THE OPPORTUNITIES AND BARRIERS TO PERENNIAL SORGHUM FOR ETHIOPIAN SMALLHOLDERS: CONSULTING THE EXPERTS AND FARMERS

by

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(Under the Direction of Maria Navarro)

ABSTRACT

This document presents two qualitative studies investigating the potential benefit of perennial sorghum for smallholders. The first study interviewed experts on newly perennialized crops and experts on smallholder contexts. Findings indicate that pre-analytic choices create barriers that limit benefit capture and participation by smallholders. A model of the relationship between pre-analytic choices and barriers is presented. How pre-analytic choices limit participation and how to share decisive agency during perennial sorghum's ongoing development are important considerations moving forward. The second study investigated smallholder farming contexts in eastern Ethiopia through observation and interviews with farmers to understand perennial sorghum's potential fit within farming systems and the relevant knowledge smallholders possess to perennial sorghum's development. Findings indicate smallholders possess extensive sorghum knowledge, practice ratooning, and maintain diverse sorghum germplasm. Enhancing sorghum's ratooning ability, developing multiple varieties of perennial sorghum, and improving water access can benefit smallholders in the context investigated.

INDEX WORDS: perennial, sorghum, smallholder, ratooning, Ethiopia

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DEDICATION

This thesis is dedicated to my wife Anna Belle and my daughter Faryn. You both amaze and inspire me every day. I would also like to dedicate this work to Eli. I’ll miss you friend.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

This document, a master's thesis, is an effort to identify potential barriers and opportunities relative to the continued development as well as the subsequent introduction and diffusion of a perennial sorghum technology for the benefit of smallholder farmers. This first chapter outlines the structure of this document, explains its purpose, and introduces the reader to relevant literature and concepts. Chapters 2 and 3 are written as individual manuscripts with the intent that they can be read and understood as distinct documents. Chapter 4 revisits the findings and conclusions of Chapters 2 and 3 in concise form before making a set of comprehensive recommendations based on the contents of both of these chapters.

Structure of the Thesis

This thesis document consists of four chapters. Chapter 1, this chapter, serves as an introduction to the research presented in Chapters 2 and 3. Chapter 2 presents a qualitative study in which experts relevant to the effort to develop, introduce, and diffuse a perennial sorghum and other perennial grain technologies to benefit smallholder farmers were interviewed. Chapter 2 analyzes the data gathered through interviews with these experts to assess and categorize barriers that may impede this effort from realizing success from multiple stakeholder perspectives. Chapter 3, also a qualitative investigation, considers the results and conclusions of Chapter 2 and investigates a specific smallholder context—the areas in and around Eastern and Western Hararghe zones of Ethiopia—through observation and farmer interviews. Chapter 3 attempts to investigate a specific smallholder sorghum farming context to determine the potential fit of a perennial sorghum within this context and elucidate the knowledge and experience Ethiopian smallholder farmers may have relevant to the ongoing development of perennial sorghum technology. Chapter 4 serves as the concluding chapter to this document, and reconsiders Chapters 2 and 3 to present a set of overarching recommendations based on the findings and conclusions of both of these chapters.

Introduction

Some plant breeders, agronomists, and agroecologists are currently developing perennial cereal, legume, and oil seed crops and the agricultural systems in which they would function. These individuals are motivated by the growing recognition of the potential for simultaneous food production and ecosystem service enhancements (such as limiting erosion, more efficient use of resources and inputs, reductions in runoff, carbon sequestration, and less frequent soil disturbance for improved soil ecosystem health) on agricultural lands by substituting many annual crops with similar perennial versions of these crops (Cox, 2014; Glover et al., 2010). While these crops are being developed with the intention that they be used in agricultural systems around the world, Cox (2014) suggests that the use of perennial crops in smallholder agricultural systems in particular may confer added benefits in the form of “reduced expenditure for seed, fertilizer, and other inputs; more reliable stand establishment and early vigour; less effort expended on weed control; extended growing seasons; less transplanting or other stoop labour, especially for women; and protection of biodiversity” (p. 1). In 2013, a workshop titled *Perennial Crops for Food Security: Proceedings of the FAO Expert Workshop* brought together the research and experts on perennial crops and declared that the outputs of this perennial technology development effort would be a paradigm shift toward more sustainable agricultural production as well as facilitating food security and poverty alleviation (Wang & Alonzo, 2014).

One of the perennial grains being developed by plant breeders as part of this effort is a new variety of perennial or "multiple-harvest" sorghum (Paterson, Cox, Kong, & Navarro, 2013). Sorghum (*Sorghum bicolor* (L.) Moench) has particular significance in smallholder contexts on the African continent that are often marked by drought, food insecurity, and degraded soils (Belton & Taylor, 2004; Paterson et al., 2014). This is because sorghum's primary center of diversity is within Africa (i.e., Ethiopia), where it has been cultivated by farmers for over a millennium (Mekbib, 2006, 2007, 2008, 2009a, 2009b) and is therefore uniquely adapted to the arid and semi-arid drought prone environments there (Belton & Taylor, 2004; Paterson et al., 2014). A model in Appendix A compares an annual to a perennial sorghum over time, outlining and summarizing the benefits of perennial sorghum for smallholder farmers as they are proposed in the literature. This research seeks to evaluate the barriers and opportunities to realizing the identified potential benefits of a perennial sorghum for smallholder farmers and the claim of enhanced sustainability of their agricultural systems.

Statement of the Problem

While perennial plants are important components of natural ecosystems, employing perennial versions of annual grain crops in the agricultural systems of smallholder farmers represents a potentially novel situation. Adebiyi, Olabisi, and Snapp (2015) referred to these nascent perennial crops as a "transformative technology." These authors explain that there is a fundamental difference between these perennial crops and their annual counterparts in agricultural systems both in functionality and the underlying science. The history of agricultural development through technology transfer has been heavily criticized as not meeting smallholder needs or addressing poverty (Röling, 2004, 2010). This suggests that despite the fundamental difference between annual and perennial crops, the achievement of enhanced agricultural sustainability, poverty alleviation, and food security for adopting smallholder farmers cannot be taken for granted.

Purpose and Objective of Study

The objective of this research is divided into two sets of questions whose answers are pursued in the individual manuscript chapters of this thesis:

- *What are the relevant expert's perceived barriers to realizing perennial sorghum and its theorized agronomic and ecological benefits, especially those barriers that may prevent smallholder farmers from adopting and benefiting from a perennial sorghum?* (Chapter 2)
- *In what ways is perennial sorghum's ability to benefit smallholder farmers limited by the decisions made without smallholder participation?* (Chapter 2)
- *What are the smallholder farming systems and livelihoods like in sorghum's center of diversity according to smallholder farmers and how might perennial sorghum fit within this context?* (Chapter 3)
- *What knowledge do smallholders possess relative to the ongoing development of perennial sorghum?* (Chapter 3)

Literature Review

Given both the complex history of agricultural development through technology transfer efforts and the potential transformative nature of newly perennialized crop technologies, there is vast ground to cover in the literature and a road map may be useful before proceeding. The first section to this literature review will explain some of the terms and concepts frequently used in this document. The next section will compare and contrast the perennial paradigm's technology effort with past agricultural technology pushes, with emphasis on the differences between the underlying goals of these separate efforts. The third section will discuss the relative success of past agricultural technology pushes from various stakeholder perspectives and the importance of recognizing the agency of smallholders as potential adopters of technology. The fourth and final section of the literature review focuses on the specific technology of perennial sorghum and its potential benefits and characteristics. This last section will include information on sorghum's significance and use in smallholder agriculture systems as well as smallholders' potential to participate in and contribute to perennial sorghum's ongoing development.

Innovation, Technology, the Perennial Paradigm, and Pre-Analytic Choices

Throughout this thesis document, perennial sorghum and the other newly perennialized crops will be referred to as both an *innovation* and a *technology.* Rogers (2003) defines an innovation as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (p. 12). Rogers agrees that the word technology is a synonym for innovation but defines technology slightly differently and suggests that it generally has both a hardware and software component. Throughout this document, the phrase *perennial paradigm* is used as a unit of collective action and thought made up of the individuals and organizations behind the "paradigm shift" Wang and Alonzo (2014) refer to in the published proceedings of the *Perennial Crops for Food Security: Proceedings of the FAO Expert Workshop* document.

Cox, Crews, and Jackson (2014) refer to the newly perennialized crops as the "hardware" component and the associated crop systems in which they will function as the "software" component of the perennial paradigm's technologies. Recognizing that the outputs of the perennial paradigm are technologies has potential consequences that will be frequently revisited throughout this document and briefly mentioned here as well. The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) (McIntyre, Herren, Wakhungu, & Watson, 2009) discusses how global intellectual property rights (IPR) frameworks on technology often concentrate ownership of agricultural resources and limit access to them, even preventing smallholder farmers from saving, exchanging, or selling seed. Ezeanya (2013) discusses how current conceptions of IPR are based in “Eurocentric” conceptions of knowledge and individual ownership of these rights, whereas the identity and heritage of indigenous communities are often tied to the knowledge developed and shared within the community. This has led some scholars, like Ezeanya, to call for reforming global conceptions of IPR to take into account these differences in conceptions around ownership of knowledge.

The perennial paradigm’s objective is the development of agricultural technologies—both hardware and software—based on perenniality to solve what it sees as the inherent unsustainability and associated ecological problems of annual-based agriculture (Jackson, 2002). Dosi (1982) discusses how a technological paradigm, like the perennial paradigm, has its own epistemological “outlook” and that this outlook helps determine the problems it prioritizes and seeks to address. These choices, in turn, shape the types of technologies that will or will not be developed (Dosi, 1982). These choices could also be called *pre-analytic choices*, or those choices of “relevant goals, variables, [and] explanatory dynamics for the select[ed] explanatory model” (Giampietro, 2004, p. 4).

Röling, Hounkonnou, Offei, Tossou, and Van Huis (2004) use the concept of pre-analytic choices to highlight how the choices made during the earliest phases of research and technology development are usually made by those with the agency and voice to do so, regardless of whether the assumptions used and models selected align with those of the people who will be directly impacted. Röling et al. (2004) acknowledge that while these choices are necessary and inescapable, there should be more analysis and reflection on these choices. These authors suggest that those entities making pre-analytic choices be more aware of these choices, their potential consequences, and to make these choices as explicitly as possible. Röling et al. (2004) recommend that the best way to proceed in making pre-analytic choices is to make them as much as possible in concert with the beneficiaries and stakeholders to research and technology.

Increased Productivity Versus Enhanced Sustainability

Parayil (2003) explains that the Green Revolution of the mid to late twentieth century was an international-scale technology transfer effort that sought to "modernize" farmers around the world. The Green Revolution's modernization effort attempted to incorporate farmers (including smallholders) into international agricultural commodity markets through encouraging the adoption of newly developed technology consisting of crop varieties with high yield potentials under conditions of ample input use (Iles, Garrett, Maywa, & Galt, 2016, Parayil, 2003, Röling, 2010).

Parayil (2003) says some scholars consider the more recent technology push consisting of agricultural technologies created through molecular breeding techniques and genetic modification as an extension of the Green Revolution. However, Parayil argues that this should instead be seen as a separate technology push he calls the Gene Revolution. Parayil (2003) suggests that in contrast to the Green Revolution's technology development effort being situated in public institutions, the Gene Revolution's technologies are being developed by private industry with the goal of increased investor profits. Regardless of the name assigned to them, both of these technology transfer efforts are within Iles et al.'s (2016) concept of "productivist" agriculture. Iles et al. (2016) explain that productivist forms of agriculture are characterized by the ecological simplification of agricultural systems with farms increasing both their relative size and yields to better integrate them into industrial production networks and globalized markets.

The perennial paradigm shares aspects of both of these "revolutions." The perennial paradigm is primarily situated in public institutions (Runck et al., 2014) and—while its technologies are not genetically modified—its hardware components, like perennial sorghum, are being created through modern molecular breeding techniques (Cox, et al., 2014; Paterson et al., 2014). But, in contrast to the productivist forms of agriculture of both the Green and Gene Revolutions, the perennial paradigm frequently invokes the concepts of natural systems agriculture (Jackson, 2002) and argues that the perennial paradigm's conceptions of agriculture are based on ecological processes (Cox et al., 2014). The perennial paradigm sees its technologies as part of an alternative form of agriculture distinct from productivist forms. Petersen and Snapp (2015) explain that alternative forms of agriculture "seek specifically to reduce environmental consequences, in addition to increasing yields and addressing the social context embedded in production agriculture" (p. 2). This is why the perennial paradigm has stated that adoption of their technologies (both hardware and software) represent a paradigm shift toward sustainable agriculture (Wang & Alonzo, 2014).

Reganold (2014), a proponent of the perennial paradigm, outlines a vision of the four domains of sustainable agriculture—production, economics, environment, and well-being. This model reflects the FAO's definition of "sustainable intensification" which has been widely accepted within the perennial paradigm (Leakey, 2014; Runck et al., 2014; Snapp, 2014). While these models appear to contrast with productivist agriculture's goals as outlined by Iles et al. (2016), the sustainable intensification concept is not without controversy and critics. Petersen and Snapp (2015) interviewed several agricultural experts on their opinions about the concept and found significant disagreement on what sustainable intensification means and if it is even possible. To deal with some of these controversies Smith, Thorne, and Snapp (2015) attempted to try and develop sets of indicators and metrics to aid researchers and practitioners in assessing the outcomes and impacts of sustainable intensification efforts in smallholder contexts.

A well articulated vision of sustainability and specific measures on how to accomplish this goal are important to achieving the perennial paradigm's desired paradigm shift. However, this does not ensure that the desired endpoint will be achieved or that all the stakeholders to the process will agree on the consequences. The perennial paradigm has recognized the need for stakeholder input, and Runck et al. (2014) has laid out a plan for this in a process called the "Reflective Plant-Breeding Paradigm." However, Runck et al.'s process does not allow for stakeholder input on many of the pre-analytic choices of the perennial paradigm such as the choice of sustainable intensification—already shown to be problematic—as the target to be met.

Defining "Success" and Appreciating Smallholder's Agency

The disagreement between stakeholders as to whether an agricultural innovation achieves the goals of its developers is attributed to a lack of understanding because of physical, social, and cultural gaps between agricultural scientists and farmers and the pre-analytic choices made before and during an innovation's development (Ajeigbe, Goodrich, Ntare, Weltzien, & Ndjeunga, 2013; Crane, 2014; Nederlof and Dangbégnon, 2007; Rhoades & Booth, 1982; Röling, 2004; Röling et al., 2004; Stoop & Hart, 2005). Discussing this divide between researchers and farmers, Stoop and Hart (2005) state that, "the Western development assistance programmes are illustrative of the *gap* that exists between theory-driven policymakers and scientists on the one hand and the realities of farming at the field level," (p. 214, emphasis added).

Nederlof and Dangbégnon (2007) studied the adoption of soil fertility practices within a research project targeting smallholder farmers in West Africa. They attempted to evaluate the relative success of this project from the perspective of the funders, researchers, and participating farmers. They discovered that while *Mucuna puriens*, a legume used as a green cover crop, was relatively technically fruitful from the funders' and researchers' perspective—data indicated that *Mucuna* improved soil fertility—farmers did not see the technology as beneficial. Nederlof and Dangbégnon (2007) discovered through their qualitative research that farmers did not evaluate the *Mucuna* innovation using technical considerations alone and moreover considered socio-economic and cultural issues, such as land tenure and a desire to obtain additional uses beyond soil improvements from a crop. This example highlights how the researchers' metrics of success reflected their pre-analytic choices of what the problem to be addressed is (i.e., declining soil fertility) and what solution to pursue (i.e., soil fertility improvements with *Mucuna*).

When an innovation does not meet the needs of smallholders or does not fit within their context for social, cultural, or other reasons, they can choose not to adopt the innovation. Röling (2004) calls this ability to reject a technology "veto power" and explains that it can occur despite the efforts and opinions of those developing, introducing, and diffusing these technologies. Farmers will also sometimes re-invent an innovation to better meet their needs and fit their context and Rogers (2003) indicates that this may be a common phenomenon. The point is that as potential adopters, farmers have the ultimate say in whether a technology is acceptable (unless forced to do so by a powerful entity but this would seem to contradict the goals of the perennial paradigm). The rejection of agricultural technologies by African smallholders—in particular, the technologies pushed during the Green Revolution—has caused some scientists and researchers often outside these farmers' contexts and distant from their lived experiences to assume that African smallholders' agriculture exists in a state of stagnation (Stoop and Hart, 2005). Röling et al. (2004) argue that African smallholders are in reality extremely innovative, and that component technologies aimed at farm and field level problems do not address the higher level issues such as a historic lack of political voice, institutional support, market access, and corruption that have hindered the ability of smallholders to escape poverty. Röling (2004) states that farmers' ability to veto a technology necessitates that the developers of technology listen to them.

Perennial Sorghum and Smallholder Farmers

The drought resistant nature of sorghum (Bozzini, 2014, Paterson et al., 2014) and its long history with and importance in smallholder farming systems of Africa (Mekbib, 2006, 2007, 2008, 2009a, 2009b) has contributed to the pre-analytic choice of developing a perennial sorghum technology (rather than some other grain) for African smallholder farmers (Cox et al., 2014; Paterson et al., 2014). Efforts to breed a perennial sorghum through hybridization of grain sorghum (*S. bicolor*) with wild perennial relatives of either *S. propinquum* or *S. halepense* are being pursued with the aid of modern molecular plant breeding techniques at The Land Institute in Salina, Kansas—who began its perennial sorghum effort in 2001—and the University of Georgia's Feed the Future Innovation Lab for Climate Resilient Sorghum (Cox et al., 2014; Glover, 2014; Paterson et al. 2014). The United States Agency for International Development (USAID) has made a 5-year, 5-million US dollar investment in the Feed the Future Innovation Lab for Climate Resilient Sorghum (Glover, 2014) to pursue a perennial sorghum in concert with The Land Institute and international partners in India, Mali, Kenya, and South Africa.

Sorghum halepense, or Johnson grass, one of the sources of perenniality being used to breed perennial sorghum is classified as an invasive weed in many countries; however, Cox et al. (2014) say that the current versions of perennial sorghum are not as invasive as Johnson grass. While being derived from Johnson grass may cause concerns over invasiveness, there may also be potential soil fertility benefits. Rout and Chrzanowski (2009) found that *Sorghum halepense* harbors nitrogen-fixing bacteria in its roots and rhizomes. Cox et al. (2014) also indicate that the ability of hybrid perennial sorghums to form associations with nitrogen fixing bacteria and other arbuscular mycorrhizal fungi, enhance phosphorus availability, and chelate iron, are being investigated.

Additionally, some sorghum varieties possess the ability to regrow from root and crown remaining after harvest. When this ability is exploited in agricultural settings it is referred to as ratooning (Rogé et al., 2016). Duncan, Miller, and Bockholt (1980) and Duncan and Moss (1987) had previously recognized sorghum's ability to produce ratoons and suggested that ratooning may improve both total yield and yield stability throughout time. Ratooning has been utilized in the agricultural systems of many cultures on several crop varieties around the world to varying degrees throughout history (Hill, 2014). The practice is utilized today in perennial forage and sugarcane—a crop closely related to sorghum—production (Paterson et al., 2014). However, Rogé et al. (2016) indicate that there is relatively little scientific literature on the ratooning of sorghum especially as practiced in African smallholder sorghum systems even though the crop originated on the continent. Rogé et al. (2016) offer a review of the existing literature on the ratooning of sorghum and suggest that smallholder farmers' practices deserve more attention as the literature suggests it is an important risk management strategy and the effects on soil fertility and grain yield are not well understood.

Sorghum's impressive ability to produce ratoons contributes to an overall greater potential for biomass production and, like the other perennial crops being developed by the perennial paradigm, greater net primary productivity under similar growing conditions compared to annual crops (Gliessman, 2015). Cox et al. (2014) state that a "medium-term outcome along the way to developing a rhizomatous perennial sorghum could be an improved ratooning sorghum" (p. 165). The pre-analytic choice of *perennial* sorghum may relegate the development of improved ratooning sorghum to "an interim objective" (Cox et al., 2014, p. 159) within perennial sorghum's trajectory regardless of whether an improved ratooning sorghum might be more appropriate and beneficial for smallholders.

Sorghum's center of diversity is on the African continent, most likely Ethiopia, and Mekbib (2006, 2007, 2008, 2009a, 2009b) highlights how Ethiopian smallholder's have maintained diverse and extensive sorghum germplasm having cultivated the crop for millennia. Cleveland (2014) explains how smallholder farmers typically rely on a *varietal portfolio* consisting of a wide assortment of crops and crop varieties with particular characteristics, uses, and environmental tolerances. Potentially already practicing ratooning and maintaining an extensive sorghum varietal portfolio, some African smallholder farmers likely have significant knowledge and experience to contribute to the development of new sorghum technologies. The nature of farmers' participation in the ongoing innovation process to develop a perennial/ratooning sorghum should be carefully considered given the pre-analytic choices already made by the perennial paradigm. This may mean (re)negotiating not only the metrics used for determining success but overcoming gaps in experience and understanding between farmers and agricultural scientists and researchers. Additionally, it may be important to consider the cautions of McIntyre et al. (2009) and Ezeanya (2013) regarding the IPRs of these farmers and their communities when developing sorghum technologies based on the germplasm of their varietal portfolios.

Limitations

No research is without its limitations. The following list outlines the major limitations of the research presented in this thesis:

- The choices (explicit and implicit) made before embarking on the research endeavor, such as the use of a social constructivist perspective, circumscribe the problems identified, questions asked, results presented, and conclusions reached.
- Researcher biases may limit the credibility of the findings.
- The data collection and analysis was primarily carried out by a single individual and the discussions and conclusions relied on this single perspective potentially further limiting the credibility of the research.
- In the interviews carried out in Chapters 2 and 3, a potential desire by interview participants to provide socially acceptable or desirable answers to the interviewer may have skewed the collected data.
- The research presented in Chapter 3 represented an effort to work across social, cultural, and linguistic barriers in a setting unfamiliar to the researcher. For example, the transcriptions of farmer interview participants were not word-for-word because of the realities of translation between languages and limitations of time and resources. The translator of these interviews, a coauthor to the Chapter 3 manuscript, reduced farmers' answers to key points and elements for further analysis by the first author.
- While five weeks were spent in the field gathering data for Chapter 3, this is not enough time to become completely acquainted with the complexities of context investigated.

Subjectivity Statement

I spent most of my childhood playing in the fifteen acre woods surrounding my family home. I started working in landscaping when I was only thirteen and I eventually obtained a bachelor's degree in wildlife biology. After undergrad, I worked as a seasonal wildlife technician and park ranger in Colorado. The majority of my post-undergrad work experience has been in the field of arboriculture, first as an integrated pest management technician and then as both a climbing and consulting arborist. One would be safe to say that I have cultivated an appreciation for perennial plants and their importance in ecosystems over my entire lifetime.

My interest in agriculture stemmed from my concerns for wildlife and the environment. You can't make it very far in wildlife biology without gaining an appreciation for the conflicts that arise when natural ecosystems are converted into agricultural systems, the scale and extent to which this continues to take place, and the resulting pollution of the remaining natural environment from agricultural practices. It would therefore be hard for me to claim that I am not biased toward the use of agricultural technologies that mimic natural systems and processes or try to reverse or limit the damage caused by large-scale conversion for agricultural purposes. I first heard of the idea of trying to utilize perennial versions of annual crops in agricultural systems some years before I was ever given the opportunity to conduct research involving them and at the time all I thought was "that sounds like a great idea." However, trying to study the social side of agriculture and the issues facing humans who rely on agriculture for both food security and economic livelihood was a very new experience for me. Tracy (2010) suggests that one of the criteria for producing good qualitative research is sincerity. Tracy (2010) explains that this does not just mean being transparent about the methods and challenges of the research conducted, but self-reflexivity about the biases, values, and proclivities of myself as a researcher.

I am not without subjectivity. However, my goal is not to be objective but rather transparent in regard to this subjectivity.

When beginning my master's program and initially learning about these new perennial crops I found myself wanting to be a proponent of these technologies. I therefore found it necessary to take courses and seek out material that challenged me to think critically about the consequences and realities of agricultural development through technology transfer. Learning about the consequences and shortfalls of past technology transfer efforts, as well as the complicated history of agricultural development, added nuance to my perspective and made me question initial enthusiasm for anything I thought improved the natural environment. I also found myself sometimes intimidated by the level of expertise and experience the experts interviewed for Chapter 2's research possessed in their respective subject areas. Even now I struggle not to be overly critical of my research when evaluating it against the work of these experts.

When I traveled alone to Ethiopia to conduct the research presented in Chapter 3, I found it useful to keep a journal. I used this journal to not only record and reflect on observations, data collection activities, and begin my analysis, but to record my feelings of being far from home, missing my daughter's first birthday, and being a privileged white American male graduate student conducting research involving smallholder Ethiopian farmers. I tried to record and reflect on instances when I thought I was receiving special treatment, when I was frustrated with setbacks, when I felt uncomfortable or scared, and when I thought I had actually gained some insight into a culture, language, and religion distant from my previous life experiences. The act of journaling allowed me to maintain a sense of wonder and thoughtfulness during my time in Ethiopia. I do not presume to have gained complete immersion in Ethiopian society; nonetheless, by looking back at the journal later, I am able to see a change in me during my time in Ethiopia. I can see myself becoming more aware and familiar with the atmosphere of daily life that surrounded me. I believe this change helped me gain perspective on my data and on my life back home.

CHAPTER 2

EXPLORING THE BARRIERS TO PERENNIAL SORGHUM FOR SMALLHOLDER FARMERS: CONSULTING THE EXPERTS[1]

[1] Brooks, J. T., Navarro, M., Paterson, A., Thompson, J. To be submitted to the journal Agriculture and Human Values

Abstract

The history of agricultural development through technology transfer to smallholder farmers, especially on the continent of Africa, has been criticized for ignoring the realities of low-input farming on the continent and the expressed needs and opinions of smallholders. A new technology development and diffusion effort under the banner of sustainable intensification is also targeting smallholder farmers in Africa. This still emerging technology is a newly perennialized sorghum hybrid. The perennial nature of this crop is theorized to be more ecologically efficient and sustainable than its annual counterparts. Perenniality is theorized to confer additional benefits to smallholder farmers through added vigor, reduced labor, and multiple-harvests of grain and fodder. This research utilized semi-structured interviews with experts involved in the innovation process of perennial sorghum and experts in smallholder contexts to understand the potential barriers to smallholder farmers capturing these benefits. Grounded theory was utilized to analyze data and constantly compare emerging constructs with additional data and the literature. Expert-identified barriers were organized into three constructs: *the innovation process, the technology,* and *the end-user.* These constructs reflect the pre-analytic choices (Giampietro, 2004; Röling, Hounkonnou, Offei, Tossou, & Van Huis, 2004) made in the early stages of perennial sorghum's innovation process. A conceptual model of the relationship between these barriers and three constructs of key pre-analytic choices is proposed. Findings also indicate that while smallholder participation in the future innovation process is likely, participation can be of either the consultative or collaborative type (Johnson, Lilja, & Ashby, 2003; Lilja & Ashby, 1999).

Introduction

Growing recognition of their merits (Cox, 2014; Glover et al., 2010) are motivating significant efforts to enhance individual cereal, legume, and oil plants' yield potential and environmental sustainability through increasing the number of harvests attainable from single plantings within an agricultural production system (Wang & Alonzo, 2014)—i.e., to create 'perennial' crops that yield carbohydrate-rich seeds. This breeding effort, coupled with work on the agronomic and agroecological systems in which these crops would function, is being framed as "a paradigm shift in agriculture" that "hold[s] great potential to move towards sustainable production systems" (Wang & Alonzo, 2014, p. iii). This breeding effort is proceeding along two routes: 1) creating "perennial" versions of familiar annual grain crops through hybridization to perennial relatives, and 2) domesticating wild perennials to create new crops for human consumption (Bonzzini, 2014; Cox, Tassel, Cox, & DeHaan, 2010; DeHaan, Van Tassel, & Cox, 2005; Glover, & Reganold, 2010; Neely, Choptiany, & Batello, 2014).

The outputs of this agricultural technology development process (see McIntyre, Herren, Wakhungu, & Watson, 2009 for more on agricultural technology) have been called "an example of a 'transformative technology,' in which the functionality and science of the technology differ in a fundamental manner from conventional grain crops" (Adebiyi, Olabisi, & Snapp, 2015, p. 101). These transformative technologies meet Rogers (2003) definition of an *innovation*: "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (p. 475). In 2013, the Food and Agricultural Organization of the United Nations (FAO) and Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA) organized a workshop to bring together the current research and experts on this inchoate agricultural innovation. The published proceedings, titled *Perennial Crops for Food Security: Proceeding of the FAO Expert*

Workshop, outlines a concerted international effort to develop perennial crops that meet multiple strategic objectives of the FAO and CRA, primarily focused on sustainability, poverty alleviation, and food security (Wang & Alonzo, 2014).

Sorghum is an important cereal grain in the lives of food insecure populations living in arid and degraded environments in Africa (Belton & Taylor, 2004; Paterson, Cox, Kong, & Navarro, 2014). Drought tolerant cereals such as sorghum are suggested to be “key for the food security and livelihood of millions of people in dryland agricultural systems” (Bozzini, 2014, p. 396). The Sorghum genus is familiar to smallholder farmers performing dryland agriculture in these drought-stricken and degraded regions of sub-Saharan Africa (Paterson et al., 2014), as the genus’ center of diversity is located in northeast Africa (Paterson et al., 2009). In some of these regions smallholder farmers have established systems of “folk” sorghum taxonomies as the crop has been cultivated for over a millennium (Mekbib, 2009b).

Sorghum’s drought tolerance coupled with its historical, social, and cultural significance in the lives of food insecure African populations together with the potential merits of perennial crops raise the question of whether a sorghum possessing perennial traits would benefit farmers within these contexts (Bozzini, 2014; Cox et al., 2014; Paterson et al., 2014). The United States Agency for International Development (USAID) has made a 5-year, 5-million US dollar investment in the Feed the Future Innovation Lab for Climate Resilient Sorghum at the University of Georgia (Glover, 2014), which includes a significant effort to advance breeding of perennial sorghum in partnership with The Land Institute in Salina, Kansas—which formally began its perennial sorghum breeding initative in 2001 (Cox et al., 2014)—and research institutions in India, Mali, Kenya, and South Africa.

The perennial sorghum being developed by these groups is described as a familiar crop to African smallholder farmers, a transformative technology, and part of a larger paradigm shift that can alter how agriculture is practiced. The outcomes and impacts of introducing such an agricultural technology in these contexts must be carefully considered, and the assumptions behind the decisions on its potential to benefit smallholders examined. This study utilizes qualitative interviews with the individuals involved in the development of perennial sorghum and other newly perennialized crops, experts researching the agronomic and agroecological systems in which perennial crops might function, and experts in development, diffusion, and smallholder farming contexts to ask: 1) What are the relevant expert's perceived barriers to realizing perennial sorghum and its theorized agronomic and ecological benefits, especially those barriers that may prevent smallholder farmers from adopting and benefiting from a perennial sorghum? 2) In what ways is perennial sorghum's ability to benefit smallholder farmers limited by the decisions made without smallholder participation?

Literature Review

Pre-Analytic Choices of the Perennial Paradigm

Thomas Kuhn states in his influential book *The Structure of Scientific Revolutions* (1970) that revolutionary shifts in thinking and theory—"paradigm shifts"—begin with an emerging crisis in a scientific discipline, often before the crisis is even acknowledged. The Land Institute is a non-profit established in 1976 by Wes Jackson with the intent to "develop an agricultural system featuring perennials with the ecological stability of the prairie and a grain and seed yield comparable to that from annual crops" (The Land Institute, 2017, Vision and Mission, para. 6). Jackson (2002) traces a long history to the crisis he refers to as the "problem of agriculture." Jackson connects this "problem" to the degradation and unsustainable use of the very resource base upon which agriculture and ecosystems rely. Jackson highlights the human-mediated loss of soil and genetic resources, and the substitution of nonrenewable fossil fuels and dangerous chemical inputs to cover up the problem of agriculture by treating the symptoms rather than the cause. Jackson (2002) argues for a paradigm shift in knowledge and technology development that looks to natural systems' structures and processes for solutions. One solution in particular has been seized on by Jackson and others who share his vision (collectively referred to here as the *perennial paradigm*) as the agro-technological solution of choice—the development and incorporation of perennial food crops into agriculture.

The perennial paradigm's choices of the problem to be addressed and the technical solution to be pursued are what Giampietro (2004) and Röling, Hounkonnou, Offei, Tossou, and Van Huis (2004) call *pre-analytic choices*. Pre-analytic choices are those choices of "relevant goals, variables, [and] explanatory dynamics for the select[ed] explanatory model" (Giampietro, 2004, p. 4) that "*ex ante* reduce one's degrees of freedom to determine research priorities, objectives, problem, subject, scale, analytical framework, variables and beneficiaries of research and development" (Röling et al, 2004, p. 222, emphasis in original). Röling et al. (2004) discuss how pre-analytic choices limit the effectiveness of agricultural research and development targeted at benefiting smallholder farmers. Röling et al. (2004) explain that pre-analytic choices are a necessary and unavoidable component of research and development, and because of this, and their restrictive effects, pre-analytic choices should, to the extent possible, be made mutually with the intended beneficiaries.

Participation in the Innovation Processes of the Perennial Paradigm

The technology historian Melvin Kranzberg's first law of technology states, "technology is neither good nor bad, nor is it neutral," (1986, p. 545). Kranzberg explains:

> Technology's interaction with the social ecology is such that technical developments frequently have environmental, social, and human consequences that go far beyond the immediate purposes of the technical devices and practices themselves, and the same technology can have quite different results when introduced into different contexts or under different circumstances. (1986, pp. 545-546).

The introduction of new perennial cropping technology into contexts where different knowledge systems are more prominent among the end-users/adopters than that from which the technology emerged has important implications for the assumptions and decisions driving continued research and development into this technology. Different knowledge systems, whether seen as "expert" and "scientific" or "traditional" and "indigenous," emerge from the historical, cultural, and social milieu in which they are embedded. Therefore, different types of knowledge are useful to different people at different times in different contexts, and a specific knowledge/technology's application can differentially affect various demographics (Agrawal, 1995). As it currently exists, the perennial paradigm, its conception of sustainable production systems, and the agency to make pre-analytic choices is primarily rooted in the expert/scientific knowledge system. Argawal (1995) problematizes the dichotomies created when distinguishing between scientific and indigenous knowledge systems. However, Ezeanya (2013) explains how differences underlying knowledge systems has resulted in conflict over the patenting of plant-based knowledge and criticism of global IPR law, particularly related to the patenting of indigenous plant-based knowledge by pharmaceutical companies.

The need for input from other knowledge sources has been recognized within the perennial paradigm and by those developing perennial sorghum; Cox (2014) says "domesticators and breeders of perennial grains have much to learn . . . from farmers' experience" (p. 2), and

Wang and Alonzo (2014) acknowledge that the use of perennial crops in agriculture dates back thousands of years. Johnson, Lilja, and Ashby (2003) analyzed the impact of user participation in the innovation process from various agricultural and natural resource management research/projects and concluded that participation "led to more relevant technologies and greater economic impact" (p. 287). User participation early in the research process was especially benficial—and a protracted and intensive work with researchers led to enhanced farmer (user) capacity and empowerment. However, the perennial paradigm's pre-analytic choice of perenniality as the solution to Jackson's (2002) problem of agriculture has already been made without this input. Furthermore, this research highlights how during the ongoing innovation process of perennial sorghum the pre-analytic choices of the problem to address (i.e., the poverty and food insecurity of African smallholder farmers) and the proposed solution (i.e., perennial sorghum) has also been made by expert scientists without smallholder input.

Lilja and Ashby (1999) describe three stages to the innovation process: design, testing, and diffusion (Table 2.1). These authors state that while these stages do not always proceed in a linear fashion, there is a general order to their process—and within each of these stages there can be various levels of participation from the target end-users of an innovation (Table 2.2). As we have seen in the case of perennial sorghum, potential end-users have been identified as resource-poor smallholder farmers in degraded sorghum growing regions of Africa, and potential benefits have been identified as enhanced environmental sustainability, food security, and livelihoods.

Smallholder Farmers and Agricultural Technology

Terms applied to some potential users of a perennial sorghum, such as *smallholder* and *resource-poor*, reflect the processes of "identity-making" (Iles, Garrett, Maywa, & Galt, 2016) that have taken place within international agricultural development for decades. While these

Table 2.1.

Stages of the Innovation Process (Johnson et al., 2003; Lilja & Ashby, 1999)

Stage	Activities	Outcomes
Design	Identification and prioritization of problems and/or opportunities for research.	Potential solutions to problems identified. Solutions maybe totally new technology/innovation or novel application of existing technology/innovation requiring testing, promotion, or both.
Testing	Evaluation of potential solutions.	Generation of recommendations regarding potential solutions: either a return to the design stage or identification of technology/innovation for mass distribution during diffusion stage.
Diffusion	The promotion of technology/innovation through persuasion and awareness building among target user group(s).	Adoption or rejection of a technology/innovation eventually resulting in consequences and impacts.

Table 2.2.

Types of Participation in the Innovation Process Based on the Locus of Decision-Making (Johnson et al., 2003; Lilja & Ashby, 1999)

Type	Description	Communication Patterns and Locus of Decision-Making
Conventional	No farmer participation	No organized communication with farmers. Decisive agency rests entirely with scientists.
Consultative	Functional participation by farmers	Organized one-way communication whereby farmer opinions, preferences, and priorities are known to scientists. Decisive agency rests entirely with scientists who may choose to ignore any farmer input.
Collaborative	Empowering participation	Organized two-way communication whereby farmers and scientists share opinions, preferences, and priorities with each other. Decisive agency is shared between farmers and scientists with individual parties being unable to alter/revoke shared decisions.
Collegial	Empowering participation	Organized communication between scientists and selected representatives of larger farmer group with knowledge of the opinions, preferences, and priorities of scientists. Decisive agency rests entirely with farmers who may choose to ignore scientists input.
Farmer Experimentation	No scientist participation	No organized communication with scientists. Decisive agency rests with individual farmers or farmer groups.

terms tend to reflect and reinforce power differentials and biases toward these individuals and their communities, they are useful here for highlighting the contextual realities faced by these farmers.

Smallholder farmers are characterized as having relatively little access to resources and capital—including land, thus the term smallholder—and opportunities to address issues of food and livelihood insecurity. Röling (2010) state that smallholder farmers account for 70 percent of persistent poverty. Röling et al. (2004) explain that this is not because of a lack of innovative capacity on the part of these farmers, but "the structural conditions within which farming takes place" (p.216)—such as government and corporate corruption coupled with a lack of political agency. These higher level constraints only exacerbate the daily issues confronting livelihoods centered around highly diversified, rainfed, subsistence farming on degraded soils under uncertain climatic and market conditions (Röling, 2010). Even between smallholders, the access to opportunity and resources is not equal. Female smallholders often have less access to productive resources and capital, as well as inferior quality of these resources (e.g., fields exhausted of nutrients from previous agricultural activities) than male smallholders (Benzer Kerr, 2008; Paterson et al., 2014).

One way that limited access to resources manifests itself is in smallholder's frequent inability to access modern "improved" cultivars of various crops. Smallholders are often described as relying on "farmer varieties" (Cleveland, 2001, 2014) or "landraces" of crops that contribute to the persistent "yield gap." Landraces are described as generally having lower yield capabilities than modern improved varieties, but—in a more positive framing of the term—are also described as possessing a "reliable mixture of genotypes locally adapted to pests and diseases" (Sands, Pilgeram, & Morris, 2014, p. 212) as well as having a relatively high yield stability across years (Cleveland, 2001). These positive characteristics of landraces and the attendant genetic variability have meant that these farmers' varieties have been crucial sources of germplasm for modern plant breeding efforts (Sands et al., 2014).

One form of agency that smallholders do possess is what Röling et al. (2014) refer to as "veto power," or the power to reject new technologies despite the efforts and opinions of those developing, introducing, and diffusing these technologies. This is why theories that seek to understand the processes of adoption and rejection, such as Rogers (2003) diffusion of innovations, have been essential to many agricultural development efforts. Theories have sought variously to overcome barriers associated with the vastly different contexts in which a technology is developed compared to the target environment into which it is diffused by reducing adoption decisions to quantifiable characteristics of the innovation/technology (Rogers, 2003) or analyzing on-farm economic considerations (see, for example, Pannell, Llewellyn, & Corbeels, 2014). However, this unidirectional transfer of technology without end-user participation in the innovation process has been heavily criticized (Rogers, 2003; Röling, 2004, 2010; Röling et al. 2014) and seen as helping to legitimize scientific knowledge as "superior" (Ezeanya, 2013; Iles et al., 2016). This has further contributed to gaps between scientists, seen as developing innovative technologies, and smallholders, seen as the passive adopters of these technologies. Considerable literature exists highlighting the multifaceted nature of these gaps in agricultural research, how these gaps contribute to failures during the innovation development and diffusion process, and the interpretation of the reasons for these failures (Crane, 2014; Nederlof and Dangbégnon, 2007; Röling, 2004; Rhoades & Booth, 1982; Stoop & Hart, 2005).

Also, some diffusion scholars such as Henrich (2001) have questioned whether the s-shaped cumulative adoption curves seen in diffusion research can be assumed to result from adoption based on environmental learning through cost-benefit analyses. Environmental learning is explained by Henrich (2001) as the process of individual potential adopters receiving information from their environment (which could include self-directed experiments) and using this information vis-à-vis their individually set thresholds for determining whether to adopt or reject an innovation. Henrich (2001) instead sees these s-curves as resulting from complex social and cultural dynamics causing biased transmission of innovations and often only partially related to the benefits conferred by an innovation. Stone, Flachs, and Diepenbrock (2014) provide an example of these social dynamics. Utilizing ethnographic observation and analysis of over a decade's worth of seed choice by cotton farmers in India, these authors identified an emergent pattern of faddism that generated adoption curves that cursorily resemble s-shaped cumulative adoption curves typically attributed to environmental learning (Stone et al., 2014).

Past efforts to transfer agricultural technology—such as the "Green Revolution" of the mid to late twentieth century—sought to "modernize" farmers around the world (Parayil, 2003) and incorporate them into global agricultural commodity markets (Röling, 2010). Green Revolution technologies are criticized as being inappropriate for smallholders because they consisted of crop varieties with high yield potentials under conditions of ample input use, largely ignoring contextual considerations (Iles et al., 2016). It has been previously established that smallholders typically reside in marginal environments with limited resource availability and access (Röling, 2010). In example of both the gap between scientists and smallholders and how pre-analytic choices limit outcomes, Cleveland (2014) states that agricultural experts developing technologies, like new crop varieties, frequently lack experience with the environments and the extent of limitations under which smallholders practice farming and therefore do not adequately account for these limitations during technology development. Cleveland says that this has lead some experts to advocate for collaborative breeding of new crop varieties in smallholders' environments. Dawson, Murphy, and Jones (2008) reviewed the literature on participatory and decentralized plant breeding, and conclude that while genetically and logistically more difficult, it is more efficient to include farmers in the breeding process when breeding for low-input systems under high environmental stress.

Success Through Sustainable Intensification?

The perennial paradigm has put forward a holistic vision of sustainability, but this does not mean that the specific metrics used will result in universal agreement on the impacts of its implementation from various stakeholder perspectives. It is through the (pre-analytic) selection of the methods and metrics for determining the success of a perennial sorghum technology that the consequences—environmental, social, and human (Kranzberg, 1986)—beyond the immediate purposes of the technology will either be accounted for or ignored. Additionally, research on technical interventions for the benefit of smallholders have found that even when expert scientists "objectively" measure "success" the intended smallholder beneficiaries may disagree (Nederlof & Dangbégnon, 2007). These misalignments between the developers and intended beneficiaries of a technology are the root of the debates between proponents and critics of the the impacts of the Green Revolution. Using only the metrics of yield (narrowly defined to grain yield) and cost reductions leads to declaring a resounding success to the Green Revolution technology push, whereas attention to the resulting social inequalities and environmental consequences often results in the reverse.

Reganold (2014) explains that the four components of sustainable agriculture—production, economics, environment, and wellbeing—directly reflect the FAO's definition of "sustainable intensification." There have been several different proposed "intensifications" in the literature (e.g., ecological intensification and agroecological intensification), but sustainable intensification has clearly won out in the scientific literature (Wezel, Soboksa, McClelland, Delespesse, & Boissau, 2015).

Petersen and Snapp (2015) interviewed several agricultural experts to assess their opinions on what sustainable intensification actually means, how to accomplish it, and whether it requires a “transformational” change to agriculture. The authors found that as a concept, sustainable intensification has initiated a dialogue important to thinking about the future of agriculture, but that experts tended to disagree on essentially every aspect of sustainable intensification. The sustainable intensification concept was found to provide no clear guidance on how to actually accomplish sustainability, with experts framing the concept in manners ranging from “business as usual” to “transformational” (similar to the literature on perennial grains and systems). Experts even criticized sustainable intensification as too ambiguous or even oxymoronic (Petersen & Snapp, 2015).

Recognizing that there is uncertainty surrounding the sustainable intensification concept, Smith, Thorne, and Snapp (2015) reviewed the literature for measures of sustainable intensification for smallholder farming contexts. They identified quantifiable metrics and assigned them to categories of indicators of sustainable intensification. These indicators are further organized into domains that imitate the four components of sustainability outlined by Reganold (2014), including productivity, economic sustainability, and environmental sustainability; however, instead of only one well-being domain, Smith et al. (2015) differentiate between “human well-being” (with indicators of food security, nutrition, and risk) and “social sustainability” (to which they assign the indicators of adoption, equity/gender equity, farmer knowledge integration, farmer participation, information access, resilience, risk, and social capital).

The Potential of Perennial Crops and Systems

Given that the FAO has co-sponsored an expert workshop on perennial grains and systems, one would surmise that the basic questions of the possibility and necessity of perennial grains have been settled. However, there is an ongoing debate in the literature on whether perennial grains are possible, or whether there exists some biological principle as to why carbohydrate-rich perennial seed crops have not already appeared in ecosystems or during the thousands of years of agricultural advancement. This question has been partially manifested as a debate between competing “strong” and “weak” perennial visions (Crews, & DeHaan, 2015; Gliessman, 2015; Smaje, 2015). The weak perennial vision argues that in nature, carbohydrate-rich edible seeds produced by perennial plants tend to be small in size and quantity, reducing overall grain yield potential (Gliessman, 2015). In the strong perennial vision, proponents believe that plant breeding efforts can overcome what Smaje (2015) sees as an inherent trade-off in resource allocation between ecological strategies. In perennial plants, there is a tendency toward increased investment of energy and resources in underground storage structures for food and asexual reproduction, allowing perennials to survive periods of adverse growing conditions (Gliessman, 2015). DeHaan et al. (2005) argued that investment in underground storage structures is not an all or nothing trade-off however, and plant breeders can simultaneously enhance expression of negatively correlated traits. Glover (2004) stated that modern plant breeders benefit from advances in biological, molecular, genetic, ecological, and computational knowledge and technology, and suggested that these innovations will allow the development of relatively high yielding perennial grains within 10 to 25 years. Much of the debate between these authors' visions seems to be centered on these perennial crops' ability or inability to achieve high grain yields—echoing the logic supporting technologies and innovations of less participatory technology pushes (e.g., Green Revolution) not centered on end user needs and contextual considerations.

Other experts seem to take issue with the strong perennial vision because of the close association with a specific perennial cropping system put forth by Wes Jackson. Jackson's (2002) solution to the problem of agriculture is through creating food-producing perennial polycultures that mimic prairie ecosystems. Gliessman (2015) refers to this idea as the "domestic prairie." Within this grain producing prairie-like agroecosystems, a polyculture of "four functional groups [would be] represented (warm-season and cool-season grasses, legumes, sunflower family)" (Jackson, 2002, p. 116)—all of these being to some extent perennial. Jackson's close association with a primary institution behind perennial crop technology development—The Land Institute—and his call for a functioning domestic prairie based solely on perennial plants, is why Smaje (2015) alleges that the strong vision abhors annuals and only seeks to push technologies based on perenniality.

Smaje (2015) critiques the strong perennial vision as a technocentric solution that fails to address the human element of the agroecosystem and argues that social reform of the food system is the key to sustainable production. Moreover, Tomlinson (2013) argues that "belief in technological or 'scientific' solutions, rather than social or economic policy solutions, and in particular, the role of specific technological developments…[to] overcome some of the ecological and resource-constraints that the current food system is facing" (p. 86) supports the dominant framing of food security and climate change mitigation as an issue of agricultural productivity. In opposition to these author's position, Crews and DeHaan (2015) give social reform short shrift and conclude that “social reform of the food system is unlikely to deliver the biophysical changes needed to return to what Rockström et al. call a safe operating space for humanity” (p. 512). Rockstrom et al. (2009) argued that three “planetary boundaries”—climate change, biodiversity loss, and the nitrogen cycle—have already been exceeded. It is true that social reform alone may not directly improve biophysical processes, but the sustainable intensification concept embraced by the perennial paradigm includes social and human considerations alongside productivity and environmental concerns. As previously discussed, the development, implementation, and impact of agricultural technologies are unavoidably social in nature. To conclude that human-mediated damage to planetary processes (Rockstrom et al., 2009) and the problem of agriculture (Jackson, 2002) can be addressed without equal or greater attention to social reform stands in direct opposition to a holistic view of sustainability.

Gliessman (2015) negotiates between competing visions, saying we will likely need a combination of both the weak perennial vision (focusing on improving how humans *do* agriculture whether annual or perennial) and the strong perennial vision (continuing the technological development of perennials with a primary goal being to increase crop yields). To counter Smaje’s (2015) assertion that “strong vision myopia” could lead to exclusion of alternatives, such as those proposed in the weak vision, Crews and DeHaan (2015) provide an example of cooperation between organizations supporting both the strong—The Land Institute—and weak visions—Green Lands Blue Waters. This latter organization seeks simply to increase perennial *cover* on the agricultural landscape through utilizing herbaceous and woody perennials as well as annuals. Greater diversity at the farm and field level to has been suggested to enhance agroecosystem functioning and efficiency for imporved sustainability (Cox et al. 2014; Picasso, Brummer, Liebman, Dixon, & Wilsey, 2011). Gliessman’s (2015) call for a “strong + weak” vision reflects the contents of the FAO expert proceedings—which contained not only many articles on perennial grains, but agroforestry (Leakey, 2014) and other strategies for maintaining "continuous living cover" such as winter annuals (Runk et al., 2014).

However, even a strong + weak vision does not guarantee that the pre-analytic choices of the perennial sorghum innovation process won't exclude what might be more appropriate direction of agricultural technology development for smallholders, perennial or otherwise. The underlying assumptions on the benefits of perenniality for smallholders are linked to perennial crops persistence through time and the reduced system disturbance compared to annual crop systems. Crews et al. (2016) compared this reduced disturbance regime to moving the agricultural field from an early to a mid-successional stage. They argue that this later successional stage means that negatives associated with soil degradation are reduced (such as erosion, leaching, and soil organic matter loss) and that a more stable plant community reduces niches for weed establishment. Cox et al. (2014) echo these arguments, stating that frequent disturbance resets or destroys important ecological processes, and that modern agronomy arose to mitigate the loss of these ecological processes through the unsustainable use of inputs often derived from fossil fuels. Additionally, perennial crops are said to have greater net primary productivity compared to their annual counterparts under similar growing conditions because of the sheer amount of biomass produced—both above and below ground (Gliessman, 2015). This biomass is important for a number of reasons relating back to Reganold's (2014) model of sustainability—such as potential soil carbon and organic matter increases, as well as multiple-use benefits such as simultaneous grain and fodder production. Because of these reasons, perennials are simply assumed to be more efficient and therefore more sustainable crops for smallholder farmers who lack access to the inputs (land, seed, pesticides, fertilizers, etc.) upon which high-yielding annual systems rely. The potential of perennials and perennial systems to function with less disturbance and outcompete weeds is assumed to reduce the need for labor in field cultivation and weeding to the benefit of smallholders (Paterson et al., 2014).

The Case of Perennial Sorghum

Sorghum's drought resistant nature (Bozzini, 2014, Paterson et al., 2014) and its long history with and importance in smallholder farming systems of Africa (Mekbib, 2006, 2007, 2008, 2009a, 2009b) has been important to the pre-analytic choice of developing a perennial sorghum for these systems (Cox et al., 2014; Paterson et al., 2014). However, the sorghum genus also possesses additional traits theorized to be beneficial for smallholders. Many sorghum varieties demonstrate varying degrees of an ability to regrow after harvest from the remaining root and crown portions of the plant. When this ability is exploited by humans in agricultural setting it is called ratooning (Rogé et al., 2016). Current breeding efforts are not the first time that sorghum's ability to produce ratoons has been investigated and suggested as a potentially capable of improving yield and stability of sorghum production throughout time (Duncan, Miller, & Bockholt, 1980; Duncan & Moss, 1987). Ratooning has been utilized with various crop species on and off for thousands of years in different parts of the world (Hill, 2014), and is routinely practiced commercially in sugarcane, a close relative of sorghum. But, there is relatively little scientific literature and knowledge on the potential benefits and limitations of sorghum ratooning in smallholder systems (Rogé et al., 2016). Rogé et al. (2016) offer a review of the existing literature on the ratooning of sorghum and suggest that smallholder farmers' practices deserve more attention as it is likely an important farmer risk management strategy with unknown effects on soil fertility and grain yield. Still, the ability of sorghum to produce ratoons and consequently additional grain or forage harvests contributes to Paterson et al.'s (2014) referring to the development of "multiple-harvest sorghum."

Cox et al. discuss how a "medium-term outcome along the way to developing a rhizomatous perennial sorghum could be an improved ratooning sorghum" (2014, p. 165). This statement traces out a potential future trajectory in perennial sorghum's development. However, it also indicates what could be a divergence point in the innovation process of sorghum for smallholders. The pre-analytic choice of *perennial* sorghum potentially excludes the development of improved ratooning sorghum as its own technology with its own innovation process, and relegates improved ratooning sorghum to "an interim objective" (Cox et al., 2014, p. 159) within perennial sorghum's innovation process. The lack of smallholder participation in the innovation process thus far prevents assessing the quality of this end goal as a pre-analytic choice.

Sorghum's ability to produce vigorous (re)growth also leads to another potential divergence points in the innovation process of perennial sorghum—is the goal to develop perennial sorghum for food, forage, fiber, or fuel? It is recognized among those advocating for an innovation process that includes food production as a primary goal, that large investments in funding are potentially steering technology development more toward biofuel production (Reganold, 2014). A perennial sorghum may be particularly susceptible to this trajectory shift, since sorghum's starch, cellulose, and sugar can all be used to produce fuel (Paterson et al., 2014).

Efforts to breed perennial sorghum are currently being pursued through hybridization of grain sorghum (*S. bicolor*) with wild perennial relatives—either *S. propinquum* or *S. halepense* (Paterson et al. 2014). This hybridization is being accomplished with the aid of modern plant breeding techniques such as, "DNA-marker aided selection to increase the frequency of genotypes that contain known Quantitative trait loci (QTLs) for ratooning and/or perenniality-related traits" (Paterson et al., 2014, p. 91). While these breeding techniques produce hybrids that do not carry the stigma associated with transgenic or "genetically modified" (GM) crops, the fact that *S. halapense,* or Johnson grass, is a notoriously invasive weed, raises questions about the potential invasiveness of any hybrid perennial sorghum derived from Johnson grass. Cox et al. (2014) state that in its current form perennial sorghum is not as perennial or invasive as Johnson grass. While some might suggest this indicates perennial sorghum is not sufficiently vigorous, Cox et al. (2014) explain that a perennial sorghum with the excessive rhizome growth of Johnson grass would limit availability of plant resources for grain and ratoon production.

The hybrids resulting from breeding efforts do not currently have much in common with annual grain sorghum (Cox et al., 2014). Importantly, degree of perenniality has not been shown to be negatively correlated with grain yield, but it is negatively correlated with seed size, expressed as kernel weight (Cox et al., 2014). Paterson et al. (2014) explain that seed size generally decreases during selection for biomass production and increased sugar content in stalks. When describing these hybrids Cox et al. write:

> Dwarf plants are rare, and tillering is excessive. Ramet emergence, tillering, flowering, and maturity all are highly asynchronous, tending to extend over periods of weeks. Until these characteristics are adjusted through breeding, perennial sorghum in temperate regions will remain unsuitable for mechanized cultivation and harvest, whatever the degree of improvement in grain yield. (2014, p.165)

This unsuitability for mechanized production systems is not presumed to carry over to African smallholder's farming systems. These authors argue that "in regions where hand harvesting and crop polycultures are the norm and where tall stover is harvested for fodder or other uses, tall plants and asynchronous maturity would not necessarily be obstacles to adoption" (Cox et al., 2014, p. 165). This suggests that viable perennial sorghum cultivars and cropping systems will first be developed in smallholder contexts.

Cox et al. (2014) also advocate that perennial sorghum cropping systems incorporate an edible, perennial, nitrogen-fixing legume to simultaneously enhance food security and address soil fertility concerns. Whereas having a parental line derived from Johnson grass generally raises questions around invasiveness, it might serve to confer benefits where soil fertility is concerned. Rout and Chrzanowski (2009) found that *Sorghum halepense* contains nitrogen-fixing bacteria in its roots and rhizomes. The potential benefits for low-input farming and soil fertility management/enhancement do not end there however. The potential of hybrid perennial sorghums to form associations that fix nitrogen, enhance phosphorus availability, chelate iron, and form associations with arbuscular mycorrhizal fungi are also being investigated (Cox et al., 2014). This represents another potential point for divergence in the innovation process of sorghum technology to benefit smallholder farmers—i.e., food security versus fertility enhancement. It is not that these two options will necessarily preclude development of a combination of these traits, but one may be minimized or excluded during development to pursue the other.

It is clearly difficult to decide a priori on specific measures of perennial sorghum's success. However, it is also impossible to move forward in perennial sorghum's development without defining end goals and making pre-analytic choices based on assumptions of what success might look like and how it can be achieved. Just as Petersen and Snapp (2015) interviewed experts to better understand sustainable intensification from those tasked with accomplishing it, we seek to illuminate the expert perspective on the barriers to realizing perennial sorghum's theorized benefits for smallholder farmers given the pre-analytic choices already made in the innovation process of perennial sorghum.

Methods

This manuscript is the result of research carried out during part one of a two-part master's research project. Part one, presented here, consisted of interviewing experts with knowledge and expertise relevant to understanding the barriers to perennial sorghum resulting in the theorized benefits for smallholder farmers. Part two of this research (Chapter 3) consisted of participant observation and interviews with smallholder farmers in Ethiopia to better understand their farming systems, and how perennial sorghum might fit within them. Data collection for part one occurred from March through July of 2016, while data collection for part two took place during June and July of 2016. An overlap in data collection for part one and two occurred as some expert interviews for part one took place in Ethiopia during part two's data collection activities.

The largely theoretical nature of both perennial sorghum and the possible benefits for adopting smallholder farmers creates a unique situation when trying to conduct research on these topics. Qualitative research is particularly useful in scenarios where there is not enough knowledge to generate a working hypothesis to test or when the research objective is the understanding of subjective experience (Auerbach & Silverstein, 2003). In this way, qualitative research can be exploratory and underpin future quantitative research. The specific qualitative research tradition of grounded theory provides a process in which a hypothesis, theory, or model is generated through the analysis of data often derived by questioning knowledgeable research participants directly experiencing the phenomenon in question (Auerbach & Silverstein, 2003).

Charmaz (2006) describes the culmination of grounded theory as being an “abstract theoretical understanding of the studied experience” (p. 4).

Presenting grounded theory studies in the format and tradition of quantitative research can be difficult for the qualitative researcher, but is generally considered more comfortable for quantitatively oriented readers (Suddaby, 2006). The actual grounded theory process in which data was coded, conceptual categories were constructed and modeled, and the literature constantly compared to the data during analysis are necessarily presented out of order to fit to the traditional categories of literature review, results, discussion, and so on. It is hoped that this short explanation will clarify how despite the presentation of important theoretical concepts early on in this article and a model at the beginning of the results, these were actually arrived at during the process of analysis while constantly comparing the data being collected to the literature and even while writing and rewriting drafts of this article.

Corbin and Strauss (1990) explain that in grounded theory “phenomena are not conceived of as static but as continually changing in response to prevailing conditions, [and] an important component of the method is to build change, through process, into the method” (p. 419). Multiple perspectives exist on the methods and processes of grounded theory, and even the progenitors of the methodology, Glaser and Strauss, eventually disagreed on the specific approaches and procedures to be followed (Heath & Cowley, 2004). We prefer the more social constructivist perspective outlined by Charmaz (2006) who argues for flexibility over strict adherence to set methodological rules, similar to the original articulation of grounded theory by Glaser and Strauss. Creswell (2013) describes this approach to grounded theory as placing greater emphasis on the “views, values, beliefs, feelings, assumptions, and ideologies of individuals than on methods of research” (p. 87). Still, clarity of the methods used and techniques employed are important to establish *sincerity* and *credibility* (Tracy, 2010) in qualitative research, concepts somewhat analogous to quantitative research's concepts of validity and reliability.

Sample Selection and Description

This used a purposeful sampling (Patton, 2015) for a targeted selection of experts who possessed the pertinent information based on our research's area of concern. We conducted this purposeful sampling by consulting the relevant literature and our existing contacts within the community of experts in the perennial paradigm on efforts to breed increased perenniality into grain sorghum, produce other perennial grain crops, or develop the associated agronomic and agroecological knowledge and systems. This initial purposeful sampling was supplemented through snowball sampling to obtain the names and contact information of additional interview candidates with expertise germane to this research. Snowball sampling allows for identification of participant candidates who possess critical information, and is useful when the community is relatively small or hard to access (Patton, 2015). Preliminary analysis of initial interviews while reading literature problematizing agricultural technology development and transfer to smallholder farmers suggested that there might be misalignments between experts developing perennial crops and smallholder farmers and the experts that work with them. By interviewing experts with specific expertise and knowledge in smallholder contexts (such as those experts interviewed while in Ethiopia) helped to develop this emerging concept and discover variation in expert opinions on barriers to perennial sorghum for smallholders—Charmaz (2006) calls this process theoretical sampling. In all, twenty experts were invited to participate in this research with sixteen ultimately participating (N=16).

Expert participants came from several academic fields and institutions with varying levels of professional expertise and experience relevant to this research. The majority of expert participants were either directly involved in the research and development of perennial sorghum and other "new" perennial crops, the research and development of cropping systems that incorporate them, or the current and future introduction and diffusion efforts. Additional expert participants were selected based on experiential and contextual knowledge in agricultural development and sorghum with emphasis on low-input and smallholder farming systems. Figure 2.1 details the expertise of participants by dividing this expertise into seven categories relevant to this research.

Figure 2.1 may be of use when encountering a participant's quote to clarify the participants' professional expertise, experience, and background. For simplicity, we have designated three levels of expertise/experience in each of the seven categories: no circle indicates no professional expertise/experience in that category, a small circle indicates some level of professional expertise/experience in that category, and a large circle indicates a relatively high amount of professional expertise/experience in the category. Each of the sixteen experts was randomly assigned a color name for a pseudonym using a random number generator to help ensure confidentiality in a relatively small community. The color pseudonyms were taken from the sixteen basic color names in HTML 4. This chart was constructed based on interview data, other readily accessible information, and validated through member checking (Schwandt, 1997).

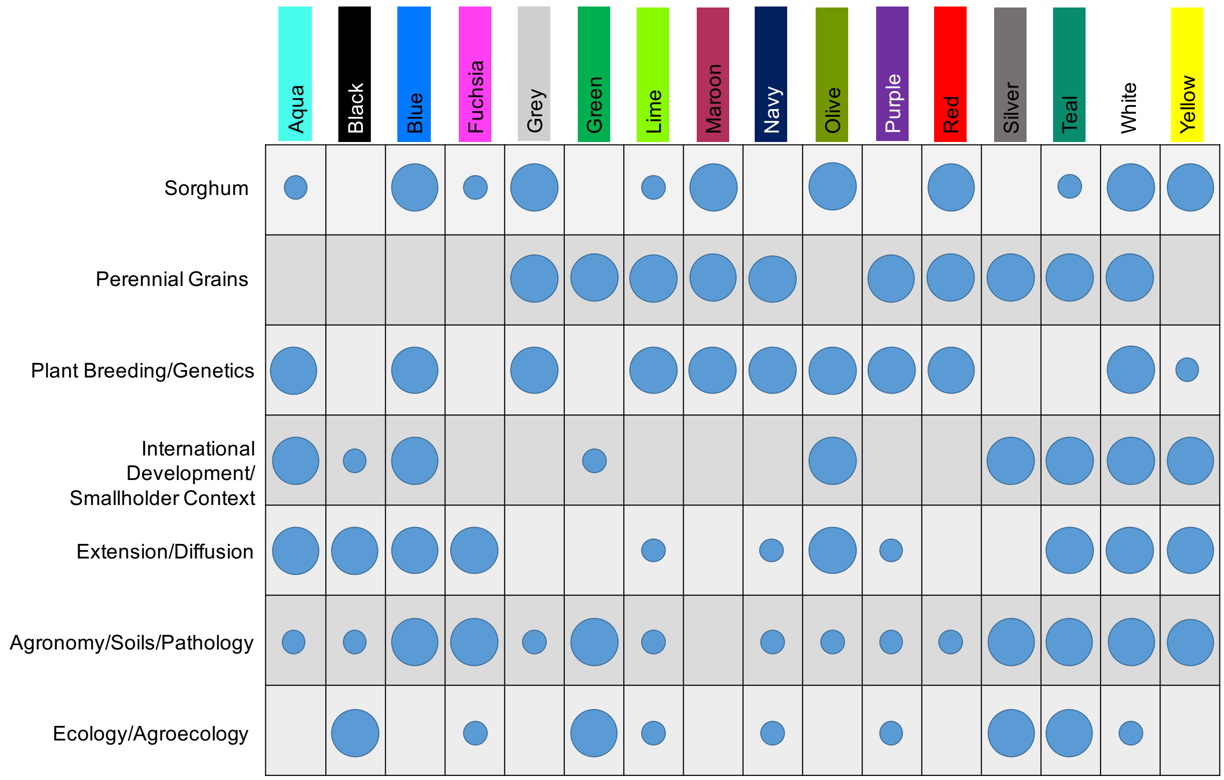

Figure 2.1. Illustration of Relevant Expertise/Experience of Research Participants. Three circle magnitudes (no circle, small circle, and large circle) indicate the relative level of expertise/experience of interviewed experts (represented by colors along the top) in each of the categories on the left.

Data Collection

Semi-structured interviews and open-ended questionnaires were conducted with the sixteen expert participants. The option of completing an open-ended questionnaire was included to encourage participation by experts who might be too busy or unwilling to participate in an interview. No incentive or compensation was provided in exchange for involvement in this research. The University of Georgia IRB approved this research along with contact (Appendix B), semi-structured interview protocol (Appendix C), and open-ended questionnaire (Appendix D) materials. Fifteen (N=15) experts participated in the semi-structured interviews, which ranged between 38 and 87 minutes in length. All interviews were conducted by JTB, and audio recorded to facilitate transcription and ensure that quotes are accurately represented. One semi-structured interview included two participants, and one participant opted to complete the open-ended questionnaire. This meant JTB conducted a total of fourteen semi-structured interviews—six were conducted face-to-face and the remaining eight (including the single interview with two participants) were conducted via Skype.

Following the suggestion of Auerbach & Silverstein (2003), the semi-structured interview consisted of six general questions/sections plus follow-up questions related to the research (Appendix B). The semi-structured nature of the interview guide allowed for interviews to maintain focus but also utilize the constant comparative method of grounded theory, allowing additional probing questions to reflect insights gained during prior data collection activities (Creswell, 2013; Schwandt, 1997). Current literature was used to create the interview, but only so far as to encourage participants to discuss issues important to them, as participant's answers are considered more important than the specific questions asked (Auerbach & Silverstein, 2003). The intent of the interview protocol was to allow participants to discuss their experiences and expertise in a narrative-like fashion and discuss at length those topics most important to them.

Interviews began with questions on participants' background and experience related to perennial sorghum or other grains, the development and diffusion of agricultural innovations, and smallholder farmers. After this opening section, subsequent questions investigated in more detail participant's lived experience with perennial production systems, agricultural development, the African and smallholder context, and possible cultural and social effects of the diffusion of a perennial sorghum technology. As suggested by Auerbach and Silverstein (2003), an opportunity for participants to share additional or novel information was included as a closing question. The open-ended questionnaire followed a similar focus and progression as the semi-structured interview guide, but consisted of fifteen open-ended questions derived from the semi-structured interview guide (Appendix D).

Data Analysis

Heath and Cowley (2004) remind us that in qualitative social science research utilizing grounded theory, in particular, researchers are seen as inherently social beings who will interpret any data through their own experiences, biases, and values. While this may be seen by some as a limitation, the goal of this type of research is to discover a “sensitizing” theory/model/concept that facilitates understanding and action (Heath & Cowley, 2004). This methodology does not presuppose that the one and only theory/model/concept has been illuminated or that it even can be.

All audio recorded interviews were transcribed and then checked by JTB via rereading transcribed texts while listening to the audio files and correcting errors. This transcription check was part of the preliminary analysis process and reflection on the data as exemplar quotes and key concepts that stood out were noted during this process. Throughout analysis, JTB listened to recorded interviews over and over to become immersed in the data. As mentioned earlier, the constant comparative method was utilized to compare emerging conceptual categories between and within interviews, as well as to the broader scientific literature. This was accomplished during the analysis of interview transcripts through the coding of repeating patterns in the data (Schwandt, 1997).

Coding and organization of data was facilitated through the use of the qualitative data analysis software ATLAS.ti (ATLAS.ti Mac, Version 1.6). The process of initial coding (Charmaz, 2006) encourages openness to the data and the numerous possible theoretical directions that could be explored by using simple codes assigned to data quickly and frequently.

During this phase both descriptive and process coding were primarily used with some values coding (Saldaña, 2009). Memoing was also employed throughout the coding process to allow for emerging constructs and thought processes to be recorded for further reflection and development toward theory (Creswell, 2013; Schwandt, 1997). ATLAS.ti facilitates the creation linkages between codes and memos, codes and other codes, as well as memos and other memos. These linkages facilitate constant comparison and interrogation of emerging conceptual connections as coding progressed to focused coding (Charmaz, 2006). During this phase initial codes were compared and (re)defined as new codes were created and many codes were grouped together into larger more conceptual categories. This necessitated revisiting previously coded transcripts to recode and check previously coded data to update codes as needed.

JTB conducted all data collection and analysis. While this allows for consistency in method, it doesn't provide multiple perspectives and reflects a limitation to the research presented here. In an effort to address this issue, the primary code list was shared with a colleague qualitative researcher, who also coded a transcribed interview to check for clarity and consistency. The conclusions of this research were also discussed with supervising committee members.

Results

During analysis of interview data, the complexity of the barriers facing perennial sorghum was clearly evident. Specific barriers identified during analysis are discussed as subcategories within each of three higher level constructs: 1) The Innovation Process, 2) The Technology, and 3) The End-User. These three constructs reflect the key pre-analytic choices made in relation to an innovation process to develop a technology to benefit an end-user. It is not that specific barriers only occur in the construct in which they are presented, but that specific barriers are often more closely associated with a specific construct (and its pre-analytic choices) especially as discussed by the interviewed experts. For example, while timeframe barriers were often discussed as important during the ongoing innovation process of perennial sorghum, timeframes are also important to the functioning of a perennial crops that produce for more than one season and decisions about when to introduce a "complete" technology to an end-user.

Also, barriers associated with the gaps that exist between expert scientists developing perennial sorghum technology and smallholder farmers targeted as potential adopters of perennial sorghum is presented as a subheading under the construct on the innovation process. However, the concept of *gaps* between experts and smallholders (as well as experts in the innovation process of perennial sorghum and experts working in smallholder contexts not directly involved in the innovation process) is a barrier to the success of perennial sorghum that occurs throughout all three constructs.

Figure 2.2 is a model of the nature of the barriers facing perennial sorghum to benefit smallholder farmers within the pre-analytic choices of the perennial paradigm. The perennial paradigm's pre-analytic choices determined the nature of the innovation process, the technology to be pursued, and the end-users targeted (the three sides of the triangle). The triangle represents the barriers as a continuous surface between the three constructs. While specific barriers such as weeds, diseases, and pests maybe thought of as situated closer to the side of the triangle labeled "The Technology"—and are therefore discussed as a subheading in that construct—they in turn reflect barriers encountered during the development process (i.e., "The Innovation Process") as expert plant breeders and agronomists struggle with these issues, and affect the ultimate appropriateness and acceptability for a potential adopter (i.e., "The End-User") depending on their preferences and the constraints of their specific context.

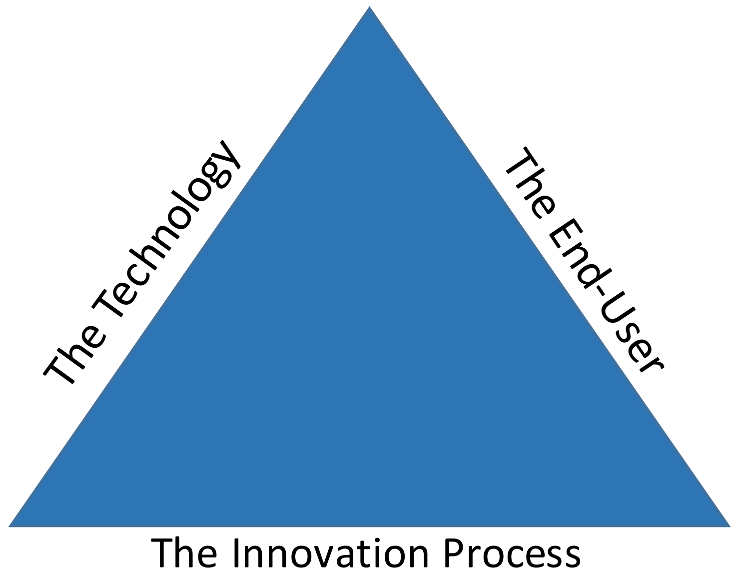

Figure 2.2. Model of the Barriers Facing a Perennial Sorghum Developed to Benefit Smallholder Farmers. The three sides of the triangle are labeled with three key pre-analytic choices made when an innovation process seeks to develop a technology to benefit an end-user. Barriers are represented by the triangle itself. Specific examples of barriers may be thought of as situated closer to one side of the triangle; however, the unbroken surface of the triangle indicates that even specific barriers are ultimately interconnected with all three pre-analytic choices.

The Innovation Process: Barriers Related to Research and Development

Development timeframes.

During interviews, expert participants familiar with the development of perennial sorghum—and other perennial grains—were quick to mention that while major strides are being made these crops largely remain hypothetical. One expert participant put it this way:

> We don't have a perennial sorghum. Perennial sorghum doesn't exist in our context anyway. Yes, plants that live for multiple years but they're not desirable yet. (Lime)

Experts familiar with breeding efforts and hands on experience with perennials often stressed the long-term nature of the development of perennial sorghum and other grains:

> For perennial crops we still are in the process of domestication, which for humans took somewhere in the neighborhood of about 9,000 years to get to the domesticated crop we see now for both sorghum and maize. (Red)

One expert described perennial grains as they currently exist as “beta versions” (Lime) of the imagined future crops, and another interviewee explained that they refer to current versions as “proto crops” (Green). These terms will be used interchangeably to refer to the current perennial sorghum germplasm. When asked to give estimates on the timeline for the development of perennial grain crops, experts explained that each crop was different. Expert Lime differentiated between the two pathways for developing perennials—domestication vs hybridization—describing hybridization as “smashing together two species” to create something new and that this results in more unknowns. Expert Maroon stressed that a big question mark as far as the amount of time still needed for developing a perennial sorghum (derived through the hybridization route) will likely be dependent on the intended use by smallholders:

> In Africa where they're growing a lot of [sorghum] to eat it directly, they demand different and higher grain qualities for human consumption. We know that the perennial types that we're using have pretty lousy grain quality, not attractive at all, so there's going to have to be a lot of selection to get back to grain types that people like. (Maroon)

This quote raises issues related to the preference and acceptability of perennial sorghum and will be returned to in the construct on The End-User. We mention these issues here because experts described how the preferences and constraints of the end-users can act as a feedback loop during the ongoing development process:

> We want to see how [perennial grain] fails and in what ways it fails, because it's probably going to fail; it's still experimental, but that's where we can then reassess our breeding goals, and then [farmers] can get a sense of how they might adjust their operation and how they can't adjust their operation. (Navy)

Despite the long-term nature of the development of perennial grains, the majority of the interviewed experts directly involved in the perennial paradigm were positive about the possibility of actually producing a perennial sorghum that could benefit smallholders. This positivity was often associated with the phenotypes expressed by beta versions:

> I mean if we could manage to make crosses. . . I actually think it may not take as long, mainly because of the kind of panicle and the tillering, all those kinds of traits, they are actually interesting to farmers. (White)

Contextual gaps.

Experts embedded in smallholder contexts and more distant to the perennial paradigm's efforts tended to express more skepticism with regard to perennial sorghum's ability to confer benefits to smallholders however. As reflected in the above quote, experts familiar with perennial sorghum's development stated that traits observed in current beta versions of perennial sorghum—tall plants, branching and loose panicles, as well as asynchronous flowering—are appealing to African smallholder sorghum farmers. These experts discussed how these traits are familiar and desirable phenotypes in smallholder contexts:

> For the American style mechanized production system most of this material still isn't adapted because it's too tall, and branching, and small-seeded and so forth. . . .but that's another reason we're thinking in a smallholder situation, where often hand harvesting is practiced that, that won't be a barrier, and in fact the height is often valued. (Grey)

Several experts distant from smallholder contexts mentioned how asynchronous flowering and grain maturation would allow staggered harvesting (assumed to be unproblematic where hand harvesting is common) reducing need for storage, possible storage losses, and smoothing fluctuations in grain supply over time. Comments by experts with smallholder contextual experience disagreed with these assumptions though:

> Once sorghum flowers, you get an insect developing that eats the ovaries, [a] midge. And that insect has, I think, a length of generation of like 2 weeks. So, every 2 weeks, it multiplies. And then if you have a difference of only a month of flowering . . . basically you cannot harvest anything because the midge will have destroyed it all, so another reason for having everything flower at the same time is to avoid the midge damage. (White)

The complications associated with the contextual gaps between where perennial sorghum’s development has taken place so far, and the setting where smallholders actually live and farm are not only related to lack of knowledge and experience on the part of perennial crop breeders. One expert experienced with perennial gains in smallholder and agronomic contexts described how the disparities between plant breeding contexts and methods conflict with the realities of farming systems, resulting in problems associated with desired phenotype expression.

> We've found that when we grew perennial wheat as a high population density, as you need to for agronomy purposes to suppress weeds, to give you high yields per area, which is what we do in agronomy, we found that the competition seemed to . . . we no longer got the perenniality. So then, we had a pathetic annual instead of a strong perennial. And we found out a lot of the breeding was originally done under single hill or lines, rows, quite far apart, so they just don't have the competition that occurs in an agronomic setting. (Teal)

Photosensitivity and flowering was also problematic because of the gap between where development has taken place thus far and where smallholders farm. This issue was mentioned in several expert interviews:

> This is one disadvantage in trying to transfer germplasm that's been developed here in the temperate zone under the long summer day lengths that we have to the tropics where . . . it's basically 12 hour day all the time. . . . [T]hat's a signal that it's time to initiate flowering so they produce heads and flower very early when they're quite small. For maximizing the amount of grain produced, that's not a very good thing. (Grey)

> The germplasm that's being experimented with in Africa right now is mostly US germplasm. It does not flower at the right time for African conditions. . . (Maroon)

Future breeding efforts and research.

The majority of interviewed plant breeding experts recognized the photosensitivity barrier to current beta versions of perennial sorghum, and these experts agreed that the incorporation of smallholder contextually adapted germplasm is the route forward:

> One thing we're initiating is making crosses between [current material] and locally adapted material to be able to select for a different reaction to day length. (Grey)

> So with regard to the issue of germplasm, we need to begin to make these things with local germplasm for specific localities. (Maroon)

There was also a general agreement that the actual breeding efforts need to be in the contexts where they will be utilized by end users. Experts involved in perennial sorghum's development cited the beginnings of these efforts, but also expressed concern over the sustained interest of funding institutions given possibility of extended development timelines.

Funding and institutional commitment was an issue that both research scientists and development professionals discussed in regards to complex and long-term endeavors, such as breeding a perennial sorghum and making it available to smallholders:

> I currently devote probably less than 5% . . . towards [breeding perennials] since I have no dedicated funding in that area and it's really difficult. (Red)

> The money dried up. Which is often the biggest problem in most of the public sector research. It's short term. You get just about to the point [of impact] or [supporting institutions] don't realize that it takes 15 to 20 years to make impacts. (Aqua)

The Technology: Barriers Related to Perenniality and Perennial Sorghum

The ***perennial*** sorghum crop system.

Experts were largely in agreement that within the framework of perennial grains the word "perennial" does not mean that these crops will be planted once and left in place indefinitely, like trees. However, it was widely recognized that the cropping systems would be significantly different from annual agricultural systems in terms of the planning and tasks with an extended cropping cycle, the nature of the problems encountered, and even how and what is measured and defined as yield. One expert with an emphasis in extension, Expert Black, suggested that in thinking about perennial grains and systems, trees might actually be a better analogue than annual grains since biomass may be as or more important than grain. In fact, some experts stressed that these perennial grains should not be seen as *replacing* annual grains, but as an *alternative* crop and system:

> If we wanted perennial wheat to be exactly like wheat . . . that may be impossible. But getting a crop that functions as a grain and can be used in different ways and will grow for multiple years, that seems very achievable. (Navy)

Experts were in agreement that to be a *perennial* grain, crops should be in place for at least two years (with multiple harvests), and that this would enhance capture of perennial grains' theoretical abilities to confer ecological and environmental benefits. Experts agreed that even longer cropping cycles could further enhance these benefits and are a goal to be pursued. However, some experts discussed how shorter cycle grain crops—e.g. 1.5 years—have potential uses and benefits, and that more flexible and diverse cropping systems are important part of the future of agriculture with enhanced sustainability.

Several experts discussed the importance of the establishment phase in a perennial grain system, and explained that this period in a perennial crop system would entail heightened vulnerability to the crops and risk to the farmer. The particularities of this risk and vulnerability will be explored more in the following subsections, but because of these problems one expert stressed the need for perennial crops to produce grain for harvest during their first year, saying:

> If you can plant [a perennial grain] and you get a harvest in year one, that's a game changer. (Lime)

Experts were asked what metrics would be useful for determining the success of a perennial sorghum system. Expert Red expressed concern with trying to hypothesize metrics because of what he saw as a lack of knowledge on system possibilities and saying that this would mean that many biases and assumptions would be necessary. Experts most frequently cited measures related to the enhancement of ecosystem services, such as water quality, erosion, soil carbon and organic matter as useful determinants of system success. Some experts invoked the concept of sustainable intensification to answer this question, implying perennial sorghum needs to meet metrics associated with this concept to be successful. In addition to metrics on ecosystem services, experts referenced metrics related to the concepts of food security (e.g., grain yield and nutrient content) and livelihood (e.g., labor requirements and income), as well as complex social metrics such as gender equality and human capacity development. Expert Purple emphasized that due to a perennial crop's protracted cropping system, it was important to understand both the resilience of the crop to shocks and the potential variability in system outputs, i.e., yield (defined broadly) over time and under different environmental conditions. Expert Teal stated that the there was currently a great amount of effort towards developing indicators and metrics for sustainable intensification, and that these would likely be applied to perennial sorghum systems.

Weeds, diseases and pests.

Experts tended to agree that many problems related to pests and diseases would likely vary regionally and even from field to field, but that there were some wide ranging pests and diseases that would be important to consider. Several experts familiar with proto perennial sorghum and other new perennials stated that weed competition during the establishment phase could be problematic as perennials typically put more energy into below ground structures making them vulnerable to being outcompeted by vigorous weeds. These same experts were quick to point out that in subsequent seasons the rapidly growing shoots from an existing and established root system could potentially outcompete these same weeds.

The potential for early and vigorous growth of an established perennial sorghum has implications for pests and diseases as well. Expert Blue was concerned that a perennial sorghum limited the flexibility of smallholders to adjust planting dates to ensure that sorghum was at the appropriate maturity stage to survive a shoot fly's attacks on the apical growing point of early vegetative stage plants. However, expert Grey suggested that rapidly growing established plants might better resist and be able to outgrow the shoot fly pest.

When experts were asked about the extended presence of a perennial sorghum in the farmer's field vis-a-vis pest and disease buildup over time, experts frequently cited the inherently more robust and resilient nature of perennials as a potential mitigating factor:

> Certainly, disease issues may be somewhat different for a plant that's having to survive for a few cropping cycles or preferably a few years. Having said that, since we're starting from perennials to breed these things, there may have been some selection of the founder material for different disease responses and best responses. (Maroon)

Still this same expert (Maroon) referred to pests and diseases as the "biggest biotic constraint" to the success of perennial sorghum and grains. Experts with smallholder contextual experience often expressed concern regarding perennials vis-a-vis pests and diseases, as well as risks to neighboring farmers not even growing a perennial sorghum:

> Perenniality becomes a big challenge when you have a soil-borne disease. If you have more soil borne fungi, bacteria, that would be a challenge. (Olive)
>
> Perennial sorghum may serve as a reservoir for stalk borers and even diseases resulting in early pest outbreaks and disease infections in nearby annual crop fields. (Yellow)

Birds were frequently cited as a major potential pest of perennial sorghum because of the crop's persistent nature in the farmer's fields:

> [Perennial sorghum] may be easily attacked by birds and pests in the off season as they are the only source of food in an area. (Yellow)

Another expert with smallholder contextual experience (Blue) echoed this point, explaining how early adopters of a perennial sorghum would face greater potential damage from birds since their fields would remain attractive for an extended period of time. When asked how smallholder annual sorghum farmers normally deal with bird damage, Expert Blue explained that the bird damage is dispersed across many farmers' fields, reducing the impact to any one farmer. Expert

White also suggested that bird damage is better distributed with simultaneous flowering—instead of the asynchronous flowering present in proto perennial sorghum.

In several interviews, the parasitic weed striga was discussed as another important disease affecting annual sorghum and potentially perennial sorghum. However, multiple experts suggested from experience and preliminary observations that perennial sorghum may be better able deplete the soil's seed bank of striga seed and therefore help clean fields.

> People always think that to control striga, you do some other crop. But actually to reduce the seed bank of striga in the soil, you need the host roots there to stimulate the striga germination. (White)

Soil, water, and drought.

Many experts discussed how the larger root system of a perennial sorghum persisting through multiple growing seasons could improve water use efficiency and drought tolerance as well as soil structure and carbon and organic matter content—leading to greater overall yields.

> [Perennial grains] also have the potential to improve infiltration so they capture more of the water of the effective precipitation and they can access it presumably deeper in the profile over the course of the whole year. So all that basically means is you're using the total resources more efficiently and thus should be able to produce more biomass. (Green)

Smallholder context Expert Blue was skeptical that a larger root system would guarantee that a perennial sorghum could survive for several months under extended drought, and even some working directly with breeding perennial sorghum worried that "[t]here might be a gap that even perennial sorghum can't overcome" (Red). However, Expert Red discussed that when working directly on proto perennial sorghum there was a marked potential to survive without irrigation:

> But we don't need to irrigate [the proto perennial sorghum] really at all. It will just sort of sit there. It won't be very productive, but it will survive. (Red)

As in the above quote, other experts stressed that survival without water for extended periods does not mean that grain production can or will occur, saying:

> So, typically a plant is going develop, it's going grow leaves and stems for a while, and then eventually it's going to produce some flowers and start producing grain and filling that grain. That's typically the last thing that happens in the cycle of the plant's growth for that year is the filling of that grain. If that is happening after all the moisture's gone, then you just get no grain. (Green)

Some experts indicated that a perennial grain would likely use more water resources in total when compared to an annual, because of the overall greater biomass production:

> [Perennials] may require actually greater water total . . . because they grow for longer periods of time and they tend to, therefore, produce more biomass. (Green)

And, that this need for water would be heightened during the vulnerable establishment phase:

> You're now really actually trying to build root biomass, so soil moisture issues are probably going be very different in trying to get the establishment needs. . . . I mean there are some concerns that during droughts, that perennials may utilize more water resources. (Black)

Site selection and soil fertility.

Experts working with perennial grains often expressed caution with regard to perennial grain’s ability to be a productive crop under any conditions:

> I think that the best opportunities are going be where land is open to erosion by water or by wind, but the soil is still of fairly good quality and the climate is still pretty good for grain production. We're not going to take perennial grains onto cool, eroded rocky mountain tops, plant them and get a good yield. (Lime)

Many experts agreed with the sentiment expressed in this quote—that perennials best fit may be in areas where the land is subject to erosion if it were planted with annual grains.

In discussing the benefits of perennial sorghum and other grains, many experts suggested that perennial grains would be able to improve overall soil fertility and organic matter. These experts cited the extensive root system of perennials as potentially being able to capture and mine deep nutrients that would otherwise be lost through leaching, as well as the large roots being a source of soil organic matter. *Contextual experts*—those experts with considerable expertise in smallholder contexts—were cautious in this regard, often referring to sorghum as a "heavy feeder" (Yellow and Blue) that can deplete soil fertility over time leading to yield reductions.

However, two experts working directly on the breeding of perennial sorghum discussed evidence that one of two sources of perenniality used in creating proto perennial sorghum hybrids has demonstrated the ability to host endophytic nitrogen fixing bacteria, and that this may extend to perennial sorghum:

> One other thing that I'll toss out, it's still kind of exploratory but there's a certain amount of evidence that some of these perennial sorghums are actually interacting with microbes in the soil and gaining nitrogen and perhaps also phosphorous. (Maroon)

Fodder, grazing, and fencing.

Experts working on perennial grains frequently talked about the potential for these crops to serve both human and animal sustenance needs. Experts discussed how a perennial sorghum might be used as a fodder crop even if it failed to produce grain because of drought or other problems. Both experts removed from and those experienced with smallholder contexts recognized that a perennial sorghum's ability to withstand direct grazing was important in smallholder contexts. Experts universally recognized that in smallholder contexts grazing livestock often become free-range in between annual grain growing seasons. Expert White discussed how this seasonal grazing was an important part of nutrient cycling and low-cost/low-labor fertilization of fields, as well as potentially removing pest and disease harboring crop residues. Some experts discussed early trials with grazing and experimental cutting of beta versions of different perennial grains, but all of these experts agreed that this aspect needed more research, especially once the development of these crops has progressed further.

The year-round persistent nature of a perennial sorghum creates a new situation in smallholder contexts relative to grazing:

> The farmland is expected to be the commons for the dry season, it's not yours anymore, it's—everyone has access to it. You put up a fence around it, now you're being greedy in keeping people from grazing on the ground. But if that's required then you know that's something that the breeders and the people who are bringing that technology are going to have to somehow communicate the need for fencing or animal control. And just that could be a really big conversion of the culture, to try to keep the animals from destroying the perennial sorghum in the off season. (Lime)

The possible social system disruption—returned to later in the construct The End-User—was not the only problem cited by experts. Contextual expert Blue was concerned about the cost and labor associated with fence installation as well as labor associated with having to cut and carry fodder to restrained livestock because a perennial sorghum was occupying fields normally used for grazing.

Various experts also mentioned issues associated with sorghum causing poisoning of livestock during the grazing of young regrowth containing poisonous alkaloids and prussic acid. Two experts (Black and Yellow) also mentioned an issue with aphid infested sorghum plants causing problems for grazing livestock.

The End-User: Barriers Related to Acceptability, Preference, and Promotional Efforts

Familiarity.

During interviews, experts working in perennial grain development often discussed how perennial sorghum may be acceptable to smallholders because of their longstanding relationship with annual sorghum. However, when asked whether smallholder farmers would recognize the proto perennial sorghum as it currently exists, Expert White replied:

> I don't think so. They may have recognized it as wild sorghum. (White)

Experts familiar with perennial sorghum explained that perennial sorghum seed size is likely to be smaller than annual varieties used for human consumption. Expert Red explained that smaller seed size is beneficial to seed producers, but that small seed size can be beneficial to smallholder farmers because of the potential for longer storage as well, stating:

> From the [seed] company and farmer's perspective you want smaller seed, because then when you're producing hybrid seed, if the yield is, let's say, 100 bushels an acre and you have small seed and you have large seed, you get twice as much seed from the small seed at 100 bushels an acre than from the large seed. . . . And, the seed actually even stores longer if it's smaller than if it's larger. (Red)

Within the previous construct The Technology, several experts argued for the need to see these crops and systems as totally different from their annual counterparts—as an alternative system. Expert Navy summed this up, saying:

> So with sorghum, because it's supposed to be perennial sorghum, don't define it necessarily as sorghum. . . . If you're going into communities in a completely different culture in a different region, it may not be beneficial to talk about it as sorghum at all. Right? So for perennial wheat . . . calling it “perennial wheat” both helps and hurts us. So you immediately think you know what I'm talking about, and the problem is that it's totally different from what I'm looking at in the field. (Navy)

During interviews, experts were asked about African smallholders’ experience and knowledge around perennial crops and systems. Experts frequently cited tree fruit crops, and less frequently tea, coffee, and sugarcane as perennial crops familiar to smallholder in Africa. Some experts also discussed how crops such as pigeon pea were being ratooned and grown perennially in some regions of Africa. Two experts (White and Teal) shared knowledge of 20th century accounts of a perennial sorghum’s use in Africa:

> We found that in fact historically there was a type of perennial sorghum, partly ratoon, grown for up to 3 years, that farmers used up until the 1940s in East Africa. It was unfortunately stamped out because of British concerns about disease reservoir. We've also found some evidence of it being important for drought, surviving famines and dry spells. So, that was really interesting. (Teal)

Subsequent research into these accounts seems to indicate that this perennial sorghum was used primarily as fodder and not for human consumption (Edwards, 1941).

Yield, input reduction, and resource savings.

Experts often agreed that grain yield will likely be an important factor in determining the acceptability of perennial sorghum for smallholder farmers. Experts familiar with proto perennial sorghum and other perennial grains stated that depending on how it is measured grain yield may be lower than that of improved annual grains grown under optimal conditions even when development is completed. Experts universally agreed that resource-poor smallholder farmers are defined by numerous and significant contextual constraints such as limited access to inputs (including improved hybrid seed, fertilizer, and irrigation), degraded environments, and small land holdings. Expert Grey explained that where the yield potential of annual grains doesn't manifest in resource-constrained contexts, perennial grains may better enhance livelihoods:

> I should note that over the continent of Africa, according to ICRISAT, the average yield is approximately 800 kilograms per hectare, continent-wide which is far, far lower than what we have here, and it's limited by all of these problems that I was just discussing. So, the fact that our perennial sorghum initially is going to have lower yield potential than elite annual sorghums, may not be as important because in a situation like that yield potential is not, the big determiner of yield. It's all about how the plant deals with all these limitations on yield and a perennial plant not only could reduce the amount that farmers have to spend on inputs, but it could actually increase the yield if the plant is more drought tolerant, it's able to tolerate or outrun diseases or insects, and especially if it were able to harvest some nitrogen from these bacteria, and have a longer growing season to establish itself earlier and better and a longer growing season and feed animals as well. It could be, even having lower yield potential, it could actually produce more food or more income. (Grey)

In describing smallholder farmers in resource-poor contexts, experts sometimes described smallholders as possessing "indigenous knowledge" and being "information rich" (Green), saying smallholders "know sorghum more than we do" (Olive), or otherwise as intelligent experts in their own contexts:

> There is nothing like a dumb smallholder. They're probably smarter than you are in many ways because they've survived. I challenge anybody at [a university], in any discipline, to go out and try to survive for a year on one hectare in sub-Saharan Africa. You'd starve,

> you'd be down at McDonalds in the biggest town faster than anything because it is a rough job. (Aqua)

Expert Aqua in part attributed this ability to survive in difficult contexts to risk aversion, a trait that several interviewed experts used to describe smallholder farmers. Some experts—experienced and inexperienced in smallholder contexts—expressed concern that enhancing the sustainability of soil and water resources may not be easily observable by smallholders. Experts frequently stated that these ecosystem service enhancements would be easiest to observe at scales larger than individual smallholder's fields and communities, and only after widespread adoption of perennial grains. Also, experts explained that these benefits would generally take many years to manifest, and some experts stated that even the direct benefits of greater food availability and increased income may only become apparent when considering the entire protracted crop cycle of a perennial sorghum.

Seed cost was one example of how perennial grain resource savings may only be realized after a full *perennial* crop cycle. Expert Maroon suggested that the cost of seed can be amortized over time, potentially making perennials more affordable to smallholder farmers who face difficulty accessing hybrid seed. However, the actual cost of perennial sorghum seed is uncertain (as well as the ability to access said seed), and expert Red explained that it will still be more expensive than seed saving and likely more expensive than annual sorghum seed:

> If you were to go to a system like most development agencies would like to see in Africa—which is seed sales and a robust commercial sector in the agricultural industry—those companies are going to want to cover the loss of not being able to sell seed every year. (Red)

Invasiveness.

Experts involved in the breeding of perennial sorghum discussed how there might be acceptability issues because one of the two sources of perenniality is a notorious weed:

> So there could be a certain amount of resistance or objection to adopting [perennial sorghum] just based on the notion that a portion of the genetic information of these cultivars would have derived from Johnson grass, from one of the world's more widespread weeds. (Maroon)

Expert Maroon goes on to state that this is largely an issue of perception and that no proto perennial sorghums come close to mimicking the “speed or efficiency” (Maroon) of Johnson grass’s propagation abilities. However, expert Red did discuss that in trial plots “volunteer” control can be problematic for their experiments, but that volunteer control might not be as problematic in smallholder situations, if row-planting is not practiced.

Still, expert Yellow was concerned that a perennial sorghum might be a weed in any rotational crops planted after a perennial sorghum, and even expressed concern with potential genetic invasiveness through cross-pollination with annual and local sorghum varieties. Expert White explained that this invasiveness issue and the potential for perennial sorghum to become a noxious weed was critical to consider. During field trials in Africa White explained they were very careful to keep track of proto perennial sorghum plants’ locations and bag grain heads to capture shattering seed.

Introduction and diffusion efforts.

Experts in agricultural development and extension discussed how the introduction of a new technology is a complex process involving institutions, communities, and individuals from international, national, regional, community, and household levels. Experts emphasized how creating situations in which smallholder farmers can easily observe benefits and interact with perennial sorghum technology will be key to its adoption, and that creating a useful and acceptable technology that meets smallholder needs and preferences will mean smallholder participation is mandatory:

> When [farmers] participate, then they will tell you the advantage of technologies and the disadvantages from their own perspective. (Blue)

> I think at first you probably have to come in, and sit with [smallholders], and try to understand what it is they're doing now, and what the system really is, and not go in, and think you already know, and know what's best for them. I think that's real hard for us to do sometimes. And again, there's a balance there because just doing things the way you've always done them isn't necessarily the best way, but sometimes there are some core reasons that have almost been forgotten about why it got that way. . . . So, what is the core reason for that? What was the limitation there? And what was it that that is a symptom of? Because, I think if you don't understand that, you tend to impose solutions that aren't really dealing with the underlying soil, climate, and ecology issues. (Fuschia)

Expert Teal shared an anecdote highlighting the importance of this task, and how institutional structures and rigid disciplinary thinking prevented initially recognizing that the smallholders they were working with were already practicing perennial-like systems:

> Our promotion [of the legume] was as an annual, because that's how we thought of the [crop], then we found, through our participatory action research, because we were actually looking at what farmers were doing with the varieties and systems we were promoting, we found that some of them were ratooning them, and insisting on growing a 3 or 4-year system, which was very fascinating, but also a little bit challenging to do research, because a lot of donors give you 1 or 2 years at a time. Master's students are 2-year time frames. So, it was just more our shortsighted kind of vision as agronomists that it took us a while to recognize [the perennial systems]. (Teal)

Experts cited farmer field schools, demonstration plots on locally situated research stations, and working directly with innovative farmers through participatory techniques as ways to enhance the observability, trialability, and understanding of perennial sorghum systems among smallholders. Experts were in agreement that this means significant work to develop relationships, build networks, identify stakeholders, and connect with innovative farmers. Expert Aqua was adamant that these farmers should always be compensated for any time, effort, and resources spent in helping researchers. Experts with experience working with farmers (not necessarily smallholders) directly explained that this innovative farmer is someone who understands the proto nature of the beta-versions and tolerates and expects failure. Several experts discussed how overpromising results or bringing a perennial technology to farmers too early could be catastrophic both for the effort to develop perennial technologies and for risk averse resource-poor farmers, setting back development and diffusion efforts as well as damaging relationships between scientists and farmers and farmer livelihoods.

Several experts also discussed how farmer acceptance of a perennial sorghum technology does not mean it will be accepted by other end-users:

> You can spend a whole of time trying to develop something that's beneficial to farmers, but until they get it in their hands, and until the ladies of the house or whoever is doing the cooking and whoever is eating the material tries it, it's hard to say what the limiting factor is going to be. Sometimes we improve one thing at the expense of something else. (Red)

If they did not bring it up themselves, experts were asked to consider issues surrounding gender vis-a-vis perennial sorghum. The diversity of cultures across the African continent kept many experts from specifics, but development experts often discussed the importance of recognizing women as farmers as well as their other roles within smallholder communities for achieving the sustainability goals agricultural development and perennial grains are seeking to attain. Often in connection to gender issues, experts discussed how there will likely be social and cultural repercussions because of the altered cropping system a perennial sorghum would entail (see the previous construct The Technology). Experts questioned how labor arrangements and timing might change within these protracted and multiple-harvest systems:

> I think the ability to spread out the harvest might even impact things like children going to school. Just translating it to the US, what used to go on in the US, we only have summer vacation because that's when people need to work in the fields. (Red)

Additionally, some experts described that building support for perennial sorghum with the institutions and development personnel working within smallholder communities would be important to perennial sorghum’s success:

> What you don't want is detractors and people that question the technology and the importance of it, because that just creates another stumbling block. (Aqua)

> An extension system can really make or break a system. It used to be that I could drive though [an area] and tell you the agents that believed in conservation tillage system, and cover crops because as soon as you got to the county line you'd start seeing it, and as soon as you got out you wouldn't. (Fuchsia)

Expert Aqua explained how this in itself can be a complex process:

> The whole agriculture community is so much more complex nowadays in terms of NGOs working, other projects working, even USAID, it's one of our biggest challenges. We go into a country and after two years we find out there's five other [projects on the same crop], all funded by USAID, that we didn't even know about. Some of which are doing almost the same thing with the same people as we are. (Aqua)

Discussion

Interviewed experts highlighted the wide ranging and complex issues that act as barriers to achieving a perennial sorghum appropriate for, acceptable to, and otherwise beneficial to African smallholder sorghum farmers. The results of this research were organized into three constructs that emerged during data analysis and serve as a model (Figure 2.2) for thinking about both the interwoven nature of the barriers facing perennial sorghum for smallholders and how they might be overcome. The constructs that emerged directly reflected the perennial paradigm's pre-analytic choices (Giampietro, 2004; Röling et al., 2004) made without smallholder participation. The pre-analytic choices of the perennial paradigm can be summarized as follows: The problem to address: Jackson's (2002) problem of agriculture; The solution: perenniality; the technology pursued: perennial sorghum; The nature of the innovation process used: so far, non-participatory; The target end-users: smallholder farmers. In the model in Figure 2.2, the perennial paradigm's pre-analytic choices of the problem to address and the solution to this problem are directly reflected in technology pursued (i.e., perennial sorghum). This is because the already in progress innovation process of perennial sorghum has moved past the majority of the design stage (Table 2.1). This model for conceptualizing barriers may be transferable to similar situations where an innovation process is pursuing a technology for targeted end-users.

It was clear from expert interviews that the innovation process of perennial sorghum is an ongoing and long-term endeavor—and that a return to design stage questions is still possible. However, current perennial sorghum efforts seem to be entering the testing stage (Lilja & Ashby, 1999); and while there is talk of smallholder participation, it remains to be seen in what capacity. Obviously, *farmer experimentation* is not part of the perennial sorghum innovation process, and based on the results of this research *collegial* participation is also unlikely (Table 2.2). *Conventional* type (where there is no participation from farmers, Table 2.2) is also unlikely given that there is acknowledgement within the perennial paradigm literature and the experts interviewed here, that smallholder farmers have valuable knowledge to contribute to the ongoing innovation process. This means that smallholder participation in the perennial sorghum innovation process will likely be of the *consultative* or *collaborative* type (Table 2.2), and will likely begin during the testing stage (Table 2.1).

While many experts connected to the concerted effort of the perennial paradigm were positive both about the possibility to develop perennial sorghum and other perennial grains, as well as the potential for this technology to benefit smallholder farmers, it remains unclear and contentious as to exactly what benefits these crops will confer to smallholders, how a perennial sorghum might actually accomplish these benefits, and if it can actually be successful. This often seemed to manifest as a disagreement in regard to whether labor and risk would be increasing or decreasing at different times in a perennial sorghum's cropping cycle when compared to an annual sorghum.

Looking to the construct on the nature of perenniality, experts tended to uniformly agree that there should be environmental and ecological benefits from a perennial sorghum, but even these benefits would in general require timeframes longer than a single cropping cycle (even a perennial one), as well as widespread adoption and use to manifest. The one exception seems to be on highly erosive sites. However, this should raise concerns of agricultural expansion into erosive sites due to perennials enhanced ability to hold soils, possibly exacerbating environmental harm through wildlife habitat loss and deforestation. While waiting for long-term environmental benefits, the physical and social environment of smallholders in sub-Saharan Africa will likely continue to become more degraded, unstable, and uncertain.

Expert responses indicate that developing a perennial sorghum that enhances environmental sustainability is a much easier task than developing a perennial sorghum that meets smallholder needs and preferences. While there are traits in the current beta/proto versions of perennial sorghum that experts believe to be useful and appealing to smallholders, perennial sorghum breeders acknowledged that the genetic complexity of breeding a grain acceptable for human consumption will likely further extend development timeframes.

Ignoring grain food quality and focusing on developing perennial sorghum as a forage and fodder as well as cooking fuel source and construction material source could still meet some of the expert-identified smallholder needs while sidestepping the difficulty of breeding for higher grain quality. This of course would mean postponing (or even sacrificing) one of the pre-analytic choices of experts working on perennial sorghum within the perennial paradigm—direct food security enhancements (food security could still potentially be enhanced indirectly through improving livestock food sources). Also, those farmers able to devote land to non-food crops are typically not the resource-poor, subsistence, and/or marginalized smallholder farmers that have been neglected by the majority of agricultural technology introductions (Johnson et al., 2003; Rogers, 2003).

Results indicate that grain quality and palatability is also not simply a matter for geneticists and crop breeders, and this concern connects to the barriers outlined in the construct The End-User. Results indicate that simply determining whether a smallholder community will find a grain acceptable for consumption (and in general) will mean taking it to smallholders so they can complete full production cycle(s), process, store, and prepare it as common food items during the testing and diffusion stages. Although engaging smallholder farmers as early as possible into the innovation process would require changes in the way research is conducted, and perhaps even to the worldview of those typically involved in the innovation process, it could potentially prevent an enormous amount of wasted effort on the part of these individuals. Just as Dawson et al. (2008) found that participatory plant breeding was challenging, they also concluded that is was more efficient.

This is no easy task, and large gaps remain between those seeking to develop perennial grains, other experts, and smallholder farmers and communities. Johnson et al. (2013) state that participatory efforts share a common characteristic involving "continuous learning ('action learning') on the part of all participants, and they minimize the 'distance' between researchers and end users through dialogue and action" (p. 288). We refer Johnson et al.'s (2003) "distance" as gaps—these gaps are physical, cultural, experiential, epistemological, and even ontological—that can make communication difficult and outcomes and impacts open to interpretation (Crane, 2014; Röling, 2004; Nederlof and Dangbégnon, 2007; Rhoades & Booth, 1982; Stoop & Hart, 2005). Experts in plant breeding recognized those physical and biological gaps that are frequently encountered when moving plants from one context to another, such as photosensitivity. However, they seemed unaware of the issues associated with the asynchronous flowering of plants voiced by experts with smallholder contextual experience. These experiential and contextual gaps meant that there was misalignment between experts located far from smallholder contexts and those more experienced with them. In fact, smallholder contextual experts and those with development and extension experience tended to express the most concern and doubt with regard to perennial sorghum's potential success and appeal in smallholder contexts.

A telling example of these gaps and how to overcome them was evident from Expert Teal's story on how smallholders actively practicing ratooning and growing crops for multiple years went unnoticed by the agronomists working with them. These agronomists were socialized to think in terms of annual production systems and blinded to viewing the crop as anything but an annual. It wasn't until these gaps were bridged through participatory research techniques that the agronomists realized they misunderstood the cropping system that the farmers were utilizing.

The expert plant breeders interviewed have recognized that to move breeding efforts forward and into the testing stage will require heavier reliance on in-context breeding efforts, and the incorporation of locally adapted genetics. Seeking this genetic material will require the experiential and cultural knowledge possessed by smallholder farmers and local experts on the varieties which possess desirable traits. This knowledge would facilitate the development of perennial sorghum for African smallholders. This knowledge can also contribute to developing perennial and other new sorghums for farmers in more input-intensive and mechanized contexts as well, since these farmer's varieties (Cleveland, 2014) and even wild sorghum varieties existing in these areas are a source of genetic diversity unavailable in modern farming contexts. Explicit recognition of smallholder's own experience and expertise relevant to perennial sorghum's development and diffusion may facilitate collaboration and communication between conventional experts and farmers through knowledge sharing. Smallholder empowerment through a collaborative participatory effort could enhance perennial sorghum technology, improve smallholder acceptability of the technology, and reduce development timeframes.

Experts were often cautious about bringing in farmers "too early" in the innovation process. They described the issues that arose as potentially detrimental to both perennial technology development efforts if expectations not met or trust is damaged as well as smallholder farmers' livelihoods in the event of crop failures. This could be true, but it is worth questioning whether these perceptions are the result of the conceptual/experiential/contextual gaps between these experts and smallholder farmers. The failure of a perennial technology is more likely because of its inability to be appropriate for smallholder contexts—just as with earlier Green Revolution technologies—rather than its proto nature. The risk averse nature of smallholder farmers as described by experts, is no doubt caused in part by a lack of trust based on past experiences with top-down technology transfers. Mitigation of risk and an understanding of this sorghum's proto nature among farmer-collaborators should be achievable through training and the proper choice of participatory methods, as well as communication and trust building efforts explicitly aimed at bridging these gaps. This is evident from expert Teal's anecdote about researchers' inability to "see" smallholders growing the legume perennially. Luckily, the long-term nature of both accomplishing this and developing a perennial sorghum seem to complement each other.

The fact that perennial sorghum is also being developed for input-intensive, mechanized agricultural contexts raises questions about who will ultimately benefit from the development of perennial grains. Making agriculture more environmentally sustainable in input-intensive, mechanized contexts is no doubt an important goal, but would this outcome actually result in positive impacts for smallholder farmers, their communities, and developing nations with agriculturally dependent economies? Any smallholder contribution to the perennial sorghum development effort—particularly in the form of locally adapted and historically, culturally, and agriculturally important germplasm—should also raise questions around intellectual property rights (IPR). This is especially true with the potential for large profits from the sale of perennial sorghum seed developed with any smallholder and/or indigenous knowledge. Current IPR regimes do not allow for recognition of more communally based conceptions of IPR that exist in many African nations (Ezeanya, 2013). These issues were not addresses by any of the experts interviewed. For the development and diffusion of perennial sorghum (and other perennial grains) to truly be a paradigm shift towards sustainability, these questions must be carefully considered.

Problems of IPR are not the only issue that likely requires structural and institutional change to achieve the paradigm shift "towards sustainable production systems" (Wang & Alonzo, 2014, p. iii). Sustainability by its very nature requires considering the future. Perennial grains by their very nature require longer term research and funding needs—longer plant lifespans equate to longer research experiments. This extends the timetables employed by the institutions that provide this funding and support research and development projects. Here the first construct on The Innovation Process intersects with the second on The Technology—in both instances there is a compulsory shift towards a longer term outlook with regard to outcomes and impacts. It would seem that the goal of achieving a more sustainable agriculture may necessitate extending the concepts of sustainability into supporting structures and institutions. In fact, experts from a variety of backgrounds pointed to the truncated nature of projects and a desire for quick outcomes as preventing lasting development impacts and inhibiting complete and nuanced understanding of contexts and research endeavors.

Some experts were quite adamant about the need for more diverse and flexible cropping systems in addition to new perennial crops to achieve sustainability goals. These experts often advocated for thinking of perennials not as replacing annual grains, but as an alternative system with its own strengths and weaknesses. This concept was highlighted by several plant breeding experts' admission that it may not be possible to breed a perennial sorghum with a yield potential—using traditional measures of a single harvest—equivalent to improved annual sorghums under optimal conditions.

Diverse options and diverse systems would help overcome the issue expert Blue expressed with regard to the inflexibility of a system based solely on perenniality. The smallholder strategy of altering planting dates paired with a portfolio of varieties each with different maturity times and environmental tolerances, allow smallholders to cope with climatic variability and uncertainty while still attempting to maximize yields under these limitations (Cleveland, 2014). A system based only on perennial sorghum would potentially restrict this important tool and increase risk to these farmers and their families.

This view towards the need for a diversity of cropping systems and crops is referred to by some as the weak perennial vision (Crews, & DeHaan, 2015; Gliessman, 2015; Smaje, 2015). However, the interviewed experts expressing this opinion did not indicate that this meant breeding plants that were weakly perennial, but that strongly perennial grains would be an important part of this goal. These opinions suggest that more broadly, some experts working within the realm of perennial grain development may in actuality be driven to create multiple alternatives for farmers to utilize in enhancing sustainability and addressing Jackson's (2002) problem of agriculture. In its extreme, experts possessing this "sustainable systems vision" urged giving these new perennial crops different names unrelated to their annual relatives—i.e., not calling perennial sorghum either *perennial* or *sorghum*. For example, Paterson et al.'s (2014) article used the term "multiple-harvest sorghum" when discussing the ratooning capabilities of sorghum.

Issues of branding aside, experts were largely in universal agreement that some proportion of smallholder farmers were highly adaptable, knowledgeable, and intelligent with the capability for rational cost-benefit analyses. While the ability of smallholders to survive under difficult conditions goes without question, Rogers (2003) tells us that the earliest adopting *innovators* are generally more risk-taking and may not be the most food insecure or resource-poor.

Experts indicated that as long as a perennial sorghum conferred "real" benefits these innovative smallholders would recognize such benefits and be able to incorporate perennial sorghum into existing farming practices or even develop new ones. Henrich (2001) argues that if this was truly the case, then the resulting rapid adoption would result in r-shaped diffusion curves and not the s-shaped curves typically observed in diffusion research. Consequently, these real benefits may still not be beneficial or accessible for the most resource-poor or marginalized smallholders; and (if not rejected outright) through biased cultural transmission processes (e.g., conformist transmission) can result in the adoption of a maladaptive technology (Henrich, 2001). For instance, perennial sorghum could—as suggested by Expert Olive—be a maladaptive technology in a region with the potential for soil borne disease outbreaks. This reasoning is likely why many experts were so cautious about introducing a potentially "transformative technology" (Adebiyi et al., 2015).

As already mentioned, interviewed experts were in agreement that smallholders are relatively risk averse. Smallholder contexts often involve unstable environmental (e.g., climate change), social (e.g., land tenure), and political (e.g., corruption and war) conditions that have been know to act as disincentives to long term investments (e.g., infrastructure and tree crops) that take time to mature and/or generate a return (Röling, 2010). Experts explained that the nature of perennial crops—while likely a quicker return on investment than tree crops—may mean there is a necessary amortization period before total benefits are realized. Experts explained how perennial grains and systems go through an establishment period with increased vulnerability while possibly simultaneously requiring greater inputs of labor and water compared to annual grains. Risk to the smallholder would also be greater during this period, especially with a potentially higher initial seed cost. These issues are why some experts stressed the need for a food/economic harvest during a perennial sorghum's first year.

The elimination of need to annually prepare fields and plant seed was seen by many experts as a reduction in labor needs. Still, it is unclear from expert interviews whether there might be altered strains on labor and other limited resources due to a protracted harvest period, increased plant needs/weak competition during the establishment phase, and the requirement to either fence fields or cut and carry to what would have been grazing livestock actively fertilizing fields through manure inputs. Several experts indicated that as perennial sorghum moves further along into the test stage of the innovation process the issues of grazing and livestock palatability will become important research questions. While experts indicated that an established perennial sorghum plant might better survive insect attacks (i.e., the shoot fly example), this does not mean that a perennial sorghum still in its establishment phase will not be wiped out all together.

It was clear from expert interviews that there was significant potential for established perennial sorghum plants to survive adverse environmental conditions, including some pests and diseases. Striga was an interesting example of this, but one that would still require labor for removal of the weed and parasitized plants. Experts familiar with proto perennial sorghum were fairly confident in its ability to survive drought conditions, but did warn that this would not mean there would be significant grain harvests. Still, simply surviving severe droughts could lead to substantial resource savings for smallholder farmers.

If perennial sorghums can be developed that could enhance soil fertility through nitrogen fixation and increased phosphorus availability, concerns expressed by contextual experts on the "heavy feeding" nature of sorghum would evaporate, and the potential benefit to smallholders would be enormous. Based on the concerns of experts with smallholder contextual experience and expert descriptions of smallholder contexts (i.e., degraded soils and limited access to inputs), this ability alone might be more beneficial to smallholders than perenniality. Enhancing soil fertility and structure simultaneously could help close yield gaps associated with the Green Revolution (Leakey, 2014), along with the potential yield gap between perennials and annuals mentioned by expert Grey.

Expert Grey's comments on the *potential* versus *actual* yield of a modern improved annual sorghum versus a perennial sorghum brings up questions of crossover and yield stability (Cleveland, 2014). Cleveland (2014) explains that yield crossovers occur when an improved variety (typically higher yielding with greater inputs), yields less than another variety (typically possessing type I stability, meaning relatively stable yield across a range of environments) in a marginal environment. Can perennials yield more in marginal (read as smallholder) environments than modern annual varieties? And, if yield is defined broadly (e.g., includes biomass or forage) being that many perennials multi-use crops, might this enhance the potential for crossover? Any additional benefits, such as the resource savings mentioned by expert Grey, could also be included in these calculations. Expert Purple's comments on potential metrics for perennial sorghum indicate assumptions of a type I yield stability—"that plant breeding goals [should be] dominated by environmental limits and high levels of variability in the factors affecting yield" (Cleveland, 2014, p. 142). This view of yield stability is more in line with models of sustainability that prioritize social and environmental concerns over simply increased productivity.

Many experts agreed on the potential for a perennial *sorghum* to be familiar to, and therefore more readily acceptable to smallholders. Some experts' comments on the beta versions of perennial sorghum did indicate these currently look quite different from what smallholders are used to. This is potentially exacerbated by current beta versions' genetics being derived germplasm not adapted to smallholder contexts. However, there does seem to be a great deal of evidence in the literature and results presented here, that not only are smallholders familiar with perennial-like production systems (e.g., ratooning), but that they may be familiar with sorghum varieties verging on perenniality already. Interview data indicates that this knowledge may have been lost or destroyed due to colonialism, but this indicates an important direction for future research. From this evidence alone, it would seem that smallholders are quite innovative, and possess knowledge and experience potentially useful to the ongoing perennial sorghum innovation process. If this is the case, many of the social and cultural changes assumed to take place (e.g., alterations to communal grazing norms) when shifting to a perennial-type agriculture system may not cause as much disruption as some experts have cautioned. Culturally and contextually similar communities already practicing ratooning and perennial-like systems could be compared to those using annual systems in an attempt to discern any dissimilarities.

While introduction and diffusion efforts have historically come after the development of a technology—experts agreed that for perennial sorghum technology to be successful in smallholder contexts development must move to these contexts. This means working to identify smallholder farmers' and their communities' needs, i.e., an initiation of participatory efforts. It still isn't clear whether these will be consultative or collaborative (Johnson et al., 2003; Lilja & Ashby, 1999). Additional effort will also likely be required to reach the most resource-limited and marginalized smallholders.

Conclusion

While perennial sorghum as well as other perennial grains, pulses, and oil crops clearly offer great potential for enhancing agricultural environmental sustainability, there is still a long way to go in the innovation process. Through participatory efforts between plant breeders, agronomists, ecologists, development professionals, smallholders (as well as other farmers), other end users, and consumers, it may be possible to develop a perennial sorghum that can enhance the food security and livelihoods of smallholders and their communities. This may be where the greatest promise and danger of perennial sorghum and other perennial grains are rooted. Perennials' development and diffusion can either remain part of the old paradigm of top-down, unidirectional technology flow that contributes to solidifying the divide between the actors in the system, or it can be part of a paradigm shift that rewrites these relationships to build a more collaborative innovation process.

Through semi-structured interviews with experts in the perennial paradigm and experts in smallholder agriculture the expert-identified barriers to perennial sorghum were organized into three constructs: 1) The innovation process, with barriers related to research and development; 2) The technology, with barriers related to perenniality and perennial sorghum; 3) The end-user, with barriers related to acceptability, preference, and promotional efforts. These three constructs directly reflect the pre-analytic choices made by those working to develop perennial sorghum and the perennial paradigm. A conceptual model was developed to highlight the interconnected nature of the expert-identified barriers with the three constructs of pre-analytic choices (Figure 2.2). A combination of the pre-analytic choices already made, and the progression of the perennial sorghum innovation process so far, has limited the nature of smallholder participation in the innovation process moving forward to two types: consultative or collaborative (Table 2.2).

The results of this research indicate the very nature of perenniality demands periods of greater risk to smallholders and shifts in resource requirements, and that meeting the needs of the truly resource-poor, marginalized, smallholder farmer will require prolonged commitments and careful risk management and reduction strategies. It will also entail bridging wide gaps through innovative participatory methods, such as participatory plant breeding that may be challenging genetically and logistically (Dawson, 2008). Efforts to bridge these gaps has already shown that smallholders have beaten plant breeders and agronomists to the punch in regard to realizing some of the benefits of perennial-like crops and systems (e.g., ratooning). Interviewed experts agreed that smallholders will likely be an integral part of perennial sorghum's innovation process as it moves forward. Any smallholder contribution cannot be taken for granted, their IPRs need to be protected, and any economic benefits shared with them. We believe this can best be accomplished through explicitly recognizing the knowledge and expertise smallholders possess relative to this innovation process, and moving forward through collaborative participatory methods (Lilja & Ashby, 1999). This means new political and institutