal. While agricultural land area has increased less than 3% from 1961-2017, Senegal's population has more than tripled (Food and Agriculture Organization, 2020b). The percentage of the population living in urban areas doubled in that time, while the proportion of employment in the agricultural sector dropped from 50% in the 1990s to a low of 30% in 2019 (World Bank, 2019a).

In this context, climate change threatens to push farmers' existing adaptations to their limits. West Africa and the Sahel have already seen slightly increased surface temperatures over the 20th century. CMIP5 RCP 4.5 and RCP 8.5, as well as earlier CMIP3 projections, predict warming of 3-6°C above a late-20th century baseline by the end of the 21st century (Niang et al., 2014). Predicted changes in precipitation for West Africa are less certain, but 20th century trends in Senegal show reduced rainfall totals and increased temperatures (Funk et al., 2012; Put, Verhagen, Veldhuizen, & Jellema, 2004). Worryingly, West Africa and the Sahel are feared to face earlier onset of changes than the rest of the continent (Niang et al., 2014).

Interview methods

This study combines semi-structured interviews with broader surveys of farmers to build a rich understanding of farmer perceptions and response strategies. In 2016, 47 semi-structured interviews were conducted with the aid of a translator in three Wolof-speaking regions (Louga, Thiés, and Tambacounda), purposively selected for their varied geoclimatic characteristics and livelihood orientations. Participants were selected from within villages where surveys were conducted using key informant information and snowball sampling to identify long-term village residents. Most participants were interviewed individually, although five interviews involved pairs—generally a parent and adult child. The average age of interviewees was 56, and in total, interviews involved 29 men and 23 women.

Discussions drew on life history interview traditions, focusing first on farmers' perception of changes in the land, lives, and livelihoods in their villages. As needed, interviewees were prompted to discuss environmental changes; the dynamics, opportunities, and constraints that underlie adaptive responses to these changes at the individual and household scale; the role migration and livelihood diversification play in their household livelihood portfolio; and how chosen response pathways impact household dynamics. Interviews were recorded, transcribed, and translated to English, then iteratively coded in Dedoose to explore patterns and discrepancies in farmers' experiences.

Survey methods

While interviews used open-ended methods to understand farmer experiences with multiple stressors, including environmental change, surveys focused on adaptive responses to a central stressor reported in interviews: rainfall disturbance. Two rounds of surveys were conducted in six regions of Senegal (Kaolack, Louga, Matam, Tambacounda, Thiés, and Ziguinchor), which differ in terms of population density, proportion of land dedicated to intensive cultivation, climate, and soil characteristics (Table 1).

Table 1. Regional demographic, climate, and soil characteristics (from Eldon & Rapaport, 2017, based on data from NOAA, Afripop, and AFSIS)

	Pop. density (per km^2)	Land use (% intensive cropland)	Mean annual rainfall on cropland within rainy season (mm)	Mean number of days with rain during rainy season	Mean annual temp (C)	Mean soil organic C on intensive cropland (top 15cm, g/kg)	Mean % sand on intensive cropland (top 15cm)
Kaolack	188	92%	498	57.69	27.5	5.41	78%
Louga	35	43%	320	39.47	27	3.18	81%
Matam	20	12%	367	46.31	28.5	6.18	58%
Tambacounda	17	13%	480	62.42	28.1	8.44	61%
Thiés	280	90%	383	42.62	25.9	4.98	76%
Ziguinchor	78	51%	832	71.73	26.4	15.88	48%

In 2016, 568 farmers (312 men and 256 women) were surveyed. A second survey reached 461 of the same farmers (238 men and 223 women) in 2018. Villages were purposively chosen on the basis of existing relationships with research partners. Village leadership aided in stratified selection of farmers, aiming for equal representation of small-scale, medium-scale, and large-scale farming households. Woman-headed households were intentionally over-sampled (10% of the total sample) to provide insight into differentiated experiences, and the gender of the respondent in men-headed households was selected randomly. A Senegalese research team (comprised of 2 men and 1 woman in 2016, and 3 men in 2018) conducted surveys.

Surveys collected a range of information on assets and intangible capitals that enabled understanding of household resources and entitlements. The first round of surveys captured respondents' hypothetical responses to a multi-year rainfall disturbance as well as each farmer's primary response strategy from among the diversity that most employ. Questions included a list of sixteen common responses to environmental stressors, which were drawn from pilot surveys and the literature, along with an "other" option, from which an additional seven strategies were identified. Drawing on interview findings, adaptations identified through the surveys were categorized as production-oriented, livelihood and asset diversification-oriented, survival-oriented, and faith-oriented (Table 3). Follow-up surveys captured whether individuals had perceived changes in rainfall and soil fertility over the course of their lifetime, the nature of those changes, and the farmers' degree of concern about those changes.

Multinomial regression models were applied to survey data to validate qualitative findings and evaluate the relative importance of risk perceptions and adaptive capacity in shaping adaptive behaviours. Categories of farmers' primary ('most important') adaptive strategies were treated as possible outcomes (Table 3). Demographic factors associated with adaptation decisions in similar studies (Bryan et al., 2009, 2013; Deressa et al., 2009; Tucker et al., 2010; Yegbemey et al., 2013) were included as covariates—specifically, respondents' gender and age, reported degree of land ownership, frequency of crop sales (a proxy for commercialization), access to credit, and reported household size. Inclusion of a 'region' variable led to quasi-complete separation, so it was removed from the model. The predictive power of the regression model with and without variables reflecting farmers' degree of concern about changes in rainfall and soil fertility and perceptions of interannual yield variability were compared. The model combining demographic factors and risk perceptions showed greater predictive power (AIC of 1068) than the model containing demographic variables alone (AIC of 1801). As such, the reported results (Table 4) reflect the model with both sets of covariates. Regression analysis was performed on 362 cases with complete data on the specified predictors. As on-farm adaptations are a reasonable expectation for individuals identifying as farmers, production-based strategies were used as the reference category.

Results & Discussion

Perceptions of change

Survey and interview data indicate that the social and environmental context of rural agriculture in Senegal is shifting. Some of the most pronounced changes are environmental, linked to changing rainfall patterns and declining soil fertility. Equally profound, in the eyes of farmers, are social and political-economic changes impacting both the viability of agricultural livelihoods and rural social structures.

Environmental change perceptions

Although climate change as a broader concept is relatively unknown, the majority of study participants recognized that the weather they experience has changed. When prompted to discuss weather changes experienced over the course of their lifetime, less than 2% of survey respondents reported no changes, and many reported experiencing multiple shifts. The most commonly described changes related to rainfall, which 98% of farmers surveyed raised as a concern, while increased temperatures were reported by 28% (Table 2). Three in five farmers said that the seasonal rains on which they depend now arrive later than they used to, and over a third cited reduced annual precipitation totals. Similar observations emerged from interviews across the study area. "Before, there used to be a rainy season for four months but now, it's no longer four months. Now it's only two and half or three months. The rain stops when the plants are at the peak of their growth," a 60-70 year old man in Thiés described. Farmers' trepidation about observed changes was notable, with 79% of those surveyed reporting that weather changes cause them 'a lot' of concern. Concerns were substantially higher in the two hottest and driest regions (97% in Louga and 92% in Matam), which have historically experienced the shortest rainy seasons and lowest seasonal precipitation totals, and where late arriving rainfall was most frequently observed in this study.

Table 2. Proportion of survey respondents (2018) reporting changed weather conditions over their lifetimes. Changes reported by less than 5% of respondents are excluded.

Late arriving rainfall	60%
Interannual variability in rainfall	55%
Less overall rainfall	37%
Early ending rainfall	36%
More dry spells mid-season	28%
Hotter weather	28%
No changes	2%

Interviews made clear that these perceptions are not only widespread, but a foremost preoccupation. In over half of conversations (n = 29), farmers brought up rainfall concerns without prompting within broader discussions of the viability of agricultural livelihoods. Most farmers who broached the subject themselves reported noticeable changes in rainfall patterns over the course of their lifetime rather than just variability.

In recognition that extreme events and recent trends have greater influence over farmer perceptions than long-term patterns (Berrang-Ford et al., 2011; Bryant et al., 2000; Thomas et al., 2007), surveys asked farmers about the time period they associated with observed changes in weather. The frequency of "unsure" responses (30%) and evident uncertainty in interviews indicate that not all farmers are comfortable speaking to this. Of those who did offer an estimate, 59% indicated that they had observed changes in the weather within the last 10 years, and 33% within the last 1-2 years. Extensive perceptions of worsening conditions are perhaps unsurprising, in light of this; recent experiences with variable and below-average rainfall—including the 2011, 2014, 2015, and 2017 growing seasons—may have fostered a sense of drastic change. This potentially explains why rainfall emerged as a key stressor in this study, even without prompting by the research team, to a greater degree than in prior research in Senegal conducted following years of average or above-average rainfall (Mertz et al., 2009; Tschakert, 2007).

Interviews underscored that problems of rainfall and soil fertility are difficult to separate in Sahelian landscapes. Interviewees in all three regions, and particularly in Louga, reported that their soil was dead or dying (in Wolof, variations of "souf sou dé sii"). Many tied the concept of dead soil to declining crop yields, a lack of fertilizers, and the wearing out of the land through continuous cultivation and reduced fallowing, and others to increasing pest pressures and a lack of rainfall. "From what I remember [from my youth], farming was good… it was productive….” said an elderly woman in Louga, “but that time is different from today because of lack of water…. You know when there is no water, the place where [peanut] is supposed to ripen doesn’t receive water so the nuts get spoilt – they don’t receive the nutrients they need to grow.” Farmers’ comments indicating that the quality of the soil depends on the rain may suggest that rainfall concerns supersede concerns about soil fertility, or that separating the two sets of concerns is immaterial.

Survey data indicate that 56% of farmers surveyed had observed declining soil fertility over their lifetimes, while 30% reported increased fertility. Regional variation in farmer perceptions of soil fertility change was dramatic (Figure 2). Observations of declining soil fertility were most common in Kaolack (95% of respondents) and Louga (81% of respondents), while a majority of farmers surveyed in Matam (58%) noted that the fertility of their soil had improved over the course of their lifetime. Heightened observations of declining fertility do not clearly align with regional soil organic matter levels or sand concentrations, but instead appear in regions with the highest population densities and extent of cultivated land (Table 1, from Eldon & Rapaport analysis of AFSIS and Afripop data (2017)). In this sense, survey data corroborate interview findings in suggesting that loss of soil fertility may be associated with heightened pressures on farmland and reduced opportunities to fallow exhausted fields.

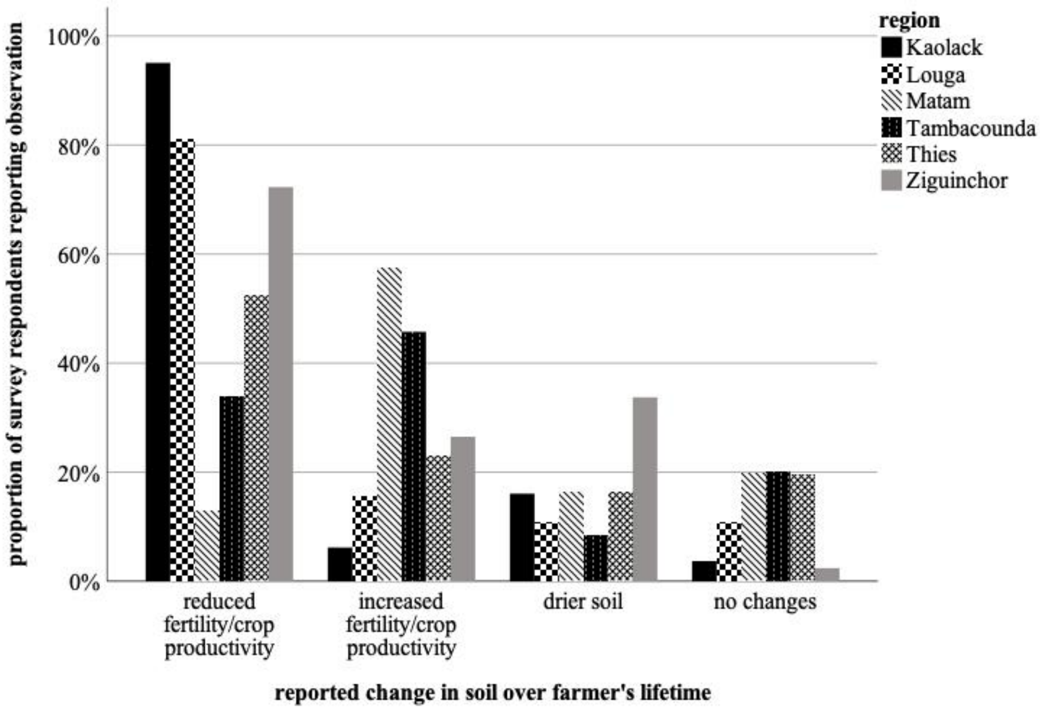

Figure 2. Regional variation in farmer perceptions of soil fertility change. Changes reported by less than 5% of respondents are excluded

"There are a lot of wants today": socioeconomic changes impacting farmers and youth

While environmental changes were brought up unprompted in most interviews, these changes were typically discussed in connection with broader social and economic pressures. Farmers stressed that modest improvements to farming over their lifetimes, including increased mechanization and the availability of new inputs, have generally failed to mitigate the declining viability of agricultural livelihoods. Stagnant yields were linked to both environmental and socioeconomic constraints, including problems accessing inputs (sometimes explicitly tied to reduced state support) and increasing conflict with pastoralists and protected areas.

Furthermore, expectations for rural lives have clearly changed since the pre-globalization era, contributing to pressures farmers face. “There are a lot of wants today,” a middle-aged woman in Thiés summarized. “Before, what you harvested was what you ate. But now, you try to get what you didn’t grow.... The change is the different lifestyle.” The rising cost of rural living, tied to standards for housing, increased education, dietary shifts from millet to rice, and reduced purchasing power (perhaps related to the 1994 currency devaluation), have been felt acutely in rural households. Changing expectations have contributed to a growing sense of individual responsibility and desire for personal accumulation among youth. “The youth are working hard because now, when the young men want to marry, they work so they can get a room for their new wife whereas before, you wouldn’t worry about where to put her. They also want to have their own toilets and kitchen and before that didn’t exist,” explained a middle-aged woman in Louga. Youth migration is not only accepted now, several explained, but expected, given the aspirations of young people. “When we miss [children who leave the village], there are phones and we can call them and know what they are up to. If they were here, they would want something they could not get,” one elderly man in Louga explained. Despite mounting challenges associated with agricultural livelihoods and the ‘rural exodus’ of youth, many farmers reported feeling greater stability than in the past, indicating that coping strategies have enabled them to weather these pressures.

Responding to intersecting stressors: farmers' adaptive decisions and constraints

Interviews showed broad patterns in adaptation that encompass on-farm production-oriented strategies, strategies oriented toward livelihood and asset diversification, faith-oriented strategies, and survival-oriented strategies (often based in reciprocity, common pool resources, or transient livelihood diversity (Dzanku, 2015)). These discussions, and prior work by Davies (1996) and others, aided in categorization of farmers' survey responses. Table 3 lists the breadth of responses to a hypothetical multi-year rainfall disturbance that farmers reported they would employ. Surveys also invited farmers to select the *most important* adaptive strategy from among the measures they employ; prayer emerged as the most common response (chosen by 24% of respondents), followed by engagement in seasonal work (16%) and varietal diversification (10%).

Table 3. Proportion of farmers employing each adaptive strategy in response to multiple years of poor rainfall, in total and disaggregated by gender. Multiple responses were allowed. Responses reported by <2% of respondents were excluded.

adaptation category	**strategy**	**overall**	**women**	**men**
production-oriented	plant in multiple cycles / staggered planting	10%	13%	7%
	plant earlier	2%	2%	3%
	plant fewer fields	2%	2%	1%
	diversify crops	18%	21%	16%
	diversify varieties of crops	25%	23%	26%
	market gardening	4%	4%	4%
	plant more fields	3%	2%	3%
diversification-oriented	household member works seasonally for pay	22%	19%	24%
	petty trade	5%	8%	2%
	other livelihoods (in village)	4%	1%	6%
	household member migrates long-term or permanently	4%	4%	4%
	sell off assets (e.g., livestock)	17%	15%	19%
	borrow money from bank/coop/institution	2%	5%	4%
survival-oriented	borrow money from friends/family	11%	16%	7%
	gather wild foods	10%	8%	11%
	sell foraged goods	2%	2%	3%
faith-oriented	pray	33%	30%	36%
	other	2%	2%	3%

Production-based adaptation: "When the rain is little, you can also only do little."

On-farm adaptive strategies described in interviews focused on two goals: increasing production to boost food availability and household income, and reducing risks associated with changing rainfall patterns and declining soil fertility. Farmer commentary highlighted the potential for these two goals to work at cross-purposes. Rising production demands, linked in farmers' eyes to rural population growth and declining yields, have constrained fallowing practices long used to maintain soil fertility. Further, pressures to increase production are leading farmers to cultivate marginal and mixed-use lands, bringing them into conflict with herders, land developers, and protected areas bordering farmland. Localized pressures of population growth, development, and conservation, combined with growing production demands at the national and global level, are driving many farmers to respond to declining farm profitability by intensifying production in ways that contribute to soil fertility loss and conflict.

On-farm adaptive strategies aimed at risk reduction focused largely on crop choices, and especially farmers' views toward specialty crops—watermelon in Louga and cotton in Tambacounda. Unpredictable rainfall had reportedly forced many farmers out of high-risk crop production; "When the rain is little, you can also only do little… it is only about 1 or 2 people who still cultivate [watermelon] because we are scared of risking it now. The water and the costs it needs are too much," explained a middle-aged man in Louga. The loans required to obtain inputs for these crops are viewed as increasingly risky as rainfall becomes more variable. "I don't see benefits to [growing cotton]. For barely four months of rainy season then you pay all debts, no. At least with rice and peanuts and so on, even if it's not enough at least you have a little to eat," remarked a middle-aged man in Tambacounda. The avoidance of high-risk cash crops signals farmers' focus on risk reduction and resilience rather than productivity maximization, a strategy observed previously in the region (Mortimore & Adams, 2001; Tschakert & Tappan, 2004).

Diversification-based adaptation: "when there is nothing… we send them out to work"

While adaptive strategies based in agricultural production are those most immediately associated with environmental change, discussions of livelihood orientation suggested direct and indirect ties between environmental change, socioeconomic pressures, and farmers' pursuit of off-farm livelihoods. Existing literature has emphasized Sahelian farmers' reliance on off-farm livelihoods that enable them to weather the region's dramatic climate variability (Batterbury & Warren, 2001; Mortimore & Adams, 2001). This study underscores farmers' reliance on livelihood- and asset- diversification, particularly in regions where agriculture is most marginal and the natural resource base least sufficient. Related adaptive strategies include practicing trade skills or petty trade at the local level, engaging in seasonal or long-term migration, and sale of assets, particularly livestock.

Both seasonal labour migration and long-term/permanent migration are widely practiced among households in the study area; across the six regions, 70% of households engaged in one or both forms of migration. However, these activities were infrequently described as explicit responses to rainfall disturbance—only 4% of farmers reported long-term migration as an adaptive response, and 22% of farmers reported turning to seasonal migration. Dry season migration is, by far, the less resource-intensive migration pathway and by nature complementary of agriculture livelihoods. "…Once you start the rainy season, you have to follow through until the very end. And if at the end and despite all your efforts you have nothing, you take your shoes and go find a job somewhere," explained a man in his fifties living near Louga.

Conversations about migration lent support to the argument that its drivers are multi-faceted and entangled with economics, environmental change, and social change. Farmers nearly always identified the lack of economic opportunities in villages and struggling agricultural livelihoods as a central factor in their households' decisions to engage in migration. "Our kids are wandering around in Dakar and other places…. All my children are away, looking for something to do. But if we had materials, they would stay here and farm because we have soil but we don't have the tools.... This is a village of hard workers but we don't have jobs," explained a middle-aged woman living in the Thiés region. Despite the common perception that changing rainfall patterns were impacting harvests, environmental change was rarely cited as the primary motivating factor behind migration. Rather, environmental challenges appear to amplify economic drivers of migration. A young man in the Thiés region, interviewed with his father, remarked:

> *In the 50s and 60s, nobody would think of sending your children outside of the village. You think about farming and feeding your family and your parents. It was in the 90s, when the rains started to change, that the kids were able to say that they want to go to Dakar to find money and the parents were more open to it. They would usually send money and come back during the rainy season to farm with their parents. But now it is more of a necessity to leave to work outside... For instance, after a bad rainy season, your kids have no option but to go outside and find a job so they can help out at home.*

Thus, although migration is infrequently cited as a reactionary response to rainfall disturbance, interview data indicate that livelihood diversification, and particularly youth migration, serves as an increasingly permanent and proactive adaptive strategy to perceived change.

In almost all interviews, farmers viewed engagement in off-farm work, whether local or distant, seasonal or long-term, as a beneficial strategy that enables maintenance of agrarian households facing declining farm profits. Long-term migration of individual family members, while potentially disruptive of on-farm labour and family structures, was here described as a crucial means through which households construct secure and resilient livelihoods (similar to De Haan, 1999; Stark, 1991). Indeed, farmers described young family members as a resource for households to leverage when needed—a reflection of the lingering strength of family and community solidarity. “We are patient and know that God has put this on us and thank him for it. And our children, when there is nothing and no prospect of having anything anytime soon, we send them out to work,” explained an elderly man in the Thiés region. Livelihood- and asset-diversification strategies, rather than undermining agricultural livelihoods, are sustaining rural households through periods of change.

Hustling and prayer: expressions of constrained adaptation options

Constraints to adaptation, while difficult to capture in surveys, came to light in interviews. Particularly striking was many farmers’ reliance on “hustling” rather than discrete adaptive strategies. Hustling, expressed as ‘*se débrouiller’* in French, ‘*hous’* in Wolof (which carries connotations of a chicken scratching and pecking), and through idioms such as the Wolof phrase ‘*goor goor lu’* (an expression of one’s resourcefulness), is associated with hand-to-mouth survival. It evokes a sense of “getting by” by exploiting any and all opportunities, generally in the informal sector, and has typically surfaced in studies of young men in urban areas struggling to climb social ladders (Gaibazzi, 2017; Munive, 2010; Scheld, 2007; Vigh, 2009).

Hustling was described as an activity distinct from employment, but one that plays a key role in sustaining rural families through difficult periods. When asked to explain, farmers described borrowing food or pocket money from friends, neighbours, or extended family members; engaging in petty trade (distinct from selling more valuable assets such as livestock); and collecting and selling or eating foraged goods such as fruit, edible leaves and local tea (*kinkilliba*), timber, bamboo, or incense. Farmers made clear that these activities were generally pursued in the absence of formal employment or larger opportunities for income-earning.

Additional evidence of constrained adaptive options emerged from farmers’ wide reliance on faith-based adaptive tools, which have been infrequently studied in the context of climate change (Artur & Hilhorst, 2012; Schipper, 2010). A third of farmers surveyed here indicated that they turn to prayer in response to rainfall disruption, making it the most popular single adaptive strategy. Among farmers’ *primary* adaptive tools, prayer was more popular than all production-based strategies combined. In interviews, too, farmers described the necessity of appealing to God to resolve their challenges—particularly rainfall, which is perceived as being under his exclusive control.

Prayer is not an insignificant action, however; it brings the locus of control over a daunting external challenge—changes in rainfall patterns, in this case—back to the farmer. Similarly, although hustling is sometimes inaccurately equated with unemployment and inaction (Munive, 2010), farmers in this study described it in terms that clearly expressed agency as well as limitations. Posttraumatic recovery literature emphasizes that coping self-efficacy, or “the perceived capability for managing… recovery demands" can have substantial bearing on ultimate outcomes (Benight & Harper, 2002). The perception of self-efficacy that hustling and prayer enable, despite a lack of long-term adaptative strategies, may indeed improve outcomes for farmer struggling to cope with ongoing change; further research on these strategies is needed.

Analysing drivers of and constraints on adaptive choices

Geographic influences

From this understanding of common adaptive strategies, patterns in their application and factors shaping farmers’ adaptive choices are considered—beginning with geographic factors. Regional variations in the prioritization of adaptive strategies, shown in Figure 3, highlight ways in which location shapes opportunities for and constraints to adaptation. In Kaolack, the most intensively farmed region and a site of historic investment in peanut and cereal production, farmers’ ‘most important’ adaptations related principally to on-farm production, while in Ziguinchor, an underdeveloped but forested region, farmers turn to survival-oriented strategies that leverage their natural resource base. In Matam, the driest and most remote region, farmers rely most heavily on faith-oriented and diversification-oriented strategies, suggesting limited options for on-farm adaptation.

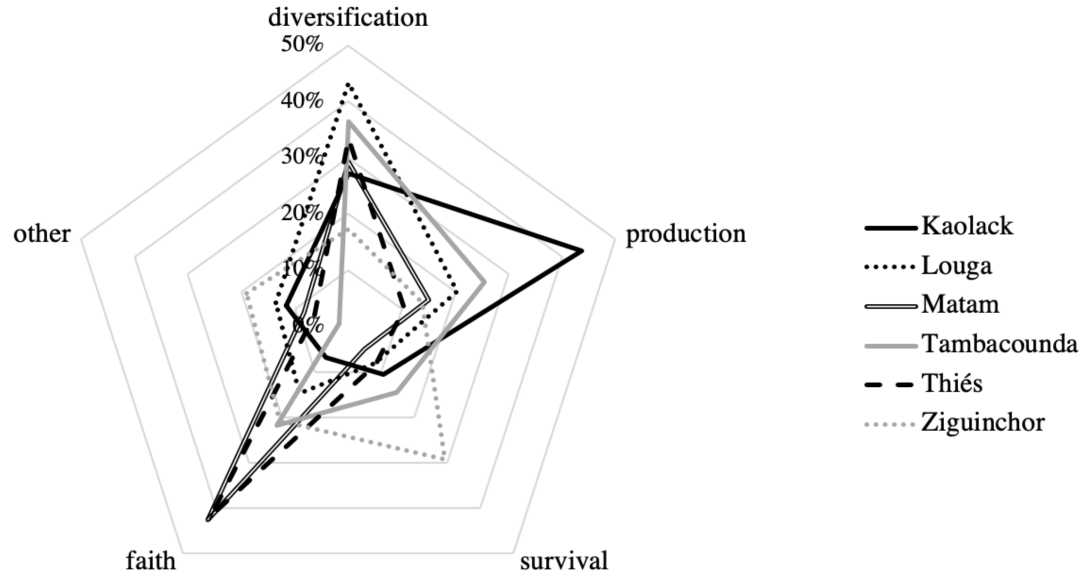

Figure 3. Disaggregation of primary coping strategies by region reveals geographic patterns in core adaptive strategies.

Limitations for women: "When the father [of my children] brings something then they will eat, if not we don't"

Senegalese socio-cultural norms, particularly in rural areas, permit women to occupy primarily domestic roles and constrain their access to and control of financial resources, which in turn influences their adaptive choices. Men tend to have priority access to household farm equipment and inputs, limiting women's capacity to employ on-farm adaptive strategies. "Women who have been blessed can buy [fertilizers and farm equipment] but it's mostly men.... If you don't have materials you are already off by noon or 1pm. But if you have materials, you keep working," explained a middle-aged woman in Thiés. "This is a village of hard workers but we don't have jobs. The women are also very resourceful but we wake up and have nothing to do..."

Survey data underscored how these constraints play out at a broader scale. Women were more likely than men to describe reliance on strategies that reflect limited mobility and resource limitations, including informal borrowing (7% of men vs. 16% of women), petty trade (2% of men vs. 8% of women), and staggered planting of crops (7% of men vs. 13% of women). Table 3 shows that both women and men considered income derived from migration and seasonal off-farm work (diversification strategies) to be crucial to sustaining their families in times of rainfall disruption, but the work itself falls to men in most cases. Women worked seasonally off-farm in only 30% of households reporting this as an adaptative strategy (relative to men in 84% of households) and migrated long-term or permanently in only 5% of households reporting migration as a strategy (relative to men in 89%).

The implications of women's relative immobility are substantial. Several women interviewed expressed that they have few options for earning money or obtaining food during times of difficulty, particularly if the men in the family do not provide for them. "When it's difficult us women we don't have anything to do.... When the father [of my children] brings something then they will eat, if not we don't," explained a young woman in Tambacounda. Notably, hustling was described most frequently by women, often but not exclusively in the context of men's absence from the rural household. Hand-to-mouth strategies are of even greater importance to women without husbands who could work off-farm or migrate; survey data indicate that woman-headed households tended to consider survival-oriented tactics most important (23% vs. 9% of men-headed households), while households headed by men were more likely to rely on asset and livelihood diversification (28% of vs. 21% of woman-headed households). Women's focus on short-term survival strategies rather than proactive adaptations aligns with findings from Mali (Brockhaus et al., 2013), underscoring constraints they face in implementing transformative adaptations that might contribute to longer term resilience.

Modelling adaptive decisions

To validate qualitative evidence of the drivers of farmers' adaptive decisions, I use multinomial regression to model responses to rainfall disturbance. The results in Table 4 support the idea that farmers' adaptive decisions in response to rainfall disturbance relate to both perceptions of risk and demographic factors. Reliance on diversification- and survival-oriented adaptive strategies are both significantly associated with reduced perception of variability in agricultural yields compared with farmers who relied on production-oriented adaptations. This indicates that the farmers focused on on-farm responses to rainfall disturbance, which include a range of risk reduction strategies, are either the most exposed to, or most *attuned* to, weather variability.

Notably, there is a strong positive association between farmers' degree of concern about changing weather patterns and a focus on diversification-oriented adaptive strategies. This suggests those farmers who perceive the greatest risk from *changing* weather patterns are leveraging off-farm rather than on-farm adaptation pathways, while those who perceive the greatest variability in yield turn to on-farm responses. These patterns are likely indicative of regional variations, highlighted in

Figure 3, rather than causation, but may also point to a better developed suite of on-farm adaptive strategies among farmers most accustomed to yield variability.

Demographic predictor variables are also associated with adaptive strategy orientations. Farmers who are less commercialized rely significantly more on faith- and survival-oriented adaptive strategies than production-oriented strategies. More secure land ownership (a marker of wealth and status) seems to correlate with non-agricultural adaptive strategies, including survival-based strategies. Reliance on faith-based strategies—the clearest expression of limited adaptation options—is linked to smaller household sizes, limited access to credit, and less farm commercialization, in addition to less concern about soil fertility (again, potentially a reflection of regional variation). These findings the importance of access to resources and entitlements and perceptions of environmental change in shaping reliance on on- and off-farm adaptive strategies.

Table 4. Multinomial regression results linking choice of primary adaptive strategy in response to a multi-year rainfall disturbance to demographic and risk perception predictor variables.

		diversification-based			survival-based			faith-based			other strategies		
variable	**variable description**	**B**	**Std. Error**	**Sig.**	**B**	**Std. Error**	**Sig.**	**B**	**Std. Error**	**Sig.**	**B**	**Std. Error**	**Sig.**
gender=woman	dummy variable	-0.392	0.353	0.267	0.334	0.469	0.477	-0.585	0.419	0.163	-0.514	0.887	0.562
age	grouped by decade (20-30, 30-40, etc.)	-0.020	0.016	0.210	-0.027	0.020	0.184	0.019	0.018	0.302	-0.024	0.040	0.545
household size		-0.029	0.020	0.155	-0.048	0.029	0.101	-0.075**	0.028	0.008	-0.008	0.052	0.878
reported degree of land ownership	0 = borrowed, rented, communal; 1 = family-owned; 2 = part self-owned; 3 = all self-owned	0.436*	0.178	0.014	0.615*	0.244	0.012	-0.060	0.189	0.750	-0.066	0.400	0.869
degree of access to credit	0 = no credit, 1 = informal credit (friends/ family), 2 = formal credit (coop, bank, etc.)	-0.090	0.219	0.681	-0.501	0.282	0.076	-0.552*	0.246	0.025	-0.195	0.550	0.723
frequency of crop sales	0 = never sells, 1 = sells only in good years, 2 = sells most years, 3 = always sells	-0.192	0.133	0.148	-0.663***	0.175	0.000	-0.626***	0.163	0.000	0.015	0.349	0.965
degree of concern about weather changes	1 = little or none 2 = somewhat 3 = a lot	1.405***	0.393	0.000	0.619	0.426	0.147	0.297	0.325	0.361	0.824	0.986	0.404
degree of concern about soil fertility change	1 = little or none 2 = somewhat 3 = a lot	-0.291	0.212	0.168	-0.143	0.267	0.592	-0.475*	0.231	0.039	-0.312	0.515	0.544
degree of perceived yield variability	0 = little or none 1 = noticeable 2 = lots	-0.987***	0.238	0.000	-0.639*	0.299	0.032	-0.499	0.263	0.058	-0.360	0.590	0.542

N = 362
reference adaptation category=production
* p < .05 ** p < .01 *** p < .001

Conclusion

The surveys and interviews that informed this study convey perceptions of drastic change in Senegalese farmers' lives. Shifting rainfall patterns and declining soil fertility are entangled in the eyes of many farmers and a substantial cause for concern in regions where agriculture is already marginal. In contrast to prior research in this region (Mertz et al., 2009; Tschakert, 2007), this study found that farmers readily cite changes in weather as both a key stressor and significant manifestation of change experienced in their lifetimes, even unprompted. This finding underscores the relative importance of *recent* rainfall disturbance in shaping farmers' perceptions of change and associated risk.

In alignment with prior research on this subject, farmers view mounting climate and soil fertility constraints as part of a story of sociocultural and political economic change. Farmer narratives from Senegal suggest environmental stressors are amplifying economic pressures on farmers that have been mounting for decades, increasing households' reliance on off-farm income and providing a trigger for youth migration. Formerly reactive coping mechanisms like labour migration and livelihood diversification have become more permanent and proactive. This bolsters prior findings showing increased reliance on livelihood diversification and remittances since the early 20th century, at least partly in response to political economic change and associated pressures on agrarian livelihoods (Antwi-Agyei et al., 2014; Bryceson, 2002; R. David, 1995). Additional longitudinal studies of adaptive behaviours, such as Campbell's (1999), may help confirm the nature of this transition.

This research also sought to uncover patterns in strategies employed to cope with environmental pressures. Regional variation is dramatic, with diversification-oriented and faith-oriented adaptive strategies play an outsized role in regions were agriculture is most marginal, concern about environmental change the highest, and options for adaptation are most constrained. Somewhat unsurprisingly given Senegalese sociocultural norms, women's adaptative strategies are limited to the sectors they are permitted to inhabit—namely survival-oriented strategies. Women's limited coping options are expressed through a qualitative focus on "hustling," a strategy that enables day-to-day, hand-to-mouth survival (particularly in the migration-related absence of male family members) but provides little in the sense of medium- to long-term stability. Both survival-oriented and faith-oriented adaptive strategies here reflect a lack of longer-term, more productive adaptive strategies that could lead to optimization and accumulation; differentiated reliance on these strategies demands structural reforms that build adaptive capacity among vulnerable groups.

The implications of perceived environmental changes and increasing reliance on off-farm livelihoods are yet to be fully realized. Farmers in this study have not yet reached the point at which existing adaptive strategies no longer suffice. However, despite most households' acceptance of migration and off-farm livelihoods as beneficial, the continued "rural exodus" of youth may have substantial impacts on the future viability of rural smallholder agriculture. Climate adaptation efforts must acknowledge farmers' ongoing adaptative processes, including evolving relationships between on- and off-farm livelihoods documented here and elsewhere (Black, Bennett, Stephen, Thomas, & Beddington, 2011) that necessitate cross-sectoral investments.

References

Agrawal, A. (2009). Local institutions and adaptation to climate change. In R. Mearns & A. Norton (Eds.), *The social dimensions of climate change: Equity and vulnerability in a warming world* (pp. 173–197). Washington, DC: World Bank. Retrieved from https://elibrary.worldbank.org/doi/abs/10.1596/978-0-8213-7887-8#page=199

Antwi-Agyei, P., Stringer, L. C., & Dougill, A. J. (2014). Livelihood adaptations to climate variability: Insights from farming households in Ghana. *Regional Environmental Change*, *14*(4), 1615–1626. https://doi.org/10.1007/s10113-014-0597-9

Artur, L., & Hilhorst, D. (2012). Everyday realities of climate change adaptation in Mozambique. *Global Environmental Change*, *22*(2), 529–536. https://doi.org/10.1016/j.gloenvcha.2011.11.013

Bationo, A., & Buerkert, A. (2001). Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, *61*, 131–142.

Batterbury, S., & Warren, A. (2001). Viewpoint: The African Sahel 25 years after the great drought: Assessing progress and moving towards new agendas and approaches. *Global Environmental Change*, *11*(1), 1–8. https://doi.org/10.1016/S0959-3780(00)00040-6

Bebbington, A. (1999). Capitals and capabilities: A framework for analyzing peasant viability, rural livelihoods and poverty. *World Development*, *27*(12), 2021–2044. https://doi.org/10.1016/S0305-750X(99)00104-7

Below, T., Artner, A., Sieber, R., & Stefan, S. (2010). *Micro-level Practices to Adapt to Climate Change for African Small-scale Farmers*. *IFPRI Discussion Papers*.

Benight, C. C., & Harper, M. L. (2002). Coping self-efficacy perceptions as a mediator between acute stress response and long-term distress following natural disasters. *Journal of Traumatic Stress*, *15*(3), 177–186. https://doi.org/10.1111/cpsp.12064

Berrang-Ford, L., Ford, J. D., & Paterson, J. (2011). Are we adapting to climate change? *Global Environmental Change*, *21*(1), 25–33. https://doi.org/10.1016/j.gloenvcha.2010.09.012

Black, R., Bennett, Stephen, R. G., Thomas, S. M., & Beddington, J. R. (2011). Migration as adaptation. *Nature*, *478*.

Bohle, H. G., Downing, T. E., & Watts, M. J. (1994). Climate change and social vulnerability. *Global Environmental Change*, *4*(1), 37–48. https://doi.org/10.1016/0959-3780(94)90020-5

Brockhaus, M., Djoudi, H., & Locatelli, B. (2013). Envisioning the future and learning from the past: Adapting to a changing environment in northern Mali. *Environmental Science and Policy*, *25*, 94–106. https://doi.org/10.1016/j.envsci.2012.08.008

Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science and Policy*, *12*(4), 413–426. https://doi.org/10.1016/j.envsci.2008.11.002

Bryan, E., Ringler, C., Okoba, B., Roncoli, C., Silvestri, S., & Herrero, M. (2013). Adapting agriculture to climate change in Kenya: Household strategies and determinants. *Journal of Environmental Management*, *114*, 26–35. https://doi.org/10.1016/j.jenvman.2012.10.036

Bryant, C. R., Smit, B., Brklacich, M., Johnston, T. R., Smithers, J., Chiotti, Q., & Singh, B. (2000). Adaptation in Canadian agriculture to climatic variability and change. *Climatic Change*, *45*(1), 181–201. https://doi.org/10.1023/A:1005653320241

Bryceson, D. F. (2002). The scramble in Africa: Reorienting rural livelihoods. *World Development*, *30*(5), 725–739. https://doi.org/10.1016/S0305-750X(02)00006-2

Burnham, M., & Ma, Z. (2016). Linking smallholder farmer climate change adaptation decisions to development. *Climate and Development*, *8*(4), 289–311. https://doi.org/10.1080/17565529.2015.1067180

Campbell, D. J. (1999). Response to Drought Among Farmers and Herders in Southern Kajiado District, Kenya: A Comparison of 1972-1976 and 1994-1995. *Human Ecology*, *27*(3), 377–416.

Cooper, P. J. M., Dimes, J., Rao, K. P. C., Shapiro, B., Shiferaw, B., & Twomlow, S. (2008). Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? *Agriculture, Ecosystems and Environment*, *126*(1–2), 24–35. https://doi.org/10.1016/j.agee.2008.01.007

Crane, T. A., Roncoli, C., & Hoogenboom, G. (2011). Adaptation to climate change and climate variability: The importance of understanding agriculture as performance. *NJAS - Wageningen Journal of Life Sciences*, *57*(3–4), 179–185. https://doi.org/10.1016/j.njas.2010.11.002

Cullen, A. C., Anderson, C. L., Biscaye, P., & Reynolds, T. W. (2018). Variability in Cross-Domain Risk Perception among Smallholder Farmers in Mali by Gender and Other Demographic and Attitudinal Characteristics. *Risk Analysis*, *38*(7). https://doi.org/10.1111/risa.12976

David, R. (1995). *Changing Places? Women, Resource Management, and Migration in the Sahel*. London.

Davies, S. (1996). *Adaptable Livelihoods: Coping with Food Insecurity in the Malian Sahel*. New York: St. Martin's Press.

De Haan, A. (1999). Livelihoods and poverty: The role of migration - a critical review of the migration literature. *Journal of Development Studies*, *36*(2), 1–47. https://doi.org/10.1080/00220389908422619

Deressa, T. T., Hassan, R. M., Ringler, C., Alemu, T., & Yesuf, M. (2009). Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Global Environmental Change*, *19*(2), 248–255. https://doi.org/10.1016/j.gloenvcha.2009.01.002

Dorward, A., Anderson, S., Bernal, Y. N., Vera, E. S., Rushton, J., Pattison, J., & Paz, R. (2009). Hanging in, stepping up and stepping out: livelihood aspirations and strategies of the poor. *Development in Practice*, *19*(2), 240–247. https://doi.org/10.1080/09614520802689535

Downing, T. E., Patwardhan, A., Klein, R. J. T., Mukhala, E., Stephen, L., Winograd, M., & Ziervogel, G. (2005). Assessing Vulnerbility for Climate Adaptation. In B. Lim, E. Spanger-Siegfried, I. Burton, E. Malone, & S. Huq (Eds.), *Adaptation policy frameworks for climate change: Developing strategies, policies and measures* (pp. 61–90). Cambridge: Cambridge University Press. https://doi.org/10.1007/978-94-007-1770-1_2

Dzanku, F. M. (2015). Transient rural livelihoods and poverty in Ghana. *Journal of Rural Studies*, *40*, 102–110. https://doi.org/10.1016/j.jrurstud.2015.06.009

Eldon, J., & Rapaport, P. (2017). *Rural Livelihood Atlas of Senegal, The Gambia and Guinea-Bissau*. Hartford, UK.

Eswaran, H., Almaraz, R., Van Den Berg, E., & Reich, P. (1997). An assessment of the soil resources of Africa in relation to productivity. *Geoderma*, *77*(1), 1–8. https://doi.org/10.1016/S0016-7061(97)00007-4

Food and Agriculture Organization. (2019). FAOSTAT. Retrieved December 4, 2019, from http://www.fao.org/faostat/en/#home

Funk, C., Rowland, J., Adoum, A., Eilerts, G., Verdin, J., & White, L. (2012). *A Climate Trend Analysis of Senegal*. *Informing Climate Change Adaptation Series Factsheet*. Retrieved from http://pubs.usgs.gov/fs/2012/3123/

Gaibazzi, P. (2017). *Bush Bound: Young men and rural permanence in migrant West Africa*. Berghahn Publishing.

Hampshire, K., & Randall, S. (1999). Seasonal labour migration strategies in the Sahel: Coping with poverty or optimising security? *International Journal of Population Geography*, *5*(5), 367–385. https://doi.org/10.1002/(SICI)1099-1220(199909/10)5:5<367::AID-IJPG154>3.0.CO;2-O

IPCC. (2018). Annex I: Glossary. In V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, … T. Waterfield (Eds.), *Global Warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,*. IPCC. Retrieved from https://www.ipcc.ch/sr15/chapter/glossary/

Kelly, P. M., & Adger, W. N. (2000). Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change*, *47*(4), 325–352. https://doi.org/10.1023/A:1005627828199

Mertz, O., Mbow, C., Reenberg, A., & Diouf, A. (2009). Farmers' Perceptions of Climate Change and Agricultural Adaptation Strategies in Rural Sahel. *Environmental Management*, *43*(5), 804–816. https://doi.org/10.1007/s00267-008-9197-0

Mortimore, M. (2010). Adapting to drought in the Sahel: Lessons for climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(1), 134–143. https://doi.org/10.1002/wcc.25

Mortimore, M., & Adams, W. (2001). Farmer adaptation, change and "crisis" in the Sahel. *Global Environmental Change*, *11*(1), 49–57. https://doi.org/10.1016/S0959-3780(00)00044-3

Munive, J. (2010). The army of "unemployed" young people. *Young*, *18*(3), 321–338. https://doi.org/10.1177/110330881001800305

Niang, I., Ruppel, O. C., Abdrabo, M. a., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2014). *IPCC Climate Change 2014: Impacts, Adaptation and Vulnerability -- Africa. Climate Change 2014: Impacts, Adaptation and Vulnerability - Contributions of the Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.*

O'Brien, K. L., & Leichenko, R. M. (2000). Double exposure: assessing the impacts of climate change within the context of economic globalization. *Global Environmental Change*, *10*, 221–232.

Ostwald, M., & Chen, D. (2006). Land-use change: Impacts of climate variations and policies among small-scale farmers in the Loess Plateau, China. *Land Use Policy*, *23*(4), 361–371. https://doi.org/10.1016/j.landusepol.2005.04.004

Put, M., Verhagen, J., Veldhuizen, E., & Jellema, P. (2004). Climate Change in Dryland West Africa? In A. J. Dietz, R. Ruben, & A. Verhagen (Eds.), *The Impact of Climate Change on Drylands: With a Focus on West Africa* (pp. 27–32). Secaucus: Kluwer Academic Publishers.

Radel, C., Schmook, B., Carte, L., & Mardero, S. (2017). Toward a Political Ecology of Migration: Land, Labor Migration, and Climate Change in Northwestern Nicaragua. *World Development*, *xx*(1056811). https://doi.org/10.1016/j.worlddev.2017.04.023

Raynaut, C. (2001). Societies and nature in the Sahel: Ecological diversity and social dynamics. *Global Environmental Change*, *11*(1), 9–18. https://doi.org/10.1016/S0959-3780(00)00041-8

Reenberg, A. (2009). Embedded Flexibility in Coupled Human-Environmental Systems in the Sahel: Talking about Resilience. In K. Hastrup (Ed.), *The Question of Resilience: Social Responses to Climate Change* (pp. 132–158). The Royal Danish Academy of Sciences and Letters.

Scheld, S. (2007). Youth Cosmopolitanism: Clothing, the City and Globalization in Dakar, Senegal. *City Society*, *19*(2), 232–253. https://doi.org/10.1525/city.2007.19.2.232.T

Schipper, E. L. F. (2010). Religion as an integral part of determining and reducing Climate Change and Disaster Risk: An agenda for research. In M. Voss (Ed.), *Der Klimawandel: Sozialwissenschaftliche Perspektiven*. Wiesbaden: VS Verlag für Sozialwissenschaften. Retrieved from https://link.springer.com/content/pdf/10.1007%2F978-3-531-92258-4.pdf

Scoones, I. (1998). *Sustainable Rural Livelihoods: A Framework for Analysis*. *IDS Working Paper* (Vol. 72). https://doi.org/10.1057/palgrave.development.1110037

Shiferaw, B., Tesfaye, K., Kassie, M., Abate, T., Prasanna, B. M., & Menkir, A. (2014). Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. *Weather and Climate Extremes*, *3*, 67–79. https://doi.org/10.1016/j.wace.2014.04.004

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, *16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Smith, W. J., Liu, Z., Safi, A. S., & Chief, K. (2014). Climate change perception, observation and policy support in rural Nevada: A comparative analysis of Native Americans, non-native ranchers and farmers and mainstream America. *Environmental Science and Policy*, *42*, 101–122. https://doi.org/10.1016/j.envsci.2014.03.007

Stark, O. (1991). *The Migration of Labor*. Cambridge: Basil Blackwell. https://doi.org/10.2307/2075765

Thomas, D. S. G., Twyman, C., Osbahr, H., & Hewitson, B. (2007). Adaptation to climate change and variability: Farmer responses to intra-seasonal precipitation trends in South Africa. *Climatic Change*, *83*(3), 301–322. https://doi.org/10.1007/s10584-006-9205-4

Tschakert, P. (2007). Views from the vulnerable: Understanding climatic and other stressors in the Sahel. *Global Environmental Change*, *17*(3–4), 381–396. https://doi.org/10.1016/j.gloenvcha.2006.11.008

Tschakert, P., & Tappan, G. (2004). The social context of carbon sequestration: Considerations from a multi-scale environmental history of the Old Peanut Basin of Senegal. *Journal of Arid Environments*, *59*(3), 535–564. https://doi.org/10.1016/j.jaridenv.2004.03.021

Tucker, C. M., Eakin, H., & Castellanos, E. J. (2010). Perceptions of risk and adaptation: Coffee producers, market shocks, and extreme weather in Central America and Mexico. *Global Environmental Change*, *20*(1), 23–32. https://doi.org/10.1016/j.gloenvcha.2009.07.006

van der Geest, K., & Dietz, T. (2004). A Literature Survey about Risk and Vulnerability in Drylands, with a Focus on the Sahel. In A. J. Dietz, R. Ruben, & A. Verhagen (Eds.), *The Impact of Climate Change on Drylands: With a Focus on West Africa* (pp. 117–146). Secaucus: Kluwer Academic Publishers.

Vigh, H. (2009). Motion squared: A second look at the concept of social navigation. *Anthropological Theory*, *9*(4), 419–438.

Warner, K., & Afifi, T. (2014). Where the rain falls: Evidence from 8 countries on how vulnerable households use migration to manage the risk of rainfall variability and food insecurity. *Climate and Development*, *6*(1), 1–17. https://doi.org/10.1080/17565529.2013.835707

Wiederkehr, C., Beckmann, M., & Hermans, K. (2018). Environmental change, adaptation strategies and the relevance of migration in Sub-Saharan drylands. *Environmental Research Letters*, *13*(11). https://doi.org/10.1088/1748-9326/aae6de

World Bank. (2019). Employment in agriculture (% of total employment) - Senegal. Retrieved July 11, 2020, from https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=SN

Yegbemey, R. N., Yabi, J. A., Tovignan, S. D., Gantoli, G., & Haroll Kokoye, S. E. (2013). Farmers' decisions to adapt to climate change under various property rights: A case study of maize farming in northern Benin (West Africa). *Land Use Policy*, *34*, 168–175. https://doi.org/10.1016/j.landusepol.2013.03.001

Yohe, G., & Tol, R. S. J. (2002). Indicators for social and economic coping capacity -- moving toward a working definition of adaptive capacity. *Global Environmental Change*, *12*, 25–40.

Ziervogel, G., Bharwani, S., & Downing, T. E. (2006). Adapting to climate variability: Pumpkins, people and policy. *Natural Resources Forum*, *30*(4), 294–305. https://doi.org/10.1111/j.1477-8947.2006.00121.x

Chapter 2. Encouraging technology adoption using ICTs and farm trials in Senegal: lessons for gender equity and scaled impact

The text of this chapter is under review for publication. Co-authors of the manuscript, Tony Jansen, Bacary Mané, and Carol Shennan, gave their approval for its inclusion here (see Appendix).

Abstract

Information and communication technologies (ICTs) are generating substantial interest from aid donors and development practitioners, including as tools for agricultural extension. However, empirical evidence of the impact of ICT-enabled extension on farmers' uptake of introduced technologies remains scarce. This four-year study evaluates an ICT-enabled extension project in Senegal using radio and mobile phone services to encourage rural smallholder farmers' use of certified seeds and organic and inorganic fertilizers across Senegal. Data were collected using large-scale annual surveys in six regions over four years as well as focus groups. The findings suggest that, in general, the forms and format of ICT-enabled extension services deployed failed to significantly contribute to the adoption of promoted technologies. Personal connections to participatory farm trials were consistently associated with adoption, and phone-based voice messaging appears to have potential to increase technology uptake. Gender-based disparities in engagement with ICT services and poorly developed systems for producing and distributing quality seeds

emerged as key factors limiting the effectiveness of this project. These findings raise concerns about the equity and effectiveness of ICT-enabled extension in promoting agricultural inputs in contexts like Senegal and have important implications for similar efforts in other countries.

Keywords

technology adoption, ICTs, ICT4Ag, extension, farm trials, gender

Introduction

For smallholder farmers in rural sub-Saharan Africa, acquiring information about prices, weather, inputs, and new tools and technologies often requires concerted effort and time. Development initiatives working to disseminate information to farmers about novel or improved farm management practices have historically relied on in-person extension services. However, this person-to-person outreach is associated with high costs, difficulty reaching farmers at a large scale, and limited accountability (Aker, 2011; Jack, 2011), as well as gender equity concerns (Meinzen-Dick et al., 2011). Cheaper, faster, and more equitable means to dialogue with rural farmers are in high demand.

Recently, information and communication technologies (ICTs), particularly mobile phones, have drawn interest from aid donors and development practitioners as tools to support knowledge transfer and encourage the adoption and diffusion of innovations at a large scale (Aker, Ghosh, & Burrell, 2016; Westermann et al., 2018; World Bank, 2011). In the agricultural sector, ICTs have been increasingly used to transmit information about crop and input prices, weather forecasts, pests and diseases, and other technical information (Aker, 2011; Nakasone, Torero, & Minten, 2014). This study documents one application of ICT-enabled extension services, which offer the attractive possibility of both cost savings over traditional agricultural extension and improved equity in information access.

Background

ICTs in agricultural development

ICTs' potential as tools to enable extension is mediated by the choice of ICTs and how they are used. ICT tools commonly applied in development include radio and simple mobile phones, which are rapidly giving way to digital technologies like smart phones and other devices that access the internet and enable multimedia sharing. Radio has long been leveraged to share information with farmers about the weather, markets, or new agricultural technologies, but mobile phones offer new possibilities for two-way communication between farmers and extension agents without the burden of travel time and cost. Phones are particularly powerful tools given their wide use in Africa, where wireless subscriptions skyrocketed from 226 per 1,000 individuals in 2007 to 806 per 1,000 in 2017 (World Bank Group, 2019). Theoretically, phones can reduce farmers' information search and transaction costs, reduce extension services' costs (and timelines), enable broader-scale and timely selling of agricultural goods (on both ends), facilitate complementary service provision (e.g., mobile money), and enable farmer feedback and timely monitoring (Aker, 2011; Nakasone et al., 2014).

However, empirical evidence of the effectiveness and equity of ICT-enabled services, particularly in comparison to other extension methods, remains scarce. Many studies of ICTs in development have focused only on access to and use of ICTs rather than their impact on farmer knowledge and behavior. In the case of ICT-based market information services, commercially-oriented farmers—those who typically sell their produce at the market, live near markets, are members of farmer groups, and have access to microfinance loans—are most likely to make use of these services (Kiiza & Pederson, 2012). Studies of ICT-based information services in India have found users of these services to be more educated with larger farms (Mittal & Mehar, 2016), as well as higher social status, higher income, and more diversified livelihoods relative to non-users (Ali, 2012).

Among the few empirical studies of ICTs' impacts in the agricultural sector, results are mixed (reviewed in Aker et al., 2016). Many ICT projects focus on provision of market information to farmers, and several have found that this information increases the price received or quantity of goods sold (Goyal, 2010; Nakasone, 2013). Others show little or no impact on farmers' sales and profits (Fafchamps & Minten, 2012; Mitra, Mookherjee, Torero, & Visaria, 2018). Casaburi et al. (2019) showed SMS-based extension services to increase yields, especially among farmers without much agronomic training. Projects using ICTs for climate information services have demonstrated their potential to increase farmers' knowledge of best practices and climate adaptation options (Mittal, 2016) and highlighted gender-based differences in their use (Diouf et al., 2019; Gumucio, Hansen, Huyer, & Huysen, 2019).

There is a limited pool of literature evaluating ICTs' effectiveness in instigating adoption of new agricultural technologies or practices. One study has linked use of ICT-based market information services to increased adoption of improved seeds, albeit among farmers who are already commercially oriented (Kiiza & Pederson, 2012). The *e-Choupal* program in India created ICT platforms for encouraging best practices, sharing market and weather information, and facilitating procurement and marketing of produce. Users of these platforms were found to have greater decision-making aptitude in reference to planning, cultivation, and post-harvest management and marketing practices, although benefits accrued primarily among more educated, wealthier, higher status individuals (Ali & Kumar, 2011). Cole and Fernando (2012) found a farmer hotline in India to be effective in incentivizing farmer investment in more effective inputs and more lucrative crops. Video-enhanced extension has also shown promise in generating farmer interest in new technologies at greater scale than traditional extension (Bentley, Van Mele, Harun-ar-Rashid, & Krupnik, 2016). A preliminary study of video-enhanced extension services in India found that videos of farmer testimonials or trainings, among other content, increased rates of adoption of some promoted technologies. However, dissemination of videos and maintenance of audience interest required direct facilitation by extension agents or others, suggesting that video may be an effective way to enhance and scale up, rather than replace, traditional extension (Gandhi, Veeraraghavan, Toyama, & Ramprasad, 2007).

Limitations on ICTs' effectiveness and equity

There are reasons to approach development-oriented ICT applications with caution. High rates of illiteracy in many rural communities limits the utility of SMS- and internet-based services. While interactive voice response (IVR) systems are more accessible, these can be challenging to set up and costly to deploy. Smart phones offer the possibility of graphical interfaces but have been slower to spread among rural populations with limited financial resources; although over 80% of adults in Senegal own a mobile phone, only 15% own a smart phone (Poushter et al., 2015). Furthermore, not all information is suited to dissemination through ICT channels. Nuanced information about inputs or practices, for example, may be ill-suited for message-based extension services that require simplicity and brevity (Aker, 2011), while context specificity is often lost in large-scale ICT-enabled outreach (Westermann et al., 2018). Often, ICTs in agriculture have been found to be most effective when targeting a specific information asymmetry and when related markets (including credit) do not present barriers to impact (Aker et al., 2016).

ICT-enabled development is also prone to many of the structural challenges associated with *any* approach to development. Targeted communities are not often granted control over or actively involved in the design and implementation of ICT tools, which may limit their effectiveness (Mansell, 2014). The quality and local relevance of disseminated information are known to have substantial bearing on the impact of ICT-enabled extension, but the allure of cost-savings can push projects to centralize content development (Glendenning & Ficarelli, 2012). Furthermore, two-way communication channels that gather farmer feedback and allow iterative programming, while recognized as beneficial, are often ineffective due to low farmer participation rates and de-prioritization relative to information dissemination objectives (Glendenning & Ficarelli, 2012; Mittal, Gandhi, & Tripathi, 2010).

The use of ICTs in agricultural development is also grounded in several assumptions. First, many ICT-enabled extension programs implicitly assume that farmers' lack of knowledge about modern agricultural technologies is a key barrier to their adoption. However, the adoption and diffusion literature suggests a range of other factors, most often related to farmers' limited investment or risk bearing capacity, that influence farmer decision-making. Characteristics of the technologies themselves matter; prospective users weigh the relative advantages (which include but extend far beyond economic advantages, encompassing factors like social prestige, acceptability and convenience), compatibility with their values, experiences, and needs, complexity, trialability, observability and replicability (Rogers, 2003). Individuals' decisions to use new technologies are also shaped by personal characteristics, including their belief system, adaptive capacity, risk tolerance, general propensity toward experimentation, and demographic variables such as age, gender, and wealth that influence their access to resources (Crane et al., 2010; Marshall, Gordon, & Ash, 2011; Mittal et al., 2010; Rogers, 2003; Roncoli, Ingram, & Kirshen, 2001).

Additional variables in adoption decisions include the quantity, quality, timeliness, and diversity of information sources, as well as farmers' ability to engage in social learning. Critics of the conventionally linear technology transfer model employed in agricultural extension argue that it poorly serves peasant farmers, who are producers of, not only passive recipients of, agricultural knowledge (Chambers, 2014). Empirical studies of agricultural technology adoption support this critique, emphasizing the importance of farmer agency and the value of collaborative development and adaptation of technologies. Studies have linked increased knowledge transmission and adoption of technologies to farmers' ability to engage in social learning—pairing, for example, traditional extension services with information exchange via social networks (Katungi, Edmeades, & Smale, 2008; Marshall et al., 2011; Mittal et al., 2010). Others have highlighted that different factors impact farmers' adoption decisions depending on whether information is coming from extension agents or peers (Adegbola & Gardebroek, 2007; Moser & Barrett, 2006).

The use of ICTs in agricultural development is also grounded in the assumption that these tools are a potential equalizer given their proliferation and supposed neutrality. In theory, they enable two-way communication with women, poorer farmers, and other marginalized groups who may not regularly engage with extension services, cooperatives, or other mainstream information sharing channels (Gurumurthy, 2004). However, this assumption overlooks distinctions between farmers' *access* to ICTs, their *control over* ICT tools, and their proclivity to *use* these tools, all of which mediate the effectiveness of ICT-enabled outreach. Critics identify this as one reason ICT-based interventions frequently fail to address structural constraints and power inequalities, and at times reinforce them instead. These risks are especially concerning in the context of gender, which frequently mediates not only access to, use of, and control over ICT tools, but also the social bounds within which ICT users can acceptably engage and communicate (Alzouma, 2005; Gurumurthy & Chami, 2014; Kleine, 2013) and act on information received through ICTs (Mittal, 2016). Women farmers in rural Africa face what is called a triple divide in access to ICTs: the digital divide, rural divide, and gender divide (Treinen & Van der Elstraeten, 2018).

This study evaluates not only farmers' use of ICT-enabled extension, but its observed impacts on farmers' behavior. By comparing impacts of these ICT services to the effects of social learning through farm trials, this research enables unique comparison of two extension models. Most significantly, I explore equity concerns associated with ICT services by examining differentiated impacts on women, testing the assumption that ICTs in development are likely to serve as equalizers.

Study background

This study examines impacts of two related projects aimed at scaling up farmers' uptake of promoted agricultural technologies in Senegal—one project focused on participatory farm trials, and the other on ICT-enabled extension. The farm trials were the core component of an Alliance for a Green Revolution in Africa (AGRA) Scaling Seeds and Technologies Partnership (SSTP) project implemented by United Purpose in Senegal from 2015-2016. The SSTP program implemented a series of subgrantee projects that sought to increase farmer uptake of new crop varieties and other technologies selected through consultations between AGRA and the *Institut Sénégalais de Recherches Agricoles* (ISRA). These technologies included certified seed for six widely grown rainfed crops, common nitrogen-phosphorus-potassium (NPK) fertilizer blends, and two low-cost, locally available organic fertilizers: dried cow manure and millet husk. Targeted seed varieties were primarily high-yielding, short-duration, open-pollenated varieties of groundnut, maize, millet, sorghum, cowpea, and rice; while groundnut is a key cash crop, the other five crops are grown primarily for household consumption in Senegal. United Purpose's SSTP project, rather than using centrally managed demonstration plots to promote these technologies, set up participatory farm trials across six regions of Senegal (Kaolack, Louga, Matam, Tambacounda, Thies, and Ziguinchor) (Eldon et al., 2020). These trials aimed to simultaneously test the performance of seed and fertilizer technologies under realistic farmer management and facilitate uptake via social learning. The project engaged 576 farmers who conducted one or both of two trials on their farm: Step 1, a trial of soil amendments applied to one improved variety and a local variety; and Step 2, a varietal comparison (United Purpose, 2017).

The ICT-focused project was funded by the New Alliance ICT Extension Challenge, which aimed to improve the capacity of smallholder farmers to use quality seeds and improved technologies through the use of financially sustainable ICT services (Payne, 2015). ICT-enabled extension projects were implemented in six African countries with the aim of scaling up adoption of SSTP agricultural technologies. The project implemented in Senegal, nicknamed *TICmbay* (combining the French acronym for ICT and Wolof word for farming), aimed at large-scale uptake of the certified seeds, fertilizers, and other technologies that were the focus of the SSTP farm trials across Senegal.

From its conception, TICmbay aimed to leverage trusted voices in local languages in order to deliver credible, accessible messages to hard-to-reach communities. Decentralized radio and interactive voice response (IVR)-based phone services sat at the center of a suite of tools designed to equitably reach men, women, and illiterate farmers in resource-poor communities. Local radio stations, both commercial and community-based, were selected using baseline survey data about farmer listenership. These stations worked with staff at Jokalanté, a Senegalese social enterprise created to sustain the project's ICT-enabled outreach work in the long-term, as well as local partners (cooperatives, farmers' organizations, and agricultural technology vendors) to develop dynamic hour-long programs and, beginning in 2017, 60-second 'spots' to promote the seed and fertilizer technologies. From late 2015 to early 2019, local radio stations broadcast programs that featured local leaders and farmers discussing their experiences with the technologies, including the SSTP farm trials. Often, the take-home messages from these programs were relatively complex; rather than promoting a single behavior change, broadcasts emphasized numerous paths to increased yields that emerged from the farm trials, and emphasized that combining certified seed varieties with one or more fertility treatments was preferable (Eldon et al., 2020).

Radio program listeners were invited to call into an automated IVR system ('YouTalk') to leave messages and record questions which local partners would then respond to on- or off-air. Callers' numbers were captured in a database so that implementors could later leverage push-IVR messaging ('mAlerts') or phone-based surveys. This database also included thousands of farmers' organization members and affiliates whose contact information was collected from in-person surveys, after the discovery that many farmer organizations lacked contact information required for ICT-enabled outreach to their members.

Study site: Senegal

Both the SSTP farm trials and TICmbay project crossed a range of agroecological zones and cropping systems. Rainfall and temperature gradients in Senegal enable a diversity of cropping systems, from lowland rice production in river valleys and the Casamance region, to cereal and groundnut-focused production in central Senegal, to agropastoral systems in the north. Key crops include pearl millet, groundnut, rice, maize, sorghum, cowpea, vegetables, and roselle. The conditions for farming are somewhat precarious in this region of Africa. Climate variability is a harsh reality, but temperatures have risen and precipitation levels have declined in recent decades (Funk et al., 2012). Soils in most parts of Senegal are sandy, exhibiting low inherent fertility and limited water holding capacity (Bationo & Buerkert, 2001; Eswaran et al., 1997).

While Senegal surpasses most other sub-Saharan African countries in current and projected food security (Thome et al., 2019), its smallholder-dominated agricultural sector performs poorly by most conventional measures, and the average household purchases 80% of its food (World Bank, 2018a). Average inorganic fertilizer consumption stood at only 16kg per hectare of arable land in 2016, relative to a 141kg/ha global average (World Bank, 2016). Irrigation is minimal, at 3% of cultivated land (World Bank Group, 2018). Due in part to these constraints, average annual cereal yields fall below the average for sub-Saharan Africa and low-income countries as a whole, at 1,275 kg/ha in 2017 (World Bank, 2017). Senegal is thus an appropriate target for development organizations looking to scale adoption of 'Green Revolution' technologies assumed to increase production.

An baseline study for the SSTP Senegal project (Ndiaye et al., 2015) found that only 14% of farmers surveyed used certified seed and slightly under half used NPK fertilizers (often heavily subsidized; see Seck (2016)). Seed saving (for unspecified lengths of time) is practiced by three-quarters of farmers. Many purchase seed of unspecified origin from markets or through other informal channels, but the formal certified seed sector in Senegal is still developing. Most of the certified seed currently produced by registered seed producers in Senegal is purchased by the government and resold at subsidized rates, but inadequate quality control measures mean subsidized seed is frequently of inferior quality (Mabaya et al., 2017). Farmers seeking certified seeds can also purchase it from trusted farmers' organizations or private entrepreneurs, but production and availability up to this point have been limited to meeting 'expressed needs' of farmers (Ndiaye et al., 2015).

Gender dynamics in Senegal

Gender is a key axis of difference among Senegalese farmers and a focus of this study. Senegalese society is highly patriarchal, even relative to other sub-Saharan African nations; only 14% of Senegalese women aged 15-49 participate in decisions related to their own health care, major household purchases, and visiting family (ANSD/Senegal & ICF, 2017). Nearly half of women farmers surveyed for this study (49%) had received no education, compared to 23% of men. As seen in Table 5, women surveyed were also much more likely to cultivate land owned by their families (typically their husbands) relative to men, who more often own at least a portion of the land they cultivate.

Table 5. Ownership of cultivated land by gender, according to 2015-16 baseline survey.

	women	**men**
At least partial ownership	48%	90%
Family-owned	43%	3%
Borrowed or communal	10%	8%

Gendered divisions of farm and household labor in Senegal mean that women engage in decision-making primarily for crops grown for household consumption—specifically rice (in regions of Casamance, although men produce rice in the more commercialized Senegal River Valley), cowpea, and vegetables grown at small scale. Of the crops targeted by the SSTP project, only two are grown by women with much regularity: cowpea and rice. Men are primary decision-makers for most other crops, including groundnut (often the primary cash crop), millet, sorghum, maize, and large-scale vegetable production. They typically own and control most tools of production (carts, plows, etc.) and in many cases acquire the seeds and farm inputs that women subsequently use. In addition to farming duties, women typically handle the majority of the household work, including cooking, cleaning, carrying water, and childcare. While many women do engage in work outside the home (albeit less commonly than men), their work is more often unpaid (ANSD/Senegal & ICF, 2017).

Methodology

The primary data source is annual surveys of 592 farmers conducted between 2015 and 2018 (Table 6). These surveys were designed for monitoring and evaluating TICmbay's impacts and are used for more expansive analysis in this study. Surveys focused on farmers' initial uptake of promoted technologies and tracked evidence of continued use in subsequent years. The agricultural technologies that were tracked were: four improved varieties of each target crop (groundnut, maize, millet, sorghum, cowpea, and rice), inorganic nitrogen-phosphorus-potassium (NPK) fertilizer blends, and two organic fertilizers: cow manure and millet husk. Baseline surveys prior to project intervention were conducted in two pilot regions in 2015, with additional baseline and follow-up surveys in 2016, 2017, and 2018. Follow-up surveys targeted the same farmers to capture cumulative project impacts and adoption dynamics, with complete data across all years available for 410 of the 592 original participants. These 410 farmers are used as the basis of adoption calculations to avoid artificially low adoption rates due to attrition. While 2015 surveys were conducted on paper, all later surveys were developed in KoboToolbox and conducted using the KoboConnect application on tablet computers. Research assistants from the University of Ziguinchor served as enumerators over the course of the project, and translators aided in focus group facilitation as needed. Data were analyzed in SPSS v.25.

Table 6. Survey and focus group timelines.

survey	**timeline**	**N**	**response rate**	**focus groups**
Baseline	July-Sept. 2015 (Thiés & Ziguinchor), July-Sept. 2016 (Kaolack, Louga, Matam, Tambacounda)	592	100%	14 (Thiés & Ziguinchor)
Year 2	July-Sept. 2016	562	95%	0
Year 3	Aug.-Sept. 2017	502	85%	10 (all regions but Thiés)
Year 4	Aug.-Sept. 2018	468	79%	12 (all regions)
Farmers with complete data (all years)		410	69%	

Surveys were conducted in four villages in each region for a total of twenty-four communities. Half of the twenty-four villages hosted farmer trials related to the SSTP project from 2015-2016. The other half of the villages were identified as relevant 'pairs,' allowing for quasi-experimental comparison. SSTP trial participants were not counted as adopters in Year 2, as they received free seeds that year. Logistic regression was used to evaluate the impacts of factors other than ICT service exposure (specifically, farmers' gender, gender of head of household, region, age, level of education, wealth, access to credit, degree of farm commercialization, membership in a local or village group, and degree of exposure to farm trials) on farmers' decisions to adopt promoted technologies.

Several additional data sources inform this study. Semi-structured, gender-disaggregated focus groups (generally of 5-15 farmers) were organized in surveyed communities in 2015, 2017, and 2018 (Table 6). These discussions allowed for continuing refinement of surveys and discussion of complex topics in greater depth, including obstacles to technology application and factors influencing engagement with ICT services. Discussions were recorded, summarized, and used to inform interpretation of survey results. Additionally, raw data from the platform used to implement mobile phone-based services were used to quantify participation in IVR push and pull services. A tool developed for local social enterprise Jokalanté was used to model radio station reach based on the Longley-Rice Model (Hufford, 1984).

Results and Discussion

Results of this study first document farmers' access to and engagement with ICT-enabled extension services—in effect, the potential for impact of these ICT tools—followed by measured impacts on adoption of promoted agricultural technologies. Finally, logistic regression is used to explore what other factors appear to predict adoption decisions.

Farmer access to and engagement with ICT-enabled extension

TICmbay's expansive reach provides evidence of the potential benefits of ICT-based outreach. From the project's start in 2015 through its final season in 2018, radio broadcasts on twenty radio stations, which were selected with input from baseline surveys, promoted use of certified seed and fertilizer technologies to an estimated potential audience of 810,000 farmers. Baseline surveys indicated that 83% of farmers had access to radio and 91% had access to a mobile phone, reinforcing that both of these tools were potentially powerful channels through which to reach farmers.

Despite high rates of access to mobile phones, the baseline study and focus groups indicated that farmers had little to no experience receiving SMS or voice messages from third parties. SMS use was found to be low for all groups but higher among men than women; roughly a quarter of men used SMS messaging but less than 10% of women did. This is unsurprising given gender-based disparities in education and literacy. As a result of these baseline findings and project partners' prior experience, SMS services were not deployed in this project, and preference was given to interactive voice response (IVR) services.

Surveys sought to capture farmers' exposure to the project's hour-long radio programs and spots, although few farmers—especially women, who in focus groups described listening sporadically—could confidently identify the names, dates and times, or hosts of broadcasts they listen to. Survey enumerators were trained to question farmers about radio program content in order to accurately capture exposure to sponsored programs. However, the decentralized nature of these programs limited branding possibilities and sometimes made clear identification of radio listeners difficult.

Ultimately, surveys found that 65% of farmers in regions receiving broadcasts were exposed to programs over the course of the project (roughly 30-45% of the farming population per year). However, there is evidence of amplification of ICT-based messages; in 2018, 54% of farmers who had been exposed to radio programs said they had shared information with neighbors and family members. The prevalence of these word-of-mouth connections suggests that the reach of ICT-enabled extension substantially exceeds estimates focused on direct exposure to ICT services.

The project used two IVR tools intended to facilitate dialogue and feedback between agricultural technology distributors (typically cooperatives) and farmers. Radio broadcasts invited farmers to call an advertised number to leave a comment or request more information, thereby logging their phone numbers in a database. A push messaging tool allowed project implementers to send IVR-based push messages—typically recorded by well-known individuals in each location, such as cooperative leaders—to farmers with registered numbers, bypassing literacy constraints. Over 36,000 farmers received a voice message notifying them about the availability of promoted technologies between 2015 and 2018. The vast majority of these were existing members of cooperatives who received pushed messages from their local cooperative leader. Farmers' proactive engagement with phone-based services was relatively modest, with just over 6,000 unique callers phoning into the call-in service over the same timeframe.

In light of limited farmer engagement with pull-IVR services, the project's goals to enable constructive dialogue between technology providers and a diversity of farmers were only modestly achieved. However, evidence points to a number of successes and the potential for expanded use of radio and IVR tools. The vast majority of farmers who used the call-in service or received IVR push messages expressed satisfaction with these services and interest in using them again. Farmers in focus groups found push messages particularly useful in notifying them about the local availability and price of seeds. Information from radio programs was sometimes viewed with skepticism, in contrast, as broadcasts in some regions were not always aligned with actual availability of seeds. Furthermore, a large majority of push message recipients (83% in 2018) reported sharing the information from the message with others.

Additionally, focus group discussions documented farmers' appreciation of decentralized programming and elicited requests for programs featuring more local farmers and local issues (such as local pest problems, livestock integration, or crop rotations). With well-known local agents voicing the radio programs, and local cooperatives staff reliably responding to questions received by the call-in service, farmers appeared, anecdotally, both inclined to trust the information received and more encouraged to engage. There is likely potential for increased use of these approaches, particularly if incentives to increase call-in rates are identified.

ICT access and use: gender equity concerns

It is well understood that *access to* and *use of* ICT services are different concepts. Data from this study illustrate how these distinctions play out in the context of gender. Focus group discussions over the course of the project uncovered barriers to engagement with ICT-enabled extension that are shaped by gendered experiences. Women often discussed having difficulty sitting down and listening to scheduled radio programs due to heavy household workloads; more often, they reported listening to the radio at random intervals and for shorter periods of time, often between tasks. They also expressed interest in agricultural programs connected to cooking, nutrition, and women's crops, which were not a focus of the broadcasts in this project.

In contrast to individual survey results showing very high rates of radio listenership among women, women in focus groups often cited access to a radio as a challenge. These findings, rather than contradicting one another, likely underscore that access is mediated by ownership and control of ICT tools. Indeed, men were much more likely to report listening to the radio on an appliance or mobile phone that they own (90% of men vs. 65% of women). Men were also more likely to have 'a lot' of control over when and to what they listen—84% of men compared to 60% of women. Similarly, although reported phone *access* was fairly equal among men and women, husbands owned a phone in 76% of households surveyed while wives owned a phone in less than half of households. Thus, theoretical access to ICT tools, which surveys consistently found to be relatively equal between men and women, is not necessarily an accurate indicator of realized access or use.

Indeed, data on women's engagement with phone-based services clear illustrate inequities in ICT services' use. Of the 40,000 farmers sending or receiving phone-based messages (excluding those farmers whose gender was unknown), only

30% were women. This primarily reflects that men are more likely than women to appear in member databases for local farmers' organizations focused on cereal crops and were thus disproportionately targeted for push messages. More meaningful is the gender gap among callers to the call-in service, only 18% of whom were women (excluding those whose gender was unknown).

While farmers often offered multiple reasons for not engaging with call-in services (Figure 4), most pointed first to phone credit (airtime)—the *accessibility* of credit in their community (60% of farmers surveyed) as well as actual cost (25%)—and to not being in the habit of calling into radio programs (42%). Focus group findings indicate that concerns about the cost of calling in are partly rooted in radio stations' frequent use of premium call-in lines, which charge callers higher rates and generate profits for radio stations. While this project did not employ premium call-in lines, some farmers incorrectly assumed they would be charged inflated prices.

Women were much more likely to say they were simply not in the habit of calling into radio programs (52% of women vs. 36% of men), likely reflective of their relative absence from public dialogue in general. Women also explained in focus groups that it was difficult to justify spending money to call into radio programs when they felt those funds could be spent more productively on food for the family. This points not only to a reluctance to engage in public discourse but also to concerns about the value perceived from engagement in these discussions. If women see little potential gain from active engagement with ICT services, and instead are pressured to devote their available funds to the family, even minimal costs are inevitably too high.

This point has serious implications for any ICT-based project in a similar cultural setting.

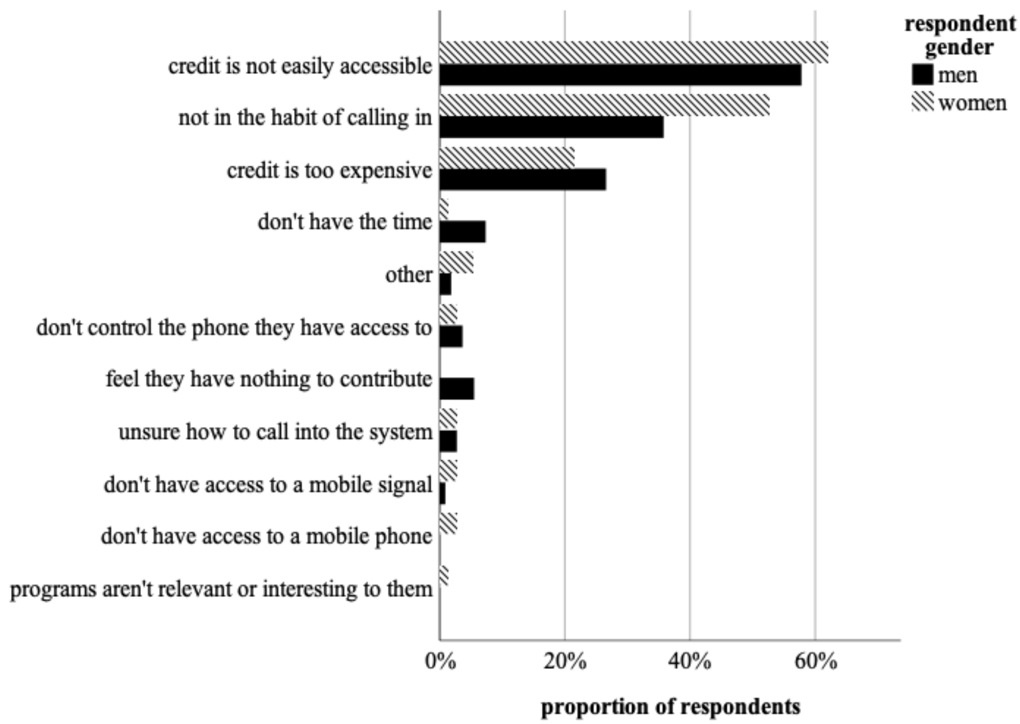

Figure 4. Reasons that farmers did not call into radio programs, from 2018 surveys. Farmers cited the cost and accessibility of credit as primary barriers to engagement with call-in services, along with not being 'in the habit' of calling into radio programs. The latter response was more common among women than men.

Impacts of ICT-enabled extension on farmer uptake of promoted technologies

While the radio and phone-based services used in this project appear to be *potentially* powerful outreach tools, active engagement with them remained modest and worryingly skewed in terms of gender. From this starting point, we examine whether farmers' exposure to ICT-enabled extension services and farm trials correlates with adoption of the promoted technologies for use in their own fields. Adoption of promoted technologies is measured here only in terms of new use, so farmers who had used the technologies previously were excluded, and spatial and temporal scale of use are set aside. Only complete records are used here (n = 410) to avoid artificially lowering adoption rates due to attrition.

Cumulative adoption data from the four years of the project show first-time uptake of one or more promoted technology by 27% of farmers, regardless of exposure to ICT-enabled extension or farm trials. Certified seed was adopted for the first time by 20% of farmers surveyed, and soil amendments by 13% of farmers. Cowpea seeds proved most popular and rice the least, with predictable differences in adoption between men and women according to typical division of crop production; men took up groundnut, millet, and sorghum seeds at disproportionately high rates, while more women adopted cowpea and rice.

Figure 5 provides insight into whether adoption of promoted technologies was influenced by ICT-enabled extension and/or personal connection to the SSTP farm trials conducted in 2015-2016. The 410 respondents who participated in all three years of follow-up surveys are grouped according to the number of years they reported exposure to ICT-enabled extension services and whether they knew someone involved in the farm trials. While the relatively small subsamples (between 34 and 84 farmers) necessitate caution in forming conclusions, these data suggest exposure to ICT-enabled extension services is not associated with increased adoption, while exposure to farm trials may be. Notably, the slight increase in adoption rates among farmers connected to farm trials, depending on their exposure to ICT services, indicates a possible synergistic effect of these two means of knowledge transfer.

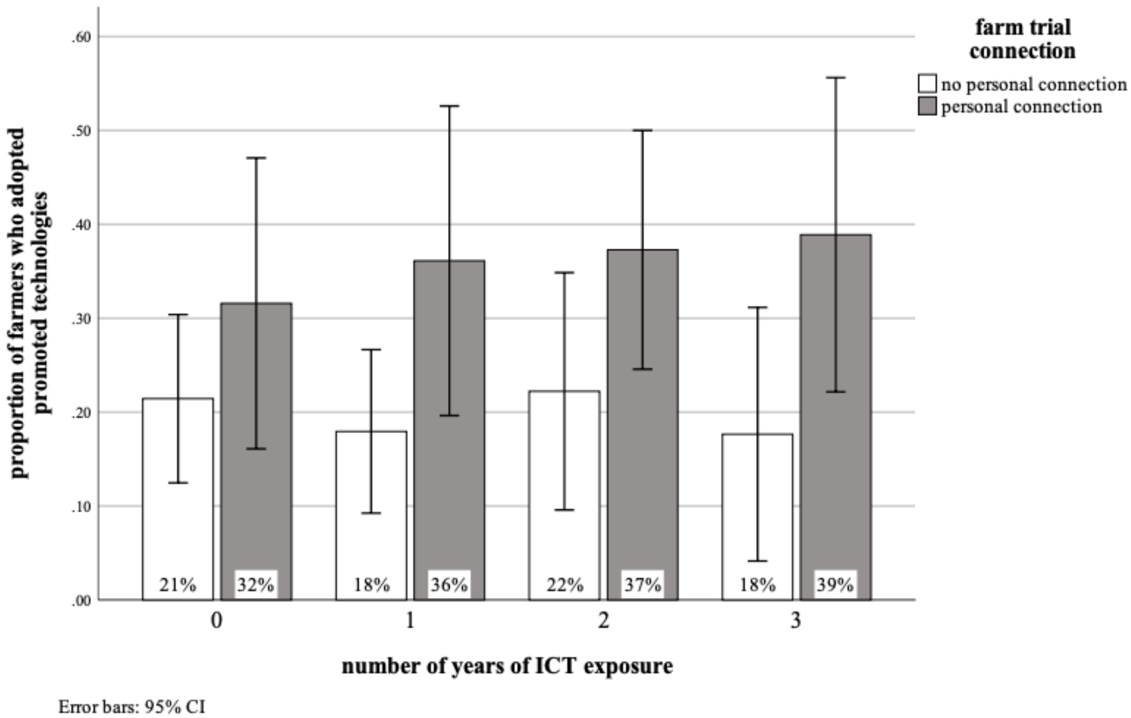

Figure 5. Technology adoption over the course of the project, disaggregated according to farmers' exposure to ICT services and farm trials. While increased exposure to ICT services does not appear to be correlated with higher rates of adoption, farmers who were connected to farm trials were somewhat more likely to adopt promoted technologies.

Differences in impact between ICT channels

The above analysis provides little evidence that exposure to ICT-enabled extension *in general*, regardless of the medium, has significant effect on farmer behavior. However, different ICT channels may have differentiated impacts on adoption decisions. Farmers in this study who received phone-based push messages promoting technologies were significantly more likely to have adopted seeds or fertilizers (40% of farmers, n = 50) than farmers who did *not* receive messages (25%, n = 360). While this suggests that IVR-based push messages may have a significant impact on adoption decisions, the nature of this service introduces important confounding variables. The database used for sending messages was composed of farmers who were either registered members of local cooperatives or farmers who had previously used the call-in service, thereby registering their phone numbers. Having already taken these steps, these farmers were potentially better connected to certified seed distributors and/or more interested in new technologies than the average farmer. However, increased rates of technology application among push message recipients is not a meaningless finding. Given that these better-connected, potential early-adopting farmers are implicit targets of projects promoting purchased inputs like certified seeds, this difference in adoption rate suggests a useful complementarity between traditional and ICT-enabled extension service.

Gender and technology adoption

The uptake of promoted technologies reflects worrying gender disparities. While 22% of all women surveyed reported that they had applied at least one promoted technology for the first time during the project, 30% of all men had (Table 7). However, shared farming responsibilities often make it difficult to discern who, at the individual level, has adopted a new technology. As such, the gender of the head of household, which is often a marker of vulnerability, may be a more meaningful signifier of gendered differences in access to resources and information than the gender of the survey respondent. A larger gap in cumulative adoption emerges when the gender of head of household is considered; only 16% of individuals in women-headed households reported adopting a promoted technology, compared to 28% of households headed by men. However, as this data is drawn from only 37 female-headed households, conclusions related to these results should be treated with caution.

Table 7. Technology adoption (any promoted technology, specifically seeds, and specifically soil amendments) among men, women, and all farmers, 2015-2018.

technologies adopted (2015-2018)	**all farmers**	**men**	**women**
any promoted technology	27% (109/410)	30% (65/214)	22% (44/196)
certified seeds	20% (83/410)	26% (56/214)	14% (27/196)
soil amendments	13% (52/410)	13% (27/214)	13% (25/196)

While similar proportions of women and men applied the promoted soil amendments for the first time, men were relatively more likely to apply certified seeds. Women were relatively more likely to adopt soil amendments, and specifically those that are sourced from the farm; while slightly more men than women applied (purchased) NPK for the first time during the project, more women than men applied manure, compost, and crop residues.

These findings likely point to differences in resource access that restrict women's ability to purchase inputs—a challenge that emerged in focus group discussions and was further explored in the final set of surveys. In 2018, farmers who purchased seeds were asked who physically bought seeds and with whose money they were purchased. While all men who adopted improved seed for the first time in 2018 purchased the seeds themselves with their own money, 56% of women reported that a man in their family (most often their husband) had used his own money to purchase the seeds she adopted. As such, only a portion of women who adopted certified seed actually demonstrated the ability to purchase them themselves. In focus groups, women sometimes discussed pooling financial resources through local women's organizations and enterprise groups (GIEs), which may be a potential avenue through which to reach larger numbers of women and bypass challenges related to their resource access.

Impacts of other variables on adoption

An implicit assumption in many ICT-based projects is that increased access to information about the usefulness, use, and availability of agricultural technologies will contribute to their uptake. In this project, modest rates of uptake of promoted technologies, despite high rates of information dissemination via ICT-enabled extension, underscore the complexity of adoption decisions. Using logistic regression on the collapsed panel data, we consider a wider range of factors impacting adoption of promoted technologies.

The model assumes that adoption of new technologies is mediated by access to knowledge about them, farmers' ability to leverage the information provided, as well as the strength of related markets (e.g., inputs, credit, and infrastructure). As such, predictor variables were the number of years of exposure to ICT-enabled extension, the degree of exposure to farm trials, and a set of demographic variables identified in existing literature evaluating ICT use and technology adoption (Ali, 2012; Bryan et al., 2009; Kiiza & Pederson, 2012). Regression results are reported in Table 8.

Table 8. Logistic regression results evaluating first-time adoption of promoted technologies in relation to ICT exposure, exposure to farm trials, and farm and household characteristics.

Variable	**Categorization of responses**	**B**	**S.E.**	**Sig.**	**Exp(B)**
ICT exposure	number of years (0-3) of reported exposure to ICT services	0.126	0.134	0.350	1.134
degree of connection to farm trials (ranked)	0 = unfamiliar with farm trials, 1 = familiar but no contact, 2 = neighbor participated, 3 = family member participated	0.404**	0.153	0.008	1.497
participant in farm trials	0 = participant, 1 = non-participant	-0.686	0.413	0.097	0.504
region (Ziguinchor)	dummy variable			0.011	
region (Kaolack)	dummy variable	0.777	0.457	0.089	2.175
region (Louga	dummy variable	0.570	0.474	0.229	1.769
region (Matam)	dummy variable	-0.579	0.536	0.281	0.561
region(Tambacounda)	dummy variable	0.177	0.429	0.680	1.193
region (Thies)	dummy variable	-1.077	0.558	0.053	0.341
house construction	1 = thatch, 2 = mud or corrugated, 3 = brick or cement	-0.024	0.211	0.910	0.976
frequency of crop sales	0 = never sells, 1 = sells only in good years, 2 = sells most years, 3 = always sells	-0.002	0.111	0.984	0.998
degree of land ownership	0 = land is borrowed, rented, or communal, 1 = land is family-owned, 2 = land is partly self-owned, 3 = land is all self-owned	-0.014	0.136	0.916	0.986
level of education	0 = no formal schooling, or only Koranic schooling, 1 = some primary, 2 = completed primary, 3 = some secondary, 4 = completed secondary	-0.139	0.147	0.345	0.871
household size	headcount in household	0.010	0.017	0.578	1.01
farmer age	by decade (20-30, 30-40, etc.)	0.004	0.012	0.754	1.004
gender of head of household	0 = man, 1 = woman	-0.361	0.541	0.504	0.697
gender of respondent	0 = man, 1 = woman	-0.112	0.315	0.723	0.894
access to credit	0 = no credit, 1 = informal credit (friends/fam.) 2 = formal credit (coop, bank, etc)	0.363	0.193	0.060	1.438
local/village group membership	0 = unaffiliated, 1 = member of a local group	-0.789**	0.28	0.005	0.454

* p < .05   ** p < .01

The regression analysis supports the conclusion that exposure to ICT services has little if correlation with adoption of promoted technologies, while a farmers' degree of exposure to the farm trials emerges as a significant predictor. With each 'step up' in exposure to the farm trials (i.e., from being unaware of them, to having heard about the trials, to knowing a neighbor who participated in them, to knowing a family member), a farmer was nearly 50% more likely to adopt a promoted technology. The only other predictor of significance in this model is membership in a local or village group, which is *inversely* correlated with adoption. This finding is unexpected in light of prior research finding a positive correlation between adoption and membership in farmers' organizations, specifically, but may reflect the varied nature of village groups in different regions of Senegal. Group membership was unusually high among women (76%, compared to 53% of men) and farmers in the Ziguinchor region (81% of farmers). Women's groups and village groups in Casamance may serve primarily for social support (sharing of chores and childcare, for example) rather than contributing to agricultural knowledge exchange, as implicitly assumed.

As this logistic regression model collapses time-variant adoption and ICT exposure data, longitudinal adoption data were also applied in a fixed effects linear model to evaluate whether adoption in each year correlated with exposure to ICT services that year. The results, which treat household and year as fixed effects, bolster the conclusion that ICT exposure is not a significant factor in adoption decisions (B = .000).

The role of market failures in inhibiting adoption

Successfully promoting the uptake of new technologies through ICTs or other channels requires associated markets for inputs and outputs to be functional (Aker et al., 2016; Jack, 2011). While this study did not aim to evaluate the strength of these markets, focus group discussions and survey data do point to market failures, particularly in Senegal's seed sector. First, only 63% of all improved seed adopters reported buying their seeds. This implies that technology cost and availability may present larger barriers to widespread use than observed adoption rates suggest.

Surveys of non-adopters further underscored that market failures likely limited farmers' decisions. Figure 6 below shows that the availability of new tools and techniques was the biggest barrier to adoption that farmers offered in the final year of the project, followed by the sense that there was no advantage, 'other' reasons (for women, primarily a lack of land – for men, primarily a lack of labor), and cost to adopt. Interestingly, women more frequently indicated that they do not see an advantage in changing their practices, suggesting that promoted technologies were not appropriately targeted toward women.

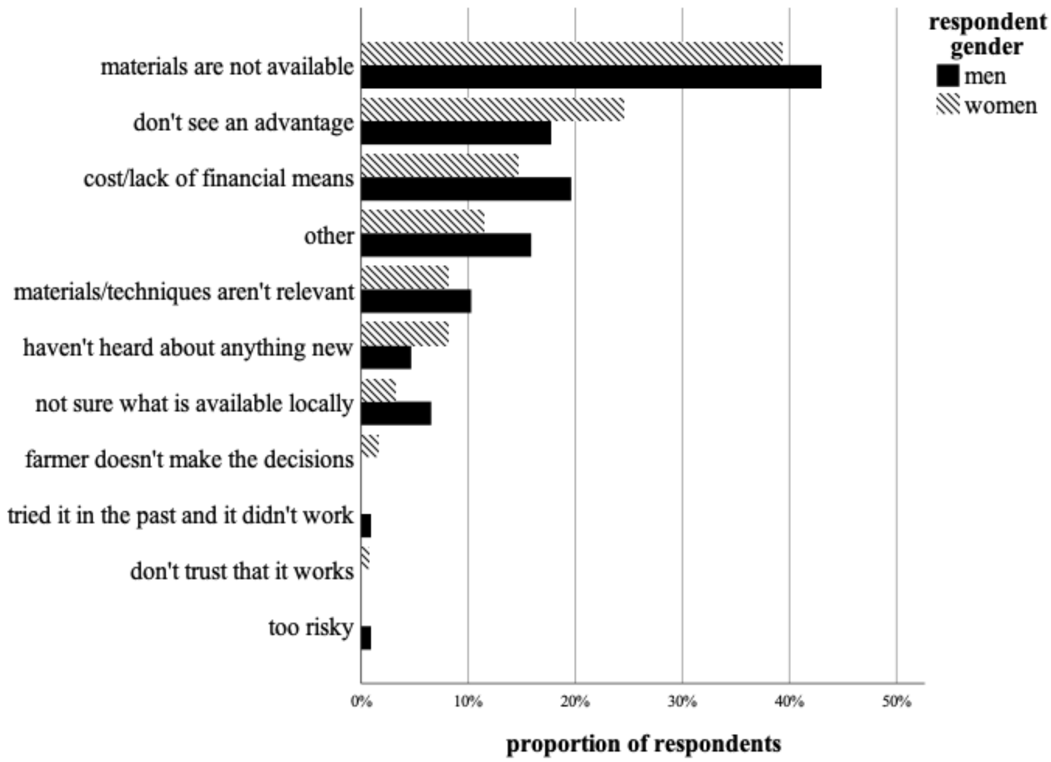

Figure 6. Reasons given for non-adoption of promoted technologies, from 2018 surveys, by gender. The availability, perceived benefit, and cost of promoted technologies were the most frequently cited reasons for non-adoption in 2018.

As is visible in Figure 7 below, 2018 survey data on non-adoption of technologies shows several notable departures from prior years' findings, when cost consistently emerged as the most substantial barrier to application of new technologies, followed by lack of information and availability. From 2016 to 2018, progressively smaller proportions of survey respondents reported that they are unsure what is locally available and are concerned about the cost of those products, indicating that ICT-enabled extension may indeed have increased awareness about technologies and communicated that costs were not unreasonable. However, an increasing number of farmers reported that promoted technologies are not available locally, indicating that farmers' knowledge of what is available had improved by 2018, when adoption was hindered by actual availability. A growing number of respondents also reported that they perceived no benefit from adoption of new technologies or practices, perhaps reflecting that increased exposure (through ICT services and, for example, neighbors' experimentation with the promoted technologies) did not convince them of benefits. This may relate to the complexity of messages emerging from farm trials (i.e., that farmers could pursue several technology options), but is also interesting in the context of several 'other' responses indicating that problems with rainfall, grazing livestock, and pests presented barriers to adoption of new technologies. It is possible that these environmental barriers negated potential gains from the adoption of new technologies, in the eyes of many farmers. However, over the course of all years' surveys, almost no farmers reported that poor past performance, distrust of the new technologies, lack of relevance, or lack of knowledge about how to use the technologies are barriers to their use.

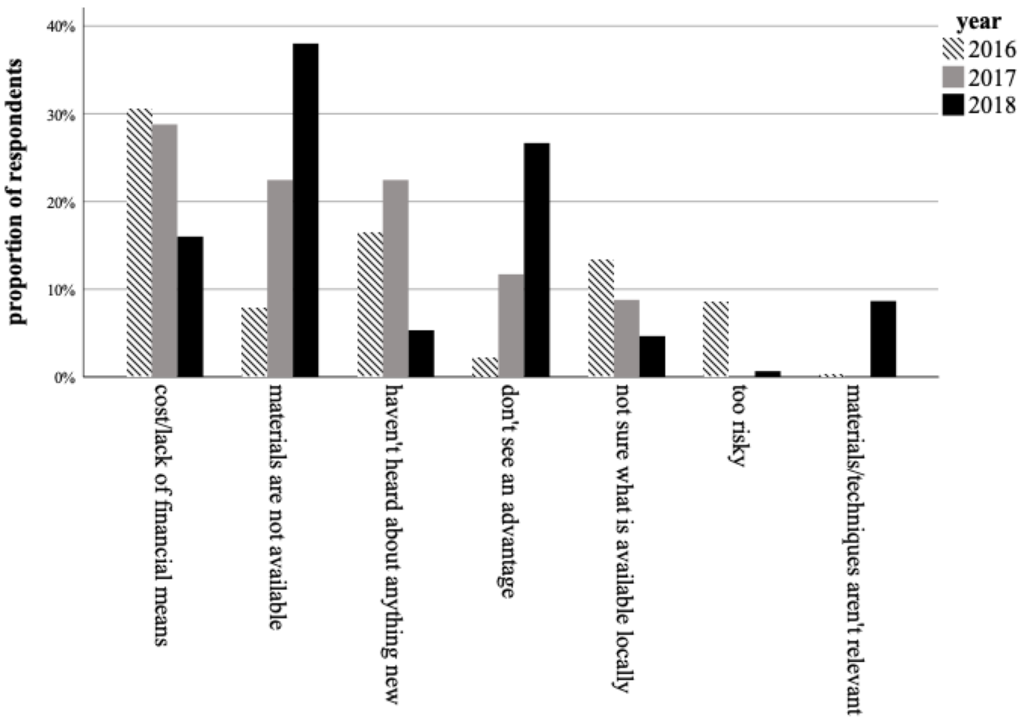

Figure 7. Reasons for non-adoption over time, among farmers exposed to ICT services. In each successive survey, a greater proportion of farmers reported that availability and perceived benefits of promoted technologies were barriers to adoption.

Focus group discussions reinforced these findings. Many conversations touched on local seed availability, and particularly the timing of seed availability, as a key barrier to their adoption; planting windows in rainfed farming system in Senegal are extremely narrow. Over the course of the project, farmers in focus groups expressed mounting frustration related to the delayed availability of seeds that were advertised to them, as farmers delayed planting while waiting for seeds that in some cases never arrived and/or made it too late for them to obtain and plant other seeds. Anecdotally, some farmers explained that they preferred waiting for government-subsidized seeds to become available rather than purchasing early from distributors.

There were also numerous complaints about seed quality and a few allegations of favoritism and discrimination in seed distribution at cooperatives and among other project managers, pointing again to the role of market failures external to the ICT-enabled extension campaigns in hampering adoption.

Conclusions

The TICmbay project in Senegal leveraged ICT services to reach a large number of farmers with access to radio and mobile phones and generated increased interest in promoted agricultural technologies. It tested out several approaches to ICT-enabled extension that have potential for broader impact. First, IVR-based services were used in place of SMS to expand accessibility. Second, decentralized programs and messaging allowed for incorporation of voices that farmers trust and languages they understand. Finally, IVR-based push messages in particular emerged as a potentially powerful tool to provide farmers with timely information, and these interventions in particular warrant further study. However, this study did not find evidence of impact of radio- and phone-based extension on farmers' uptake of the technologies promoted in this project. This leaves many questions unanswered as to if and when ICT services can be effective tools in extension.

This study suggests that the choice of technologies to promote over ICT channels, as well as associated market failures, played a substantial role in farmers' adoption decisions. In comparing farmers' reasons for *not* adopting promoted technologies over three consecutive years, we found that knowledge about new technologies indeed improved as ICT-based outreach expanded. However, over time, farmers increasingly reported that adoption was limited by availability of the promoted technologies and farmers' failure to perceive benefits from adoption. The first response points to the importance of matching the roll-out of ICT-enabled extension to the readiness of the input sector and associated markets to respond to increased demand. Otherwise, mistimed use of ICT-enabled extension may undermine trust in ICT services more broadly.

Farmers' failure to perceive benefits from the promoted seeds and fertilizers, despite extensive ICT-based outreach, has multiple possible causes. One is lingering distrust of certified seeds linked to the Senegalese government's poorly managed seed subsidy program (Mabaya et al., 2017). Another is the complexity of messages delivered over ICT channels in this project; as farm trials pointed to a range of successful combinations of the seed and organic and inorganic fertilizer technologies, ICT-based messages did not focus on a single take-home message or technology. Both of these aspects of the project likely undermined its effectiveness, as ICT interventions are known to be most effective when targeting specific information gaps amidst well-functioning markets (Aker et al., 2016). Finally, farmers may not have perceived benefits of promoted technologies because benefits were indeed limited. For resource-poor farmers in a high-risk environment like Senegal, technology packages that primarily target subsistence crop production may not be a high priority for investment. It also appears, in this case, that target beneficiaries—especially women—were not adequately engaged in the selection of these technologies, which might have led to greater and more equitable adoption. Using ICTs to expand uptake of farmer-generated or farmer-selected technologies might have more potential than a project promoting technologies selected in a top-down manner, as seen here.

Gender emerged as a particular area of concern in this study, despite being a stated priority for both donors and implementers of the project. Although women and men listen to radio programs at reasonably equivalent rates, women were much less likely to engage with phone-based services (in particular, the IVR call-in service). This is unsurprising given that mobile phones and radios are often owned and controlled by men. However, women's limited engagement in public discourse, generally, and the pressures women feel to conserve their limited financial resources are likely to present obstacles to their engagement in any ICT-based programs. Focusing on women's crops and interests (including by engaging them in technology selection) and leveraging specialized approaches to engaging women, such as highlighting women's voices and working directly with local women's groups, could aid in reducing the gender gap in technology adoption. In this project, women did adopt low-cost soil amendments and cowpea seeds at relatively high rates, indicating the potential of projects that respond directly to women's unique constraints. Future communication and information-sharing campaigns targeting women should be integrated with broader development interventions that acknowledge and respond to women's unique status—their limited access to land, education, and finance; their roles in farming, which in this case excluded them from benefitting from many promoted crop varieties; and their responsibilities in the household.

Logistic regression allowed for evaluation of other variables that might influence farmers' adoption of promoted technologies. This analysis showed that while exposure to ICT services is not correlated with adoption, personal connections to the SSTP farm trials consistently emerged as a significant predictor of adoption. These findings suggest, first, that information provision via ICTs was likely not sufficient to overcome barriers to adoption of new technologies. Second, participatory farm trials remain a potentially powerful tool in incentivizing uptake of technologies. Future research in this field should explore the extent to which ICT tools can *enhance* traditional extension tools and farmer-to-farmer learning, rather than fully replace them. If ICT services can add value, the challenge becomes evaluating how much, for whom, and at what cost relative to traditional extension services. Ultimately, the results of this study demand thoughtful future application of ICTs in development that leverage the benefits of sharing information at scale and supporting dialogue without exacerbate existing inequalities.

References

Adegbola, P., & Gardebroek, C. (2007). The effect of information sources on technology adoption and modification decisions. *Agricultural Economics*, *37*(1), 55–65. https://doi.org/10.1111/j.1574-0862.2007.00222.x

Aker, J. C. (2011). Dial "A" for agriculture : a review of information and communication technologies for agricultural extension in developing countries. *Agricultural Economics*, *42*, 631–647. https://doi.org/10.1111/j.1574-0862.2011.00545.x

Aker, J. C., Ghosh, I., & Burrell, J. (2016). The promise (and pitfalls) of ICT for agriculture initiatives. *Agricultural Economics*, *47*, 35–48. https://doi.org/10.1111/agec.12301

Ali, J. (2012). Factors affecting the adoption of information and communication technologies (ICTs) for farming decisions. *Journal of Agricultural and Food Information*, *13*(1), 78–96. https://doi.org/10.1080/10496505.2012.636980

Ali, J., & Kumar, S. (2011). Information and communication technologies (ICTs) and farmers' decision-making across the agricultural supply chain. *International Journal of Information Management*, *31*(2), 149–159. https://doi.org/10.1016/j.ijinfomgt.2010.07.008

Alzouma, G. (2005). Myths of digital technology in Africa: Leapfrogging development? *Global Media and Communication*, *1*, 339–356.

ANSD/Senegal & ICF. (2017). *Senegal: Enquête Démographique et de Santé Continue [Demographic and Health Survey, Senegal]*. Retrieved from https://dhsprogram.com/publications/publication-FR345-DHS-Final-Reports.cfm

Bationo, A., & Buerkert, A. (2001). Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, *61*, 131–142.

Bentley, J. W., Van Mele, P., Harun-ar-Rashid, M., & Krupnik, T. J. (2016). Distributing and Showing Farmer Learning Videos in Bangladesh. *Journal of Agricultural Education and Extension*, *22*(2), 179–197. https://doi.org/10.1080/1389224X.2015.1026365

Bryan, E., Deressa, T. T., Gbetibouo, G. A., & Ringler, C. (2009). Adaptation to climate change in Ethiopia and South Africa: options and constraints. *Environmental Science and Policy*, *12*(4), 413–426. https://doi.org/10.1016/j.envsci.2008.11.002

Casaburi, L., Kremer, M., Mullainathan, S., & Ravindra Ramrattan. (2019). *Harnessing ICT to Increase Agricultural Production: Evidence From Kenya*. Retrieved from https://scholar.harvard.edu/files/kremer/files/sms_paper_with_tables_20190923_merged.pdf

Chambers, R. (2014). *Rural Development: Putting the Last First*. Routledge. Retrieved from https://books.google.com/books?hl=en&lr=&id=zLeOAwAAQBAJ&pgis=1

Cole, S. A., & Fernando, A. N. (2012). *The Value of Advice: Evidence from Mobile Phone-Based Agricultural Extension* (No. 13– 047). *Harvard Business School Working Papers*. https://doi.org/10.2139/ssrn.2179008

Crane, T. A., Roncoli, C., Paz, J., Breuer, N., Broad, K., Ingram, K. T., & Hoogenboom, G. (2010). Forecast Skill and Farmers' Skills: Seasonal Climate Forecasts and Agricultural Risk Management in the Southeastern United States. *Weather, Climate, and Society*, *2*(1), 44–59. https://doi.org/10.1175/2009WCAS1006.1

Diouf, N. S., Ouedraogo, I., Zougmoré, R. B., Partey, S. T., Gumucio, T., & Group, F. (2019). Factors influencing gendered access to climate information services for farming in Senegal. *Gender, Technology and Development*, *0*(0), 1–18. https://doi.org/10.1080/09718524.2019.1649790

Eldon, J., Baird, G., Sidibeh, S., Dobasin, D., Rapaport, P., Cheng, W., & Shennan, C. (2020). On-farm trials identify adaptive management options for rainfed agriculture in West Africa. *Agricultural Systems*, *182*(January). https://doi.org/10.1016/j.agsy.2020.102819

Eswaran, H., Almaraz, R., Van Den Berg, E., & Reich, P. (1997). An assessment of the soil resources of Africa in relation to productivity. *Geoderma*, *77*(1), 1–8. https://doi.org/10.1016/S0016-7061(97)00007-4

Fafchamps, M., & Minten, B. (2012). Impact of SMS-based agricultural information on Indian farmers. *World Bank Economic Review*, *26*(3), 383–414. https://doi.org/10.1093/wber/lhr056

Funk, C., Rowland, J., Adoum, A., Eilerts, G., Verdin, J., & White, L. (2012). *A Climate Trend Analysis of Senegal*. *Informing Climate Change Adaptation Series Factsheet*. Retrieved from http://pubs.usgs.gov/fs/2012/3123/

Gandhi, R., Veeraraghavan, R., Toyama, K., & Ramprasad, V. (2007). Digital Green: Participatory Video for Agricultural Extension. In *2007 International Conference on Information and Communication Technologies and Development*.

Glendenning, C. J., & Ficarelli, P. P. (2012). *The Relevance of Content in ICT Initiatives in Indian Agriculture* (No. 01180). *IFPRI Discussion Papers*.

Goyal, A. (2010). Information, Direct Access to Farmers, and Rural Market Performance in Central India. *American Economic Journal: Applied Economics*, *2*(3), 22–45.

Gumucio, T., Hansen, J., Huyer, S., & Huysen, T. Van. (2019). Gender-responsive rural climate services : a review of the literature Gender-responsive rural climate services : a review of the literature. *Climate and Development*, 1–14. https://doi.org/10.1080/17565529.2019.1613216

Gurumurthy, A. (2004). *Gender and ICTs: Overview Report*.

Gurumurthy, A., & Chami, N. (2014). *Gender equality in the information society*. Retrieved from http://www.genderit.org/sites/default/upload/gender_and_icts_briefing_2014.pdf

Hufford, G. (1984). *The ITS Irregular Terrain Model, version 1.2.2: The algorithm*. Boulder.

Jack, B. K. (2011). *Market inefficiencies and the adoption of agricultural technologies in developing countries*. *White Papers, Agricultural Technology Adoption Initiative*.

Katungi, E., Edmeades, S., & Smale, M. (2008). Gender, Social Capital and Information Exchange in Rural Uganda. *Journal of International Development*, *20*, 35–52. https://doi.org/10.1002/jid.1426

Kiiza, B., & Pederson, G. (2012). ICT-based market information and adoption of agricultural seed technologies: Insights from Uganda. *Telecommunications Policy*, *36*, 253–259. https://doi.org/10.1016/j.telpol.2012.01.001

Kleine, D. (2013). *Technologies of choice?: ICTs, development, and the capabilities approach*. Cambridge: MIT Press.

Mabaya, E., Ba, M. M. D., Ndiaye, M., & Mugoya, M. (2017). *Senegal Brief 2017 - The African Seed Access Index*. Retrieved from https://tasai.org/wp-content/themes/tasai2016/img/tasai_brief_2017_senegal_final_lr.pdf

Mansell, R. (2014). Power and Interests in Information and Communication and Development: Exogenous and Endogenous Discourses in Contention. *Journal of International Development*, *26*, 109–127. https://doi.org/10.1002/jid

Marshall, N. A., Gordon, I. J., & Ash, A. J. (2011). The reluctance of resource-users to adopt seasonal climate forecasts to enhance resilience to climate variability on the rangelands. *Climatic Change*, *107*(3), 511–529. https://doi.org/10.1007/s10584-010-9962-y

Meinzen-Dick, R., Quisumbing, A., Behrman, J., Biermayr-Jenzano, P., Wilde, V., Noordeloos, M., … Beintema, N. (2011). Agricultural Extension. In *Engendering Agricultural Research, Development and Extension* (pp. 62–82). Washington, DC: International Food Policy Research Institute. Retrieved from https://books.google.com/books?id=9dSd9xjSP2sC

Mitra, S., Mookherjee, D., Torero, M., & Visaria, S. (2018). Asymmetric information and middleman margins: An experiment with West Bengal potato farmers. *Review of Economics and Statistics*, *C*(1), 1–13. https://doi.org/10.1162/REST

Mittal, S. (2016). Role of Mobile Phone-enabled Climate Information Services in Gender-inclusive Agriculture. *Gender, Technology and Development*, *20*(2), 200–217. https://doi.org/10.1177/0971852416639772

Mittal, S., Gandhi, S., & Tripathi, G. (2010). *Socio-Economic Impact of Mobile Phones on Indian Agriculture* (No. 246). Retrieved from http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&dopt=Citation&list_uids=11832231

Mittal, S., & Mehar, M. (2016). Socio-economic Factors Affecting Adoption of Modern Information and Communication Technology by Farmers in India: Analysis Using Multivariate Probit Model. *Journal of Agricultural Education and Extension*, *22*(2), 199–212. https://doi.org/10.1080/1389224X.2014.997255

Moser, C. M., & Barrett, C. B. (2006). The complex dynamics of smallholder technology adoption: The case of SRI in Madagascar. *Agricultural Economics*, *35*(3), 373–388. https://doi.org/10.1111/j.1574-0862.2006.00169.x

Nakasone, E. (2013). The Role of Price Information in Agricultural Markets: Experimental Evidence from Rural Peru. In *Agricultural & Applied Economics Association 2013 Annual Meeting* (pp. 1–54).

Nakasone, E., Torero, M., & Minten, B. (2014). The Power of Information: The ICT Revolution in Agricultural Development. *Annual Review of Resource Economics*, *6*, 533–550. https://doi.org/10.1146/annurev-resource-100913-012714

Ndiaye, M., Audet-Bélanger, G., & Gildemacher, P. (2015). *Scaling Seeds & Technologies Partnership – Baseline phase II*. Retrieved from www.kit.nl

Payne, J. (2015). The New Alliance ICT Extension Challenge Fund: Two Key

Challenges.

Poushter, J., Bell, J., Carle, J., Cuddington, D., Deane, C., Devlin, K., … Zainbulbhai, H. (2015). *Cell Phones in Africa : Communication Lifeline*. *Pew Research Centre*.

Rogers, E. M. (2003). *Diffusion of Innovations* (5th Ed.). New York: Free Press.

Roncoli, C., Ingram, K., & Kirshen, P. (2001). The costs and risks of coping with drought: Livelihood impacts and farmers' responses in Burkina Faso. *Climate Research*, *19*(2), 119–132. https://doi.org/10.3354/cr019119

Seck, A. (2016). *Fertilizer Subsidy and Agricultural Productivity in Senegal* (AGRODEP Working Papers No. 0024).

Thome, K., Smith, M. D., Daugherty, K., Rada, N., Christensen, C., & Meade, B. (2019). *International Food Security, 2019-2029*. Retrieved from www.ers.usda.gov

Treinen, S., & Van der Elstraeten, A. (2018). *Gender and ICTs: Mainstreaming gender in the use of information and communication technologies (ICTs) for agriculture and rural development*. Rome. https://doi.org/10.4324/9780203968239

United Purpose. (2017). *AGRA Grant Narrative Report: Increasing awareness and uptake of improved seeds through farmer demonstrations and farmer to farmer networks in Senegal*.

Westermann, O., Förch, W., Thornton, P., Körner, J., Cramer, L., & Campbell, B. (2018). Scaling up agricultural interventions: Case studies of climate-smart agriculture. *Agricultural Systems*, *165*(June), 283–293. https://doi.org/10.1016/j.agsy.2018.07.007

World Bank. (2011). *ICT in Agriculture: Connecting Smallholders to Knowledge, Networks, and Institutions*. Washington, DC. Retrieved from file:///Users/rachel/Downloads/646050ESW0P1180lture0e0Sourcebook12.pdf

World Bank. (2016). Fertilizer consumption (kilograms per hectare of arable land) - Senegal. Retrieved March 31, 2020, from https://data.worldbank.org/indicator/AG.CON.FERT.ZS?locations=SN-ZG-1W

World Bank. (2017). Cereal yield (kg per hectare) - Senegal. Retrieved July 11, 2020, from https://data.worldbank.org/indicator/AG.YLD.CREL.KG?locations=SN-ZG-1W-XM

World Bank. (2018). Food imports (% of merchandise imports) - Senegal. Retrieved March 31, 2020, from https://data.worldbank.org/indicator/TM.VAL.FOOD.ZS.UN?locations=SN

World Bank Group. (2018). *Systematic Country Diagnostic of Senegal*. https://doi.org/10.1596/30852

World Bank Group. (2019). *Africa's Pulse, No. 19: Analysis of Issues Shaping Africa's Economic Future* (Vol. 19). Washington, DC. https://doi.org/10.1596/978-1-4648-1421-1

Chapter 3. Post-project decision-making: farmer technology use choices in a risky environment

Abstract

Efforts toward a new Green Revolution in Africa have focused on expanding smallholder farmers' use of improved seeds, fertilizers, and other inputs. Many of the reasons the first Green Revolution failed to take hold in Africa, including agroecosystem complexity, poorly-suited seed technologies, poor infrastructural and market development, and technology costs, remain potential obstacles to uptake and retention of 'new' Green Revolution technologies. This study is a post-intervention follow-up examining farmers' use of and decision-making around introduced seed and fertilizer technologies two years after their participation in farm trials. Using surveys, participatory resource allocation mapping, and soil sampling in three regions of Western Senegal, I explore retention and disadoption of improved seeds and fertilizers in the context of heterogeneous and high-risk farm conditions. Findings suggest that farmer decisions to disadopt seed technologies are often involuntary and related to environmental risk. Additionally, most active farmer decisions were oriented toward risk management rather than maximizing productivity. Both outcomes suggest that promoting seeds through small-scale farm trials may be inadequate to achieve sustained adoption, and that these technologies do not contribute adequately to the resilience of smallholder farms in Senegal.

Keywords

trial-based scaling; soil fertility gradients, technology adoption, risk, resilience

Introduction

Historically, research and extension processes in global agricultural development have served to develop and deliver external innovations to smallholder farmers through a ‘technology transfer’ model, with the purported hopes of boosting yields, raising farmers’ income, and improving global food security. In the twentieth century, the Green Revolution and Consultative Group for International Agricultural Research (CGIAR) network established institutional pipelines through which these agricultural technologies, and particularly high-yielding seed varieties, are developed and disseminated (Evenson & Gollin, 2003). Generally, this process had led from scientifically rigorous agronomic research and testing, often conducted at experiment stations, to the dissemination of ‘improved’ crop varieties and other ‘proven’ agricultural technologies to farmer ‘end-users’ (Farrington, 1989; Röling & Jiggins, 1998). Farmer uptake is expected to result from rational economic decision-making, if and when farmers perceive advantages of the promoted technologies (Evenson & Gollin, 2003; Patel, 2013).

Under this model, the Green Revolution successfully expanded the use of high-yielding varieties and associated fertilizers, pesticides, and irrigation technologies in many parts of the world. Adoption and retention of Green Revolution technologies in sub-Saharan Africa has lagged, however, suggesting a more complex process of diffusion of agricultural innovations in this context. Commonly cited reasons for the Green Revolution's failure in Africa include agroecological complexities and the delayed introduction of regionally-appropriate seed varieties, including those of millet, sorghum, barley, pulses, and root crops (Evenson & Gollin, 2003). These failures have inspired calls for increased farmer participation in research and development processes aimed at more effective refinement and tailoring of innovations to diverse African smallholder contexts (Ashby & Sperling, 1995; Farrington, 1989; Martin & Sherington, 1997; Röling & Jiggins, 1998).

Questions remain about the viability of many new Green Revolution technologies in African smallholder context, even when participatory research approaches are applied. This study builds on adoption and diffusion of innovations theory to consider farmers' retention and use of improved seed and fertilizer technologies in the wake of a participatory agronomic trial in Western Senegal. This sort of follow-up on development projects is often neglected, limiting our understanding of medium- to long-term adoption dynamics and real-world feasibility of agriculture technologies. I examine patterns in farmer retention and disadoption of introduced technologies, then evaluate whether farmers' perception of soil fertility gradients on their farm align with measurable soil characteristics and what role these perceptions play in technology use decisions. This research contributes to our understanding of farmer decision-making processes, necessary to inform modeling of farm production and crop plan management (Dury, Schaller, Garcia, Reynaud, &

Bergez, 2012) and better align agricultural research and development with farmer needs and priorities.

Understanding adoption dynamics

Agricultural extension and other innovation diffusion efforts generally rely, whether implicitly or explicitly, on a rational actor model that assumes informational barriers to be primary obstacles to technology adoption. Material constraints such as access to credit, labor availability, land tenure, and the functionality of associated markets sometimes figure into these models as well, but rarely change the placement of 'adoption' as the endpoint of the dissemination process. Indeed, donor-mandated evaluations and peer-reviewed studies of projects promoting agricultural technologies are often based on standardized and simplistic adoption indicators focused on initial uptake, with relatively little concern for farmer satisfaction, disadoption, and village-, household-, or farm-scale heterogeneity of use. Medium- and long-term studies of technology impact, particularly those that consider the spatial or temporal scale of technologies' use and downstream effects on household incomes, food security, and nutrition, are relatively less common (Loevinsohn, Sumberg, Diagne, & Whitfield, 2013).

Furthermore, technology adoption studies have often considered farmer adaptation, through which growers modify or personalize a tool or technique to make it more suited to their farm, a confounding variable or "noise" (Martin & Sherington, 1997; Rogers, 2003). This outlook is adopted in part because adaptation can result in low rates of official adoption of complex technology packages (e.g., Giller, Witter, Corbeels, & Tittonell, 2009). However, farmer adaptation is a critically important process in the development and diffusion of locally appropriate technologies. Modifications can occur for a number of reasons, including the complexity, vagueness, or broad scope of the original innovation; a user's lack of knowledge; a high degree of local ownership or prior local experimentation; or direct encouragement (Rogers, 2003). While the adaptation process is rarely documented, it introduces vital practical knowledge regarding complex ecological systems (Shennan, 2008) and illuminates structural and environmental constraints that shape farmer decision-making around these technologies (Reece & Sumberg, 2003). This study seeks to explore the complexities of the adoption process beyond initial uptake by considering retention, adaptation, and the role of structural and environmental constraints in farmer decision-making around introduced technologies.

Farmers' crop and seed choices

This research follows up on a set of participatory farm trials in Senegal testing improved seed technologies and inorganic and organic fertilizers under realistic farm management conditions (Eldon et al., 2020). Agronomic research, largely conducted at experiment stations, suggests that many such improved seeds, soil fertility technologies, and cultural practices have substantial potential to boost yields, contribute to pest control, and alleviate some of the pressures of continuous cultivation in semi-arid West Africa. For example, controlled trials of nitrogen fertilization and millet-legume rotations have been found to significantly increase millet yields (Bagayoko et al., 1996; Bationo & Ntare, 2000; S. C. Mason, Maman, et al., 2015). However, the incredible variability in farmers' circumstances and preferences make generalizations based on experimental station research problematic. Decentralized on-farm research on such technologies is less common, but also suggests gains can result from diverse combinations of improved seeds and organic and inorganic fertilizers, even when applied in less-than-optimal quantities (Eldon et al., 2020).

However, the mixed legacy of the Green Revolution (Patel, 2013) and the lack of widespread adoption of improved seed, particularly in Africa (Eriksson et al., 2018; Walker, 2006) point to challenges and concerns in promoting improved seed varieties. Some central preoccupations relate to the appropriateness and ethics of seeds technologies, which contribute to farmer dependence on externally-sourced inputs, especially privatized germplasm (Kloppenburg, 2010). The associated loss of resilience through reduced genetic diversity and agrobiodiversity (Zimmerer, 2010) introduces a layer of agronomic vulnerability that compounds increased economic dependence. Socioeconomic equity presents a further concern, as relatively few benefits of Green Revolution seeds and other technologies historically accrued to resource-poor farmers (Patel, 2013). In addition to these ethical concerns, there exist practical concerns about the viability of modern seed varieties in smallholder systems. Controlling for the impacts of climate, crop yields in much of Africa fall below the potential maximum for currently available crop varieties (Licker et al., 2010), indicating either insufficient use of high-yielding varieties, failure to employ related best management practices, or both.

Growing awareness of farmers' constraints and preferences has led to increasing calls for participatory breeding and varietal selection programs that better responds to farmers' needs and priorities (Eriksson et al., 2018; Walker, 2006). Farmers' crop choices are known to be shaped by a range of factors, including agroecology suitability, research and extension systems, household access to financial resources and other assets, technologies' availability, farmers' access to land, labor, and markets, and perceived risks and opportunity costs (Farrow et al., 2019). Varietal choices are more specifically associated with higher yield, short growth cycles, product characteristics (often related to grain size and color or ease of harvesting and processing, with implication for labor requirements), plant characteristics, and marketability (Adjei-Nsiah et al., 2008; Gridley, Jones, & Wopereis-Pura, 2002; Kitch, Boukar, Endondo, & Murdock, 1998; Omanya et al., 2007).

Critically, yield and profit maximization are not the exclusive goal of farmers – risk management and resilience are frequent concerns (e.g., Nyikal & Kosura, 2005), particularly in light of unpredictable disturbance (Darnhofer, Fairweather, & Moller, 2010). Evidence points to trade-offs between maximizing farm productivity under optimal conditions and achieving resilience under suboptimal conditions—that is, avoiding substantial downside losses (Abson, Fraser, & Benton, 2013; Gaudin et al., 2015; Sirrine et al., 2010; Snapp et al., 2010). Farmers' desired position on the resilience-productivity spectrum inevitably varies, impacting what they perceive to be most 'rational.'

Factors unrelated to either yield or risk management also come into play; taste, appearance, and marketability play a role in crop choices, particularly after an acceptable yield threshold is reached (Kitch et al., 1998). Context can play an outsized role in farmer choices as well; West African farmers have identified lack of awareness and conservative attitudes toward new technologies, seed availability, bird and pest damage to early maturing varieties, and inadequate fertilizer access as barriers to adoption of improved millet varieties (Omanya et al., 2007). Almekinders et al. (2019) conclude that seed choices are extremely variable and context-dependent, shaped by many of the above factors as well as farmers' social position, their wider farming system, and unpredictable exogenous variables.

Given the complexity of farmers' crop and varietal choices, it is unsurprising that uptake of an 'improved' technology, even when farmers have first-hand knowledge of potential benefits and direct access to seeds, is not a guarantee. Pircher, Almekinders, and Kamanga (2013) found uptake of legumes for improved soil fertility to be limited in the years following participatory trials and seed distributions. The primary reasons for non-adoption varied according to farmers' resource access, but primarily related to limited seed availability, lack of interest, lack of perceived benefit, and labor constraints. Similarly, Ronner et al. (2016) found that, despite promising average yields produced in trials of soybean varieties, widespread adoption did not automatically follow due to extreme variability in farming conditions that mediates the success of these technologies. Variable genotype x environmental interactions mean that a high-performing variety in one location may be poorly suited for a neighboring community (Omanya et al., 2007). This study provides insight into farmer retention and adaptation of, uniquely, improved varieties of both legume and non-legume crops in Senegal.

Constraints to seed access

In many cases, seed availability presents a central barrier to adoption and continued use of modern varieties. Seed systems in many parts of Africa remain under-developed, particularly for legumes and other non-grain crops (Farrow et al., 2019). Constraints include limited breeding activities, slow varietal turnover, and limited availability of foundation seed (Access to Seeds Foundation, 2019). By their very nature, the open-pollinating varieties that would be most accessible to resource-poor farmers are inherently poor investments for seed companies, given the prevalence of farmer-saved seed, highly localized preferences, and storage/transportation difficulties associated with vegetatively propagated crops (S. David, Mukandala, & Mafuru, 2002; S. David & Sperling, 1999).

Senegal's seed system struggles against weak institutions and distribution networks, inadequate quality control, and certified seed production geared toward meeting only 'expressed needs' of farmers (Mabaya et al., 2017; Ndiaye et al., 2015). Most certified seed that is produced in Senegal is purchased by the government and subsidized for farmers, but carries a reputation for inferior quality. A 2015 study in Senegal (Ndiaye et al., 2015) found that only 14% of farmers surveyed used certified seed, while many others purchase seed of unspecified origin (*tout-venant* seed) and three-quarters practice seed saving (for unspecified lengths of time).

Even where seed systems are adequately functional, structural challenges undermine farmers' seed access. Farmers' resource constraints and environmental variability can lead to loss of seed stock to opportunistic sale, household consumption, or storage loss (S. David et al., 2002; S. David & Sperling, 1999). In cases where seeds have been introduced to farmers directly and free of charge, continued use of improved seed technologies is not a guarantee. Disadoption of beans in Tanzania has been tied to accidental seed loss and well as poor marketability (S. David et al., 2002), while poor profitability and rainfall insufficiency led to high rates of disadopton of NERICA rice in Uganda (Kijima, Otsuka, & Sserunkuuma, 2011). The amount of seed farmers receive, variety popularity and productivity, environmental conditions, and farmers' socioeconomic circumstances influence farmers' tendency to share and ability to retain seed (S. David & Sperling, 1999).

Farmers' soil fertility management choices

Soil fertility technologies, including inorganic mineral fertilizers, crop residues, and manure, have long been researched and promoted for farmers' use in the West African Sudano-Sahelian zone (Schlecht et al., 2006). These technologies respond to soil fertility constraints associated with both inherent limitations (Bationo & Buerkert, 2001) and intensifying cultivation, including reduced use of fallowing (Bagayoko et al., 1996).

While manure, crop residues, and compost are typically produced on the farm, inorganic fertilizers require monetary investment. If farmers do not perceive expected returns to outweigh investments and the risk of failure to be adequately low, they are unlikely to invest in these technologies (Schlecht et al., 2006). Unsurprisingly, inorganic fertilizer use has paralleled government subsidy policies; extensive fertilizer use in the 1960s and 1970s dropped off in the late 1980s when structural adjustment policies led to withdrawal of subsidies, and later rebounded with reintroduction of subsidies in the 2000s (Seck, 2016).

Prior studies suggest that West African farmers prioritize use of inorganic fertilizers for cotton and other non-grain cash crops; its wider use on farms is limited by availability, cost, access to credit, and potential profit (Enyong et al., 1999; S. C. Mason, Ouattara, et al., 2015). A 2015 study found that 45% of Senegalese farmers used inorganic nitrogen-phosphorus-potassium (NPK) fertilizers, 68% applied manure, and only 1% applied compost to their primary millet field. Substantially lower proportions of farmers apply these inputs to their primary groundnut and cowpea plots (Ndiaye et al., 2015), despite the fact that groundnut is a key cash crop for many households. This study aims to clarify farmers' spatial decision-making around soil fertility technologies in light of this discrepancy.

Some concerns exist about the intensive use of inorganic fertilizers in this region. Without simultaneous use of organic amendments to boost soil organic matter content, pH buffering capacity, and nutrient holding capacity, some inorganic nitrogen and phosphorus fertilizers (particularly urea, a nitrogen fertilizer commonly used in African systems) may contribute to rapid soil organic matter decomposition and acidification (Bationo & Buerkert, 2001) without achieving intended yield gains (Diop, 1999; Tittonell & Giller, 2013). Investments in inorganic fertilizers, having ‘failed to transform farming systems in low productive drylands,’ are not always justified in the eyes of farmers (Mortimore, 2010) and may contribute to poverty traps.

Manures and backyard composts are frequently promoted as organic amendments. In integrated crop-livestock systems common in the region, manure is often available either from livestock pens near homes or intentional corralling in fields. Farmers sometimes provide herders with food and fodder in exchange for penning livestock in fields during dry season (Enyong et al., 1999). Research suggests manure is one of if not the most widely applied inputs on Senegalese farms (Ndiaye et al., 2015), although not always available, particularly in sufficient quantities, to resource-poor farmers.

Crop residues are also widely available but supply is inadequate to meet soil nutrient needs, both due to productivity constraints and residues’ competing uses as livestock feed, fuel, and building material (S. C. Mason, Ouattara, et al., 2015). Residues not committed to these purposes are often consumed by free grazing livestock and termites or microbially decomposed, which occurs rapidly in the region’s tropical climate (Bationo & Buerkert, 2001). Remaining residues present challenges in the field preparation process, as they disrupt plowing and harrowing processes. As a result, crop residues remaining in fields before planting are frequently collected and burned in the fields (Bationo & Mokwunye, 1991; Enyong et al., 1999).

Input use patterns

Farmers' decisions about where on their farm to apply seed and soil fertility technologies are complex and varied. Strategic placement (e.g., in relation to perceived soil fertility), placement in pursuit of social conformity (Moser & Barrett, 2006), and rotation are among the documented decision-making models. Rotational practices relate foremost to crop rotation. Grain-legume rotations have been shown to bolster soil fertility, reduce pest and disease pressures, and increase yields in common West African cropping systems (Bagayoko et al., 1996; Bationo & Ntare, 2000; S. C. Mason, Maman, et al., 2015). Evidence of the prevalence of crop rotation in the West Africa region is mixed; some scholars argue that the practice is uncommon (e.g., Schlecht et al., 2006), while others describe groundnut-millet and cowpea-millet rotations as dominant cropping systems in Senegal (e.g., Diop, 1999).

Evidence suggests that spatial patterns in soil fertility technology use on farms are not arbitrary. Fields near household compounds are often the most intensively managed, especially with regard to soil fertility technologies (Brouwer, Fussell, & Herrmann, 1993; Vanlauwe, Tittonell, & Mukalama, 2006). Population pressures and land fragmentation mean farmers' fields are often dispersed, and application of soil fertility technologies in distant fields is challenging, especially where labor constraints exist (Enyong et al., 1999). Management practices and farmers' resource endowments thus influence microvariability in soil fertility (Brouwer et al., 1993; Deckers, 2002; Mtambanengwe & Mapfumo, 2005; Schlecht et al., 2006). Arguably, this microvariability serves to bolster resilience, as the uneven distribution of water and nutrients (the two most limiting factors in agricultural production in semi-arid West Africa) reduces the risk of complete crop losses (Brouwer et al., 1993).

Farmer perceptions of soil fertility gradients are shaped by soils' appearance and fields' relative performance (crop productivity as well as characteristic like disease prevalence, erosion, and water holding capacity), and typically align with measured fertility levels (Mtambanengwe & Mapfumo, 2005; Murage, Karanja, Smithson, & Woomer, 2000; Smaling, Stoorvogel, & Jager, 2002; Tittonell, 2007). Substantial prior research, particularly in East Africa, suggests that farmers often opt to invest most heavily in the areas they perceive to be most fertile through placement of high-value crops (Murage et al., 2000), denser planting, more intensive use of inputs, earlier planting, and/or increased labor (Rowe, Wijk, Ridder, & Giller, 2006; Tittonell, 2007; Tittonell, Vanlauwe, Leffelaar, Shepherd, & Giller, 2005). Relatively few studies have considered how soil fertility gradients shape farm management decisions in West Africa, and Senegal in particular, leading to their inclusion in this study.

Study context

Senegal sits in the West African Sudano-Sahelian zone. Its climate, particularly north of The Gambia, is semi-arid tropical, with a single rainy season from July to October that supports rainfed agricultural production. Like the rest of the Sahel, Senegal is prone to extreme climate variability, including recurrent droughts. There is evidence of increasing temperatures and decreasing rainfall over the last 60 years (Funk et al., 2012), but climate change projections for the region remain uncertain.

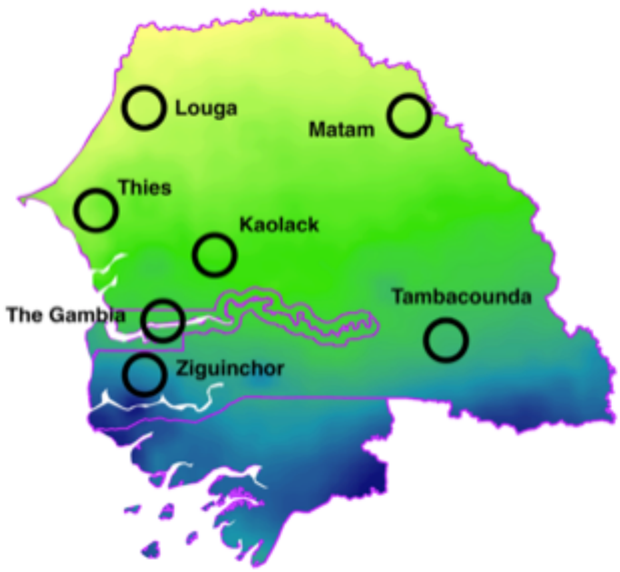

Figure 8. SSTP trial sites spanned six regions of Senegal and areas of the Gambia. Credit: United Purpose (2017)

Agricultural systems in Western Senegal are dominated by millet and groundnut production—millet being the staple crop and groundnut a primary cash crop—in parkland savanna agroecosystems. Sorghum, cowpea, maize, sorrel, and vegetables are also commonly cultivated. Soils are mostly well-drained and sandy Ferralic Arenosols, with some Calcaric Cambisols in the Thiés region (European Soil Data Centre (ESDAC), 2014), generally with low inherent fertility (Bationo & Buerkert, 2001). West-central Senegal was historically part of the Peanut Basin, a site of substantial agricultural investment, and remains densely populated relativ e to the rest of the country. The population is primary Wolof and Serer.

This study follows farmers in Western Senegal who participated in a decentralized trial of improved crop varieties and soil fertility treatments. The Scaling Seeds and Technologies Partnership (SSTP), funded by the Alliance for A Green Revolution in Africa (AGRA) and implemented through the NGO United Purpose, used hundreds of participatory farm trials across Senegal and The Gambia in 2015 and 2016 as semi-controlled experimental replicates (Figure 8).

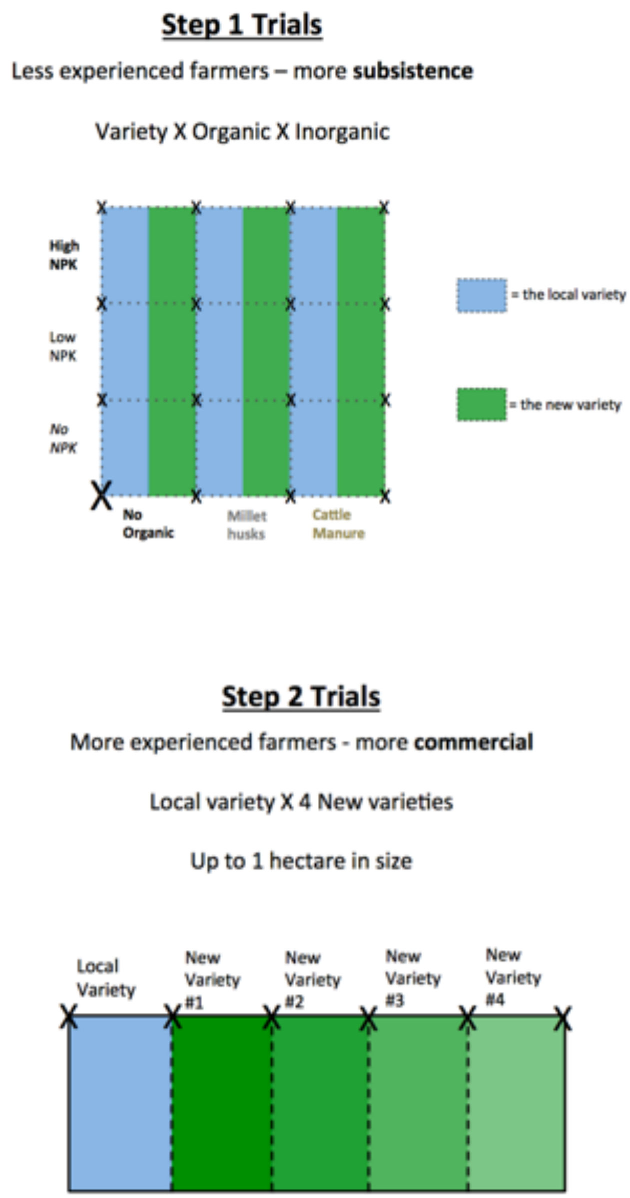

Figure 9. SSTP Step 1 and Step 2 trial designs.
Credit: United Purpose (2017)

Field selection and preparation, crop establishment, and harvest were supervised by local field agents, while day to day management decisions were made by individual farmers. Local field staff affiliated with regional cooperatives selected, trained, and provided seed and inorganic and organic fertilizer inputs to participating farmers. Farmers each produced one to two crops for either a Step 1 or Step 2 trial (Figure 9) in 2015 and/or 2016. In total, 360 trials were organized in 2015 and 672 trials were organized in the 2016 growing seasons (United Purpose, 2017).

Crop varietals and soil fertility technologies were selected through consultations between AGRA, the *Institut Sénégalais de Recherches Agricoles* (ISRA), and implementing partners. The varietal trials tested the performance of improved genotypes for six crops (groundnut, cowpea, millet, maize, sorghum, and rice) relative to a local variety of the same species as a control. Step 1 participants tested a single new variety and Step 2 participants tested four new varieties. Varietals included in the trial (Table 3) were chosen on the basis of yield, agroecological suitability, and availability; all varietals, with the exception of a single hybrid maize variety, were open-pollinating and could be saved year to year.

Table 9. Improved varieties included in the SSTP trials.

Crop	**Step 1 Variety**	**Step 2 Varieties**
Cowpea	Yacine	Yacine, Melakh, Pakao, Mougne
Groundnut	Fleur 11 (2015), 55-437 (2016)	Fleur 11, 7333, 55-437, GH119/20
Millet	Souna 3	Souna 3, Sosat C88, Gawane, Thialack 2
Maize	Early Thai	Early Thai, Swan, Tieba, Pan 12
Rice	Nerica 4	Nerica 6, Nerica 1, 144B9 (IRAC 10), Nerica 4
Sorghum	621A	621A, 621B, 622A, 622B

In addition to the testing of improved varieties, Step 1 farmers' crops were treated with select organic and inorganic fertilizer treatments: inorganic fertilizer applied at a high rate (150 kg/ha of 15-15-15 NPK preplant for all crops plus 150 kg/ha urea topdressing for cereals) and lower rate (50 kg/ha of 15-15-15 NPK preplant for all crops in addition to 50 kg/ha urea topdressing for cereals), dry cow manure (3000 kg/ha), and millet husk, a locally available crop residue (3000 kg/ha).

The SSTP trials involved farmers directly in testing new technologies for two main purposes that are common in participatory research: to enable realistic evaluation of the technologies' potential in different regions, and to facilitate adoption (Ashby & Sperling, 1995; Martin & Sherington, 1997; Röling & Jiggins, 1998; Shennan, 2008).

Table 10. Crops grown and number of participating farmers for Step 1 and Step 2 trials in each region of Senegal for 2015 and 2016.

		2015		**2016**	
Region	**Crops**	Step 1	Step 2	Step 1	Step 2
Louga	groundnut, cowpea, millet, sorghum	30	30	48	48
Matam	groundnut, cowpea, millet, sorghum	30	30	48	48
Thies	groundnut, cowpea, millet, sorghum	30	30	48	48
Kaolack	groundnut, cowpea, millet, sorghum, maize	30	30	60	60
Tambacounda	groundnut, cowpea, sorghum, maize, rice	30	30	60	60
Ziguinchor	groundnut, cowpea, millet, sorghum, maize, rice	30	30	72	72

Methods

The study explored three interrelated questions to inform debates about the viability of improved seeds and soil fertility technologies in a semi-arid smallholder context: 1) Which technologies had farmers retained, disadopted, or adapted in the years following their participation in the trial? 2) How do farmers' understandings of their on-farm environment shape technology use decisions? 3) Do farmer perceptions of soil fertility gradients align with measurable soil characteristics?

With the aid of a Wolof translator, I interviewed twenty-two former farm trial participants (thirteen men and nine women) in three regions with differing geophysical characteristics. Nine farmers were surveyed across four communities in Louga, six farmers in two communities in Kaolack, and seven in four communities across Thies. Sampling was purposive and based on official project participant lists and the research team's relationships with communities. In villages with many trial participants, farmers were randomly from the list, resampling as needed to ensure representation of women. Surveys were piloted in 2017 before official data collection in August-September 2018, using KoboCollect software on a mobile phone.

Closed-ended questions measured farmer behavior in the wake of the farm trial, including continued use, scaled-up use, or disadoption of introduced tools, and any farmer adaptation of these technologies. Open-ended questions explored decision-making processes, including farmer preferences and explanations of their choices. Categorization of survey responses allowed for a degree of quantification and comparison of farmer decisions. As the majority of farmers surveyed had grown improved cowpea (n = 10) and/or groundnut (n = 7) in the trial, these two crops are the implicit focus of the results presented here. Smaller numbers of farmers had tested millet (n = 6), sorghum (n = 4), and maize (n = 1) varieties during the trial.

A scenario-based mapping game was then employed to explore farmers' perceptions of soil fertility gradients and how these relate to technology use decisions. In the tradition of participatory resource allocation and flow mapping (P. Dorward, Clarkson, & Stern, 2015; P. Dorward, Shepherd, & Galpin, 2007;

Mascarenhas & Kumar, 1991) and similar studies of fertility gradients and related management decisions (e.g., Ramisch, 2005; Smaling, Stoorvogel, & Jager, 2002; Tittonell et al., 2005), farmers were asked to map their farm, including all characteristics they consider important, and shade high- and low-fertility areas in different colors. They were asked to indicate with props where they have planted certain crops and specific varieties this season and/or in past seasons. Several scenarios were proposed (such as receipt of additional inputs) and farmers asked to indicate where they would choose to apply specific technologies. These activities helped elucidate the norms and principles underlying farmer choices (Duch & Palmer, 2004; Habyarimana, Posner, Humphreys, & Weinstein, 2006; Halbrendt et al., 2014; Henrich et al., 2005), and allowed directing of farmers' focus beyond exogenous barriers to technology use, such as input costs, credit access, and unreliable rainfall. Farmer responses were classified and recorded in surveys, and open-ended responses paraphrased. Survey data were analyzed in Excel and SPSS.

To address question 3, composite soil samples were taken from the fields identified as most and least fertile in 20 of the surveyed farmers' maps. (One farmer was too sick to facilitate sampling, and another perceived no differences between his fields.) Fields were measured to calculate cultivated area before soil cores were taken at 0-15cm depth at a frequency of 30 cores per hectare. Composite samples from each field were then air dried and stored at room temperature. Soil pH and EC for each sample were measured using Oakton pH and pH/CON 700 Benchtop Meters (1:1 w/w). Visible organic material was removed from other dried subsamples before homogenization using a ball mill and testing for percent soil organic matter using the weight loss on ignition method. Homogenized subsamples were also tested for total percent weight C and N using a dumas (flash) combustion peripheral and isotope ratio mass spectrometer at the UC Santa Cruz Stable Isotope Laboratory. Data were analyzed in R using Wilcoxon signed rank tests, independent sample t-tests, and ANOVA.

Results and Discussion

Surveys showed that former trial participants viewed their experiences in the trial positively. General reflections suggested that the yield gains they experienced created lasting impressions. Two years after the conclusion of the trial, only a slight majority of farmers surveyed (12/22) felt that they were still benefiting 'a lot' from the seed varieties and soil amendments promoted in the trial, primarily through improved household food security and increased farm income. Another six farmers reporting benefiting 'somewhat,' while the remaining four felt that received little to no benefit from the technologies post-trial. Three of these four farmers (all in Kaolack) referred to lost harvests, partly due to rainfall problems last year, and the fourth explained that he did not have the equipment, labor resources, or market to take advantage of the tools.

Retention, disadoption, and adaptation of trial technologies

Seeds

SSTP post-project surveys indicated that farmers who had participated in the trial placed greater value on certified seeds relative to saved seeds or those sourced from neighbors or local markets than they did before the trial (Eldon et al., 2020). However, retention of seed technologies two years after trial completion was modest, considering that seeds had been distributed directly to these farmers and the majority of varieties were open-pollinating; 59% of farmers (13/22) surveyed were still using some or all of the improved varieties. Of the fifteen surveyed farmers who had participated in Step 2 varietal trials, and thus received four varietals, only four farmers were still using all of the varieties tested. Notably, none of the farmers who had grown sorghum (n = 4) or maize (n = 1) were still using introduced varieties, and only one of six farmers who trialed the millet varieties had retained them. In contrast, most farmers who tested the groundnut varieties (6/7) and cowpea varieties (8/10) had retained seeds for at least one improved genotype. Of the thirteen who were still using trial varieties, only five (four women and one man) had planted the seeds on more land this year than last year. Most of those who had not scaled up their use cited inadequate land, labor, or materials.

Most farmers who retained groundnut trial varieties grew the most popular variety (55-437, known as Fourrée), sometimes alongside local varieties. Overall trial data indicate that on average, the 55-437 variety increased yields the most over local varieties (United Purpose, 2017); farmers’ varietal preference is unsurprising given that groundnut is a key cash crop. In contrast, most farmers who retained cowpea trials varieties grew several of the improved varieties in addition to their local varieties. Local cowpea varieties were favored equally with the most popular improved cowpea variety (Yacine) because they produce more fodder than the trial varieties, and because some women specifically prized diversity and the risk reduction it brings. Unlike groundnut, cowpea varietal preferences were not focused on yield, but varied according to which required the least labor to grow, were easiest to clean and cook, and tasted the best – notably, Yacine yields, on average, were lower than those of two other trial varieties found to be less popular (United Purpose, 2017). These findings are in line with other research on varietal preferences in Africa showing that cooking time in particular matters in selecting legumes for household consumption (S. David et al., 2002).

Adaptation of seed technologies related primarily to planting arrangements. While the trials had introduced specific spacing arrangements to optimize yields, roughly half of the farmers retaining seed varieties (7/13) said they were still planting them as they learned in the trials. Most other farmers had begun to intercrop and intermix varieties, as this reduces demands for land and labor.

Seed disadoption was tied to a number of causes. Three women and six men had stopped using the trial varieties completely, and an additional two women and five men had disadopted some of the varieties. Most reasons related to a loss of harvest, either due to pest problems or poor rainfall, which led farmers to lose the seed stock saved from the trial. This aligns with results from other studies showing limited retention of introduced seed technologies (e.g., S. David et al., 2002). Pest pressures, in particular, are a known threat to the viability of short-cycle varieties, which can incur heavy bird damage before other varieties mature (Omanya et al., 2007).

Soil fertility technologies

Retention of soil fertility technologies promoted in the trial shows more promise. Nearly all farmers (20/22) had continued using dried cow manure on their fields, while a majority (13/22) had continued applying inorganic fertilizer, and half had continued applying millet husk. The primary barrier to wider use of organic amendments was availability; no farmers reported having access to enough inputs to apply to all of their fields. Relatedly, the substantial disadoption of millet husk relative to manure was primarily attributed to its competing use as animal fodder, although a few farmers reported not seeing adequate yield gains to justify use of millet husks in the field. A minority were also concerned about the cost involved in transporting both organic and inorganic materials from the compound to their fields. However, post-project surveys showed that trial participants' valuation of collecting manure and crop residues for use in fields and tethering livestock in fields had increased across the study area, while perceptions of the value of burning residues decreased (Eldon et al., 2020). Some farmers also expressed an interest in continued experimentation with organic amendments, particularly composting. Still, more than a third of farmers (8/20) reported that they have continued burning crop residues.

Disadoption of inorganic fertilizer was linked primarily to its cost, which farmers perceived was not justified. Some also feared negative impacts on long-term soil fertility, saying that inorganic fertilizer works more quickly than organic inputs but that benefits are short-lived; it "feeds the leaves" but not the soil, in the words of one farmer. This finding aligns with SSTP project reporting showing that farmers who participated in the trial prioritized organic fertilizers and new seeds over inorganic fertilizers (United Purpose, 2017)

Gender-based differences in retention and disadoption

Potentially meaningful, in discussions of trial technologies, were relative rates of retention among men and women. Women had continued using improved trial varieties at a higher rate than men (6/9 women, 7/13 men), perhaps due to the crops they were engaged in growing for the trials; most women had been given cowpea varieties, which proved more popular than the millet and sorghum varieties which were given primarily to men. However, women also retained inorganic fertilizers (6/9 women, 7/13 men) and millet husk (5/9 women, 6/13 men) at higher rates than men.

Notable gender differences also emerged in the reasons farmers offered for seed disadoption. All five women who stopped using some or all trial varieties lost the seeds involuntarily: two to harvest failures, one to a storage failure, one because her husband did not allow her land to grow the seeds after the trial, and one for health reasons. Men's reasons for disadoption were more diverse; although loss due to harvest failure was still the dominant reason for disadoption, six of the eleven men who stopped using trial varieties did so by choice – for instance, because they preferred other varieties, seed prices for the new varieties were too high, or markets were inadequate to sell the new varieties. The *choice* to disadopt is one that women surveyed did not report.

Technology use decisions in a heterogenous farm environment

Participatory mapping exercises revealed that all but one farmer perceived microvariability in soil fertility and other conditions on their farm. At times, this variability occurred at the field level, but sometimes at the sub-field level, where slope and drainage impact crop performance. In field visits, farmers described the soil types and characteristics that impact fertility, ideal crop placement, and water holding capacity. 'Dior' soils were common in the study area, and are typically ferruginous sandy or sandy loams, typically identified as farmers' least fertile. Farmers characterized 'dek dior' soils, which tend to be darker, hydromorphic, colluvial soils occupying depressions and valleys (Tschakert & Tappan, 2004), as relatively fertile.

Despite perceived variability in soil, farmers almost universally reported that they practice crop rotation rather than strategic crop or varietal placement in response to soil characteristics. A minority (7/22) said explicitly that soil fertility gradients can play a role in their planting decisions, with most planting their priority crops or varieties on the richest soils. However, basing cropping choices on soil fertility requires adequate decision-making authority and access to and control over land; only two women reported that fertility plays into their decisions, while all others described exclusively rotating crops. Under a hypothetical scenario in which farmers had access to more improved seed, 8/22 said they would plant it on their strongest soil, and 6/22 said they would simply incorporate it into their rotation.

The findings suggest that decisions around the use of soil fertility technologies is, logically, more often based on perceived soil fertility. While six of the twenty farmers using manure reported being able to apply it to all of their cultivated land, the remainder must prioritize, primarily due to limited availability. Among these fourteen farmers, six prioritized their weakest soil, and another four applied manure to specific crops rather than specific fields. None reported applying it to their strongest soil. Use of inorganic fertilizer and millet husk followed similar patterns, with no farmers reporting that they apply these to their strongest soil unless they had access to adequate quantities to apply them everywhere. Hypothetical scenarios proposing access to additional inputs led a plurality of farmers (8/22) to say they would apply additional inorganic fertilizer evenly across their cultivated fields, and smaller numbers to say they would apply it to their weakest soil (6/22) or to specific crops (4/22). Notably, again, no farmers said they would prioritize their strongest fields if provided with additional inorganic fertilizer. If farmers had access to more manure or crop residues, similar patterns emerged.

This finding runs counter to much existing research on soil fertility gradients, which has often suggested farmers (especially in East Africa) prioritize high-fertility, more responsive fields for intensive management. It does, however, align with prior research from the West African semi-arid tropics suggesting preferential use of mulches and manures on poorer soils and hardpans (Schlecht & Buerkert, 2004) as well as rotational use of limited inputs (Enyong et al., 1999). In explaining their choices, numerous farmers said that their best soil did not need further amendment or would not respond to it. Poor soils, in contrast, might fail to produce anything if not treated with available inputs.

When researchers accompanied farmers to their most and least fertile fields to take soil samples and discuss management, the most fertile fields appeared to have received more organic amendments in the near- and medium-term past (Table 11). Only in the case of inorganic fertilizer applied this season did more farmers report having applied it to their least fertile field than to their most fertile. This could be interpreted as a discrepancy with survey results suggesting farmers prioritize their least fertile fields, but may simply reflect that least fertile fields were perceived as such *because* recent applications of soil fertility technologies prioritized other fields.

Table 11. Proportions of farmers reporting use of soil fertility technologies on their least and most fertile fields this year and over the last five years.

	this year		past 5 years	
amendment	least fertile field	most fertile field	least fertile field	most fertile field
manure	55% (11/20)	70% (14/20)	50% (10/20)	85% (17/20)
inorganic (NPK)	40% (8/20)	30% (6/20)	60% (12/20)	60% (12/20)
millet husk	20% (4/20)	25% (5/20)	25% (5/20)	40% (8/20)
none	35% (7/20)	25% (5/20)	10% (2/20)	5% (1/20)

Soil properties and farmer perceptions of fertility

Given evident discrepancies between surveyed farmers' use of available soil fertility technologies and existing research showing farmers' tendency to prioritize their most productive, ‘responsive’ fields, it is worthwhile to comparing farmer perceptions with measurable soil characteristics. Soil samples taken from farmers’ least fertile fields were thus compared to soil samples taken from farmers’ most fertile fields on a set of common measures of fertility: pH, salinity, soil organic matter content, total carbon, and total nitrogen.

Overall, pH levels and salinity levels were manageable, and unlikely to serve as constraints on productivity. Soil organic matter levels, total soil carbon, and total soil nitrogen were low on average. Regional differences were substantial; while soils in Thiés were slightly more saline, on average, they outperformed soils in the other two regions in every other category – notably, with nearly double the soil organic matter of Tambacounda soils and nearly quadruple that of Louga.

Table 12. Averaged soil properties for farmers’ most and least fertile fields, with test stastic reflecting comparison.

Soil property	**Farmer’s perception of soil quality**		**Test statistic**
	least fertile	most fertile	
pH (1:1)	6.1	6.5	$p = 0.011$*
EC (µS)	54.2	48.6	$p = 0.812$
Soil organic matter (% wt)	1.01%	1.09%	$p = 0.388$
Total soil carbon (% wt)	0.31%	0.37%	$p = 0.202$
Total soil nitrogen (% wt)	0.06%	0.06%	$p = 0.430$

Fields that farmers perceived as most fertile exhibited slightly higher pH, but other measures did not exhibit significant differences (Table 12). While there appear to be trends suggesting that farmer perceptions of fertility align with measurable properties, as has been shown in prior studies (Mtambanengwe & Mapfumo, 2005;

Murage et al., 2000; Smaling et al., 2002; Tittonell, 2007), additional data is needed given the small sample size.

Conclusion

This follow-up study, conducted two years after completion of participatory field trials of improved seeds and soil fertility technologies in Western Senegal, builds our understanding of smallholders' farm management priorities and illuminates the role of structural and environmental constraints to 'improved' technology use in the region. While trial participants might be expected to derive long-term benefits from engagement in such a trial, which provided training and direct, no-cost access to open-pollinating seeds, evidence of post-project benefits are mixed.

Findings show modest rates of retention of improved seed technologies, with disadoption often appearing involuntary and related to downside losses and resource constraints. Varietal preferences were shown to be driven by productivity in the case of groundnut (a key cash crop), while preferences for cowpea, a subsistence crop, were determined by taste, ease of cooking, and a desire for risk reduction through diversification. Modest rates of seed retention have at least two possible explanations. First, the trial-based promotion of these seed technologies was perhaps inadequate to lead to sustained adoption; larger quantities of seed or distributions in additional years may have mitigated the losses documented here. Second, these technologies may not be sufficiently relevant and/or viable in Senegal's high-risk farming environment, where the possibility of total losses skew economic valuations of potential benefits.

Substantial disadoption of inorganic fertilizers, a costly but widely available input, indicates that the latter factor likely plays a role.

Retention of low- and no-cost soil fertility technologies proved mixed. Despite extensive continued use of manure, millet husk was disadopted by half of farmers, most of whom preferred to use it as animal fodder. The relative success of manure is not insignificant, but its limited availability impedes significantly expanded use. Evident interest in compost and the modest success of millet husk—not widely seen as a valuable soil fertility technology in the past, but perhaps a viable option for farmers without substantial fodder requirements—suggest potential for further exploration of these tools.

Conversations about farmers' cropping and technology use decisions showed that while most perceive microvariations in soil fertility on their farm, few farmers' planting decisions are based on these perceptions. Instead, most farmers practice crop rotation, a means to maintain adequate soil quality, control pests and disease, and, arguably, to manage the risk of losses from poor soil conditions in an environment where fallowing is often no longer feasible. In such a context, soil fertility gradients ensure that all crops are not simultaneously and equally vulnerable to drought stress (Brouwer et al., 1993). Soil sampling revealed few statistically significant differences in tested soil properties between farmers' perceived best fields and worst fields. Still, trends suggest that a meaningful pattern in soil fertility measurements could emerge provided a larger sample.

Farmers' use of soil fertility technologies, in contrast to seed technologies, responded more readily to perceived soil conditions. While other studies have found that farmers prioritize their most fertile, most responsive fields for investments of inputs and labor, farmers surveyed for this study dedicated most soil fertility technologies to their weakest fields. Thus, rather than optimizing productivity on their best fields, farmers appeared focused on ensuring minimum output. This aligns with other research from the West African semi-arid tropics suggesting that farmers strive for risk reduction (Enyong et al., 1999; Stoop, 1986) and 'a satisfactory level of "assured" production' rather than necessarily aiming to maximize yields in good years (Brouwer et al., 1993).

While much agronomic research and extension, including breeding programs, have focused foremost on yields, farmers' preference for resilience rather than productivity maximization underscores the need to support alternative technological objectives. In particular, focusing research and development processes on risk management, flexibility, and continuous adaptation (Mortimore & Adams, 2001; Niemeijer, 1996; Tschakert & Tappan, 2004) could lead to more sustained uptake of improved technologies and tangible benefits for a broader swath of farmers.

References

Abson, D. J., Fraser, E. D., & Benton, T. G. (2013). Landscape diversity and the resilience of agricultural returns: a portfolio analysis of land-use patterns and economic returns from lowland agriculture. *Agriculture & Food Security*, *2*, 15. https://doi.org/10.1186/2048-7010-2-2

Access to Seeds Foundation. (2019). Access to Seeds Index 2019 - Synthesis Report, (June), 56. Retrieved from https://www.accesstoseeds.org/app/uploads/2019/06/Access-to-Seeds-2019-Index-Synthesis-Report.pdf

Adjei-Nsiah, S., Kuyper, T. W., Leeuwis, C., Abekoe, M. K., Cobbinah, J., Sakyi-Dawson, O., & Giller, K. E. (2008). Farmers' agronomic and social evaluation of productivity, yield and N 2-fixation in different cowpea varieties and their subsequent residual N effects on a succeeding maize crop. *Nutrient Cycling in Agroecosystems*, *80*(3), 199–209. https://doi.org/10.1007/s10705-007-9133-3

Almekinders, C. J. M., Beumer, K., Hauser, M., Misiko, M., Gatto, M., Nkurumwa, A. O., & Erenstein, O. (2019). Understanding the relations between farmers' seed demand and research methods: The challenge to do better. *Outlook on Agriculture*, *48*(1), 16–21. https://doi.org/10.1177/0030727019827028

Ashby, J. A., & Sperling, L. (1995). Institutionalizing Participatory, Client-Driven Research and Technology Development in Agriculture. *Development and Change*, *26*(4), 753–770. https://doi.org/10.1111/j.1467-7660.1995.tb00573.x

Bagayoko, M., Mason, S. C., Traore, S., & Eskridge, K. M. (1996). Pearl millet/cowpea cropping system yields and soil nutrient levels. *African Crop Science Journal*, *4*(4), 453–462. Retrieved from https://tspace.library.utoronto.ca/html/1807/20979/cs96086.html

Bationo, A., & Buerkert, A. (2001). Soil organic carbon management for sustainable land use in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, *61*, 131–142.

Bationo, A., & Mokwunye, A. U. (1991). Role of manures and crop residue in alleviating soil fertility constraints to crop production: With special reference to the Sahelian and Sudanian zones of West Africa. *Fertilizer Research*, *29*(1), 117–125. https://doi.org/10.1007/BF01048993

Bationo, A., & Ntare, B. R. (2000). Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi-arid tropics, West Africa. *Journal of Agricultural Science*, *134*(3), 277–284. https://doi.org/10.1017/S0021859699007650

Brouwer, J., Fussell, L. K., & Herrmann, L. (1993). Soil and crop growth micro-variability in the West African semi-arid tropics: a possible risk-reducing factor for subsistence farmers. *Agriculture, Ecosystems & Environment*, *45*, 229–238.

Darnhofer, I., Fairweather, J., & Moller, H. (2010). Assessing a farm's sustainability: insights from resilience thinking. *International Journal of Agricultural Sustainability*, *8*(3), 186–198. https://doi.org/10.3763/ijas.2010.0480

David, S., Mukandala, L., & Mafuru, J. (2002). Seed Availability, an Ignored Factor in Crop Varietal Adoption Studies: A Case Study of Beans in Tanzania. *Journal of Sustainable Agriculture*, *21*(2), 5–20. https://doi.org/https://doi.org/10.1300/J064v21n02_03

David, S., & Sperling, L. (1999). Improving technology delivery mechanisms: Lessons from bean seed systems research in eastern and central Africa. *Agriculture and Human Values*, *16*(4), 381–388. https://doi.org/10.1023/A:1007603902380

Deckers, J. (2002). A system approach to target balanced nutrient management in soilscapes of sub-Saharan Africa. In B. Vanlauwe, J. Diels, N. Sanginga, & R. Merckx (Eds.), *Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice* (pp. 47–61). Wallingford, Oxon: CAB International.

Diop, A. M. (1999). Sustainable agriculture: New paradigms and old practices? Increased production with management of organic inputs in Senegal. *Environment, Development and Sustainability*, *1*(3–4), 285–296. https://doi.org/10.1023/A:1010026922142

Dorward, P., Clarkson, G., & Stern, R. (2015). *Participatory Integrated Climate Services for Agricultura (PICSA): Field Manual*.

Dorward, P., Shepherd, D., & Galpin, M. (2007). *Participatory farm management methods for analysis, decision making and communication*.

Duch, R. M., & Palmer, H. D. (2004). It's Not Whether You Win or Lose, but How You Play the Game: Self-Interest, Social Justice, and Mass Attitudes toward Market Transition. *American Political Science Review*, *98*(3), 437–452.

Dury, J., Schaller, N., Garcia, F., Reynaud, A., & Bergez, J. E. (2012). Models to support cropping plan and crop rotation decisions. A review. *Agronomy for Sustainable Development*, *32*(2), 567–580. https://doi.org/10.1007/s13593-011-0037-x

Eldon, J., Baird, G., Sidibeh, S., Dobasin, D., Rapaport, P., Cheng, W., & Shennan, C. (2020). On-farm trials identify adaptive management options for rainfed agriculture in West Africa. *Agricultural Systems*, *182*(January). https://doi.org/10.1016/j.agsy.2020.102819

Enyong, L. A., Debrah, S. K., & Bationo, A. (1999). Farmers' perceptions and attitudes towards introduced soil-fertility enhancing technologies in western Africa. *Nutrient Cycling in Agroecosystems*, *53*(2), 177–187. https://doi.org/10.1023/A:1009745225465

Eriksson, D., Akoroda, M., Azmach, G., Labuschagne, M., Mahungu, N., & Ortiz, R. (2018). Measuring the impact of plant breeding on sub-Saharan African staple crops. *Outlook on Agriculture*, *47*(3), 163–180. https://doi.org/10.1177/0030727018800723

European Soil Data Centre (ESDAC). (2014). *Soil Atlas of Africa*. Retrieved from https://esdac.jrc.ec.europa.eu/content/soil-map-soil-atlas-africa

Evenson, R., & Gollin, D. (2003). Assessing the Impact of the Green Revolution, 1960 to 2000. *Science*, *300*(5620), 758–762.

Farrington, J. (1989). Farmer participation in agricultural research. *Food Policy*, *14*(2), 97–100. https://doi.org/10.1016/0306-9192(89)90002-X

Farrow, A., Ronner, E., Van Den Brand, G. J., Boahen, S. K., Leonardo, W., Wolde-Meskel, E., … Giller, K. E. (2019). From Best Fit Technologies to Best Fit Scaling: Incorporating and Evaluating Factors Affecting the Adoption of Grain Legumes in sub-Saharn Africa. *Experimental Agriculture*, *55*(S1), 226–251. https://doi.org/10.1017/S0014479716000764

Funk, C., Rowland, J., Adoum, A., Eilerts, G., Verdin, J., & White, L. (2012). *A Climate Trend Analysis of Senegal*. *Informing Climate Change Adaptation Series Factsheet*. Retrieved from http://pubs.usgs.gov/fs/2012/3123/

Gaudin, A. C. M., Tolhurst, T. N., Ker, A. P., Janovicek, K., Tortora, C., Martin, R. C., & Deen, W. (2015). Increasing crop diversity mitigates weather variations and improves yield stability. *PLoS ONE*, *10*(2), 1–20. https://doi.org/10.1371/journal.pone.0113261

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34. https://doi.org/10.1016/j.fcr.2009.06.017

Gridley, H. E., Jones, M. P., & Wopereis-Pura, M. (2002). *Development of New Rice for Africa (NERICA) and participatory varietal selection*.

Habyarimana, J., Posner, D. N., Humphreys, M., & Weinstein, J. M. (2006). *Why*

Does Ethnic Diversity Undermine Public Goods Provision? An Experimental Approach (No. 2272). Bonn.

Halbrendt, J., Gray, S. A., Crow, S., Radovich, T., Kimura, A. H., & Bahadur, B. (2014). Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture. *Global Environmental Change*, *28*, 50–62. https://doi.org/10.1016/j.gloenvcha.2014.05.001

Henrich, J., Boyd, R., Bowles, S., Camerer, C., Fehr, E., Mcelreath, R., … Tracer, D. (2005). ‘Economic Man’ in Cross-cultural Perspective: Behavioral experiments in 15 small-scale societies. *Behavioral and Brain Sciences*, *28*, 795–655.

Kijima, Y., Otsuka, K., & Sserunkuuma, D. (2011). An inquiry into constraints on a green revolution in sub-Saharan Africa: The case of NERICA Rice in Uganda. *World Development*, *39*(1), 77–86. https://doi.org/10.1016/j.worlddev.2010.06.010

Kitch, L. W., Boukar, O., Endondo, C., & Murdock, L. L. (1998). Farmer Acceptability Criteria in Breeding Cowpea. *Experimental Agriculture*, *34*, 475–486. https://doi.org/10.1017/CBO9781107415324.004

Kloppenburg, J. (2010). Impeding dispossession, enabling repossession: Biological open source and the recovery of seed sovereignty. *Journal of Agrarian Change*, *10*(3), 367–388. https://doi.org/10.1111/j.1471-0366.2010.00275.x

Licker, R., Johnston, M., Foley, J. A., Barford, C., Kucharik, C. J., Monfreda, C., & Ramankutty, N. (2010). Mind the gap: How do climate and agricultural management explain the “yield gap” of croplands around the world? *Global Ecology and Biogeography*, *19*(6), 769–782. https://doi.org/10.1111/j.1466-8238.2010.00563.x

Loevinsohn, M., Sumberg, J., Diagne, A., & Whitfield, S. (2013). *Under what circumstances and conditions does adoption of technology result in increased agricultural productivity? A Systematic Review*. Retrieved from http://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/3208/Productivity systematic review report 3.pdf;jsessionid=D703B6B5BCBCD8BB32679E1DF27C42D7?sequence=1

Mabaya, E., Ba, M. M. D., Ndiaye, M., & Mugoya, M. (2017). *Senegal Brief 2017 - The African Seed Access Index*. Retrieved from https://tasai.org/wp-content/themes/tasai2016/img/tasai_brief_2017_senegal_final_lr.pdf

Martin, A., & Sherington, J. (1997). Participatory research methods—Implementation, effectiveness and institutional context. *Agricultural Systems*, *55*(2), 195–216. https://doi.org/10.1016/S0308-521X(97)00007-3

Mascarenhas, J., & Kumar, P. D. P. (1991). *Participatory mapping and modelling users' notes* (RRA Notes). London.

Mason, S. C., Maman, N., & Palé, S. (2015). Pearl Millet Production Practices in Semi-Arid West Africa: A Review. *Experimental Agriculture*, *51*(4), 501–521. https://doi.org/10.1017/S0014479714000441

Mason, S. C., Ouattara, K., Taonda, S. J. B., Palé, S., Sohoro, A., & Kaboré, D. (2015). Soil and cropping system research in semi-arid West Africa as related to the potential for conservation agriculture. *International Journal of Agricultural Sustainability*, *13*(2), 120–134. https://doi.org/10.1080/14735903.2014.945319

Mortimore, M. (2010). Adapting to drought in the Sahel: Lessons for climate change. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(1), 134–143. https://doi.org/10.1002/wcc.25

Mortimore, M., & Adams, W. (2001). Farmer adaptation, change and "crisis" in the Sahel. *Global Environmental Change*, *11*(1), 49–57. https://doi.org/10.1016/S0959-3780(00)00044-3

Moser, C. M., & Barrett, C. B. (2006). The complex dynamics of smallholder technology adoption: The case of SRI in Madagascar. *Agricultural Economics*, *35*(3), 373–388. https://doi.org/10.1111/j.1574-0862.2006.00169.x

Mtambanengwe, F., & Mapfumo, P. (2005). Organic matter management as an underlying cause for soil fertility gradients on smallholder farms in Zimbabwe. *Nutrient Cycling in Agroecosystems*, *73*, 227–243. https://doi.org/10.1007/s10705-005-2652-x

Murage, E. W., Karanja, N. K., Smithson, P. C., & Woomer, P. L. (2000). Diagnostic indicators of soil quality in productive and non-productive smallholders' fields of Kenya's Central Highlands. *Agriculture, Ecosystems and Environment*, *79*(1), 1–8. https://doi.org/10.1016/S0167-8809(99)00142-5

Ndiaye, M., Audet-Bélanger, G., & Gildemacher, P. (2015). *Scaling Seeds & Technologies Partnership – Baseline phase II*. Retrieved from www.kit.nl

Niemeijer, D. (1996). The dynamics of African agricultural history: Is it time for a new development paradigm? *Development and Change*, *27*(1), 87–110. https://doi.org/10.1111/j.1467-7660.1996.tb00579.x

Nyikal, R. A., & Kosura, W. O. (2005). Risk preference and optimal enterprise combinations in Kahuro division of Murang'a district, Kenya. *Agricultural Economics*, *32*(2), 131–140. https://doi.org/10.1111/j.0169-5150.2005.00012.x

Omanya, G. O., Weltzien-Rattunde, E., Sogodogo, D., Sanogo, M., Hanssens, N., Guero, Y., & Zangre, R. (2007). Participatory varietal selection with improved pearl millet in West Africa. *Experimental Agriculture*, *43*(1), 5–19. https://doi.org/10.1017/S0014479706004248

Patel, R. (2013). The Long Green Revolution. *The Journal of Peasant Studies*, *40*(1), 1–63. https://doi.org/10.1080/03066150.2012.719224

Pircher, T., Almekinders, C. J. M., & Kamanga, B. C. G. (2013). Participatory trials and farmers' social realities: Understanding the adoption of legume technologies in a Malawian farmer community. *International Journal of Agricultural Sustainability*, *11*(3), 252–263. https://doi.org/10.1080/14735903.2012.738872

Ramisch, J. J. (2005). Inequality, agro-pastoral exchanges, and soil fertility gradients in southern Mali. *Agriculture, Ecosystems & Environment*, *105*, 353–372. https://doi.org/10.1016/j.agee.2004.02.001

Reece, J. D., & Sumberg, J. (2003). More clients, less resources: toward a new conceptual framework for agricultural research in marginal areas. *Technovation*, *23*, 409–421. https://doi.org/10.1016/S0166-4972(01)00122-5

Rogers, E. M. (2003). *Diffusion of Innovations* (5th Ed.). New York: Free Press.

Röling, N. G., & Jiggins, J. (1998). The ecological knowledge system. In N. G. Röling & M. A. E. Wagemakers (Eds.), *Facilitating Sustainable Agriculture: Participatory learning and adaptive management in times of environmental uncertainty* (pp. 283–311). Cambridge: Cambridge University Press.

Ronner, E., Franke, A. C., Vanlauwe, B., Dianda, M., Edeh, E., Ukem, B., … Giller, K. E. (2016). Understanding variability in soybean yield and response to P-fertilizer and rhizobium inoculants on farmers' fields in northern Nigeria. *Field Crops Research*, *186*, 133–145. https://doi.org/10.1016/j.fcr.2015.10.023

Rowe, E. C., Wijk, M. T. Van, Ridder, N. De, & Giller, K. E. (2006). Nutrient allocation strategies across a simplified heterogeneous African smallholder farm. *Agriculture, Ecosystems and Environment*, *116*, 60–71. https://doi.org/10.1016/j.agee.2006.03.019

Schlecht, E., & Buerkert, A. (2004). Organic inputs and farmers' management strategies in millet fields of western Niger. *Geoderma*, *121*(3–4), 271–289. https://doi.org/10.1016/j.geoderma.2003.11.015

Schlecht, E., Buerkert, A., Tielkes, E., & Bationo, A. (2006). A critical analysis of challenges and opportunities for soil fertility restoration in Sudano-Sahelian West Africa. *Nutrient Cycling in Agroecosystems*, *76*(2–3), 109–136.

https://doi.org/10.1007/s10705-005-1670-z

Seck, A. (2016). *Fertilizer Subsidy and Agricultural Productivity in Senegal* (AGRODEP Working Papers No. 0024).

Shennan, C. (2008). Biotic interactions, ecological knowledge and agriculture. *Philosophical Transactions of the Royal Society of London, B*, *363*(1492), 717–739. https://doi.org/10.1098/rstb.2007.2180

Sirrine, D., Shennan, C., Snapp, S., Kanyama-Phiri, G., Kamanga, B., & Sirrine, J. R. (2010). Improving recommendations resulting from on-farm research: agroforestry, risk, profitability and vulnerability in southern Malawi. *International Journal of Agricultural Sustainability*, *8*(4), 290–304. https://doi.org/10.3763/ijas.2010.0471

Smaling, E. M. A., Stoorvogel, J. J., & Jager, A. De. (2002). Decision Making on Integrated Nutrient Management through the Eyes of the Scientist , the Land-user and the Policy Maker. In B. Vanlauwe, J. Diels, N. Sanginga, & R. Merckx (Eds.), *Integrated Plant Nutrient Management in Sub-Saharan Africa: From Concept to Practice* (pp. 265–283). Wallingford, Oxon: CAB International.

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-kerr, R., & Kanyama-phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences*, *107*(48), 20840–20845. https://doi.org/10.1073/pnas.1007199107

Stoop, W. A. (1986). Agronomic management of cereal/cowpea cropping systems for major toposequence land types in the West African sacanna. *Field Crops Research*, *14*(C), 301–319. https://doi.org/10.1016/0378-4290(86)90066-3

Tittonell, P. (2007). Heterogeneity of crop productivity and resource use efficiency within smallholder Kenyan farms: Soil fertility gradients or management intensity gradients? *Agricultural Systems*, *94*, 376–390. https://doi.org/10.1016/j.agsy.2006.10.012

Tittonell, P., & Giller, K. E. (2013). When yield gaps are poverty traps: The paradigm of ecological intensification in African smallholder agriculture. *Field Crops Research*, *143*, 76–90. https://doi.org/10.1016/j.fcr.2012.10.007

Tittonell, P., Vanlauwe, B., Leffelaar, P. A., Shepherd, K. D., & Giller, K. E. (2005). Exploring diversity in soil fertility management of smallholder farms in western Kenya II. Within-farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture, Ecosystems & Environment*, *110*, 166–184. https://doi.org/10.1016/j.agee.2005.04.003

Tschakert, P., & Tappan, G. (2004). The social context of carbon sequestration: Considerations from a multi-scale environmental history of the Old Peanut Basin of Senegal. *Journal of Arid Environments*, *59*(3), 535–564. https://doi.org/10.1016/j.jaridenv.2004.03.021

United Purpose. (2017). *AGRA Grant Narrative Report: Increasing awareness and uptake of improved seeds through farmer demonstrations and farmer to farmer networks in Senegal*.

Vanlauwe, B., Tittonell, P., & Mukalama, J. (2006). Within-farm soil fertility gradients affect response of maize to fertiliser application in western Kenya. *Nutrient Cycling in Agroecosystems*, *76*, 171–182. https://doi.org/10.1007/s10705-005-8314-1

Walker, T. S. (2006). *Participatory Varietal Selection, Participatory Plant Breeding, and Varietal Change*.

Zimmerer, K. S. (2010). Biological Diversity in Agriculture and Global Change. *Annual Review of Environment and Resources*, *35*(1), 137–166. https://doi.org/10.1146/annurev-environ-040309-113840

Conclusion and implications for policy and future research

The outcomes of this research have relevance to key debates about the future of agricultural development, food security, and poverty alleviation efforts in Africa. Chapter 1 provides insight into farmers' adaptive responses to intersecting stressors, including climate change. While complementary on- and off-farm livelihoods have long been a survival strategy for farming households in a region known for climate variability, this study provides evidence that off-farm activities are increasingly permanent and proactive, drawing young people away from rural areas for the long-term. It also suggests that pursuit of off-farm livelihoods may be a heightened priority of farmers facing changes in weather, indicating that climate change may trigger increased focus on non-agricultural pursuits. Future research in this area should attempt to document changes in adaptive strategies longitudinally, with attention to how disruptive events such as droughts influence reliance on on- and off-farm strategies. Additional studies are also needed to understand how local policies and aid initiatives can support migration practices that strengthen both source and destination communities. These should focus, in particular, on impacts on rural women, given that men make up most migrant populations and women remaining in rural areas are disproportionately reliant on short-term, survival-oriented strategies.

In practical terms, these findings underscore the need for a reframing of rural development approaches. Rather than focusing on keeping young Africans at home and on-farm (Abrahams, 2017; R. Mason, 2015; Nielsen, 2016; Raty & Shilhav, 2020), the development community must acknowledge the role migration now plays in sustaining rural households. In this context, migration is a tool that supports rural households and helps maintain the viability of struggling smallholder farms. In light of this, rural development efforts should more consistently provide cross-sectoral support that enables pursuit of off-farm livelihoods and smooths migration pathways for rural youth, perhaps by provide training facilities to support and protect migrants.

The second chapter examines the use of information and communication technologies (ICTs) to disseminate knowledge about modern agricultural technologies to farmers in remote areas. The findings provide several clear lessons for ICT4Ag/ICT4D practitioners. First, although ICTs present a powerful means through which to *reach* farmers, enabling productive two-way information exchange is clearly more challenging. Practitioners need to be thoughtful about when and how ICTs are used, and attentive to risks that these tools may exacerbate existing inequalities. This study provides stronger evidence to support use of participatory farm trials, a farmer-to-farmer learning mechanism, than use of ICTs in disseminating agricultural technologies. ICTs may be relatively simple, cheap, and effective at sharing certain types of information, but the lack of impact on farmers' adoption decisions here suggests they may not be more cost-effective as a technology dissemination tool. More empirical research, and particularly more controlled studies of efforts promoting simpler, widely-available agricultural technologies, is needed to understand the circumstances in which ICT-enabled extension can yield meaningful impacts. In particular, there is a need for research around efforts to center women in ICT initiatives to understand if such approaches can yield more equitable outcomes.

Additional findings from Chapter 2 raise questions about promotion of new Green Revolution technologies in this context. Senegal's seed system is under-developed and appeared unable to satisfy increased demand for these technologies that ICT-enabled extension sought to create. Both Chapter 2 and Chapter 3 raised questions about the 'sticking' power of these agricultural technologies. Retention rates for improved seeds in particular were lower than could be expected among farmers to whom they were given directly only two years prior. The risk of downside losses in this region appears to be high enough that any small-scale technology distributions may have limited impact in the medium- to long-term, and may contribute to farmers' skepticism about the benefits of promoted technologies that require investment.

These studies of farmer decision-making in Senegal illustrate several points. First, they show the diversity of farmer circumstances and constraints they face; resource-poor farmers, and particularly women, remain ill-positioned to benefit from resource-intensive farming practices or exploit medium- to long-term adaptative strategies that could build resilience. Development efforts will need to better respond to these differences, beyond superficial inclusion of gender as a variable in data analysis, if they hope to achieve equitable benefits. Women must be empowered to make household decisions and have control over land and financial resources in order to benefit from mainstream agricultural development efforts like those researched here. Similarly, efforts to support climate change adaptation must acknowledge the limited number of tools available to women and other resource-poor farmers; buying ‘climate-smart’ seeds may not prove a useful way to address their broader constraints.

Second, smallholder farmers in Senegal are making decisions that prioritize risk management, particularly by diversifying their agricultural systems and broader livelihood systems. There is little in these findings to suggest that specialization and commercialization of these systems is realistic for or necessarily preferred by smallholder farmers under current conditions. Assuming that development funders continue to promote these pathways, conversations must broaden to confront the outsized role risk plays in farmers’ decision-making; wider exploitation of new Green Revolution technologies geared toward commercialized monoculture and scale-up is likely to require more expansive safety nets that make such investments feasible for resource-constrained farmers.

Recently, ‘climate smart agriculture’ initiatives have aspired to aid farmers in risk management and build resilience. Some such efforts have been criticized for superficially re-focusing new Green Revolution priorities without substantive rethinking of central productivist objectives or attention to broader structural and political-economic obstacles to farmer resilience (Karlsson, Naess, Nightingale, & Thompson, 2018; Pimbert, 2015; Shilomboleni, 2020). Other efforts have more successfully prioritized technologies and approaches that can increase productivity while contributing to agroecosystem and livelihood resilience. Low-cost, resource-conserving agroecological techniques hold particular promise to reduce farmer reliance on external inputs while diversifying sources of income. Agroecological approaches are highly context-specific and encompass a range of tools and practices, but often center soil health, improved water management, increased planned and associated biodiversity, and farmer autonomy (Altieri, Nicholls, & Montalba, 2017; Debray et al., 2019; Sinclair et al., 2019). Relevant practices include crop and varietal diversification, intercropping (particularly with legumes), push-pull pest management systems, reduced tillage, use of hedgerows and vegetative buffer strips, contouring, bunding, and expanded use and recycling of organic inputs, to the extent possible in dryland systems like Senegal (Debray et al., 2019). More systemic approaches seek to integrate field crop and livestock production into complementary resource conservation practices; agroforestry, for example, has been shown to improve soil quality, aid in water management, and provide alternative income sources for farmers in Africa (Mbow et al., 2014).

Uptake (or renewed uptake) of many of these practices has been slow in sub-Saharan Africa for a number of reasons. Complex approaches often fit poorly into dominant models for extension and technology transfer (Rogers, 2003) that are better suited to communicating established practices than aiding in localized application of principles (Nicholls & Altieri, 2018). High knowledge requirements and labor costs have raised concerns about viability and equity of some of the above approaches (Giller et al., 2009; Kerr et al., 2019), warranting further research. Politics present a central obstacle as well; limited funding and policy support for agroecology-focused research and programming has led to its deprioritization (Biovision Foundation for

Ecological Development & IPES-Food, 2020; DeLonge et al., 2016; Parmentier, 2014; Pimbert & Moeller, 2018). There are thus structural as well as knowledge-related barriers to the wider spread of such climate-smart alternatives.

The future of farming in Senegal and the semi-arid Sahel remains uncertain. Continued emigration from rural areas and agricultural livelihoods appears probable, while promotion of new Green Revolution technologies is likely to benefit wealthier farmers disproportionately. Further research is needed to understand the conditions under which specialization, intensified production, and farm consolidation can contribute to the resilience of rural livelihoods and the natural resource base on which farming households rely, with particular attention to alternative approaches to rural development. Agricultural growth in Africa need not replicate the environmental degradation, loss of small farms, deterioration of rural communities, and reduced dietary quality seen elsewhere. Alternative agricultural models that support resilient smallholder production and livelihoods likely hold promise for a more diverse population of farmers. However, prioritizing these approaches will require critical evaluation of the existing funding priorities, programmatic approaches, and knowledge production systems outlined above.

References

Abrahams, J. (2017, July 4). Europe's risky experiment: Can aid be used to deter migration? *Devex*. Retrieved from https://www.devex.com/news/europe-s-risky-experiment-can-aid-be-used-to-deter-migration-90426

Altieri, M. A., Nicholls, C. I., & Montalba, R. (2017). Technological Approaches to Sustainable Agriculture at a Crossroads: An Agroecological Perspective. *Sustainability*, *9*(349), 1–13. https://doi.org/10.3390/su9030349

Biovision Foundation for Ecological Development & IPES-Food. (2020). *Money flows: what is holding back investment in agroecological research for Africa?* Retrieved from https://www.agroecology-pool.org/MoneyFlowsreport

Debray, V., Wezel, A., Lambert-Derkimba, A., Roesch, K., Lieblein, G., & Francis, C. A. (2019). Agroecological practices for climate change adaptation in semiarid and subhumid Africa. *Agroecology and Sustainable Food Systems*, *43*(4), 429–456. https://doi.org/10.1080/21683565.2018.1509166

DeLonge, M. S., Miles, A., & Carlisle, L. (2016). Investing in the transition to sustainable agriculture. *Environmental Science and Policy*, *55*, 266–273. https://doi.org/10.1016/j.envsci.2015.09.013

Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34. https://doi.org/10.1016/j.fcr.2009.06.017

Karlsson, L., Naess, L. O., Nightingale, A., & Thompson, J. (2018). 'Triple wins' or 'triple faults'? Analysing the equity implications of policy discourses on climate-smart agriculture (CSA). *Journal of Peasant Studies*, *45*(1), 450*174. https://doi.org/10.1080/03066150.2017.1351433

Kerr, R. B., Hickey, C., Lupafya, E., Dakishoni, L., Bezner, R., Hickey, C., … Dakishoni, L. (2019). Repairing rifts or reproducing inequalities? Agroecology , food sovereignty, and gender justice in Malawi. *The Journal of Peasant Studies*, *0*(0), 1–20. https://doi.org/10.1080/03066150.2018.1547897

Mason, R. (2015, June 21). Fallon: UK aid budget should be used to discourage mass migration from Africa. *The Guardian*.

Mbow, C., Van Noordwijk, M., Luedeling, E., Neufeldt, H., Minang, P. A., & Kowero, G. (2014). Agroforestry solutions to address food security and climate change challenges in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 61–67. https://doi.org/10.1016/j.cosust.2013.10.014

Nicholls, C. I., & Altieri, M. A. (2018). Pathways for the amplification of agroecology. *Agroecology and Sustainable Food Systems*, *00*(00), 1–24. https://doi.org/10.1080/21683565.2018.1499578

Nielsen, N. (2016, June 28). EU to use aid and trade to stop Africa migration. *EU Observer*. Retrieved from https://euobserver.com/migration/134067

Parmentier, S. (2014). *Scaling-up Aagroecological Approaches: What, Why and How?* https://doi.org/10.1007/s13398-014-0173-7.2

Pimbert, M. P. (2015). Agroecology as an Alternative Vision to Conventional Development and Climate-smart Agriculture. *Development*, *58*(2–3), 286–298. https://doi.org/10.1057/s41301-016-0013-5

Pimbert, M. P., & Moeller, N. I. (2018). Absent agroecology aid: On UK agricultural development assistance since 2010. *Sustainability (Switzerland)*, *10*(2). https://doi.org/10.3390/su10020505

Raty, T., & Shilhav, R. (2020). *The EU Emergency Trust Fund for Africa: Trapped between aid policy and migration politics*. https://doi.org/10.21201/2020.5532

Rogers, E. M. (2003). *Diffusion of Innovations* (5th Ed.). New York: Free Press.

Shilomboleni, H. (2020). Political economy challenges for climate smart agriculture in Africa. *Agriculture and Human Values*, (July). https://doi.org/10.1007/s10460-020-10126-5

Sinclair, F., Wezel, A., Mbow, C., Chomba, S., Robiglio, V., & Harrison, R. (2019). *The Contribution of Agroecolical Approaches to Realizing Climate-Resilient Agriculture*. Rotterdam and Washington, DC.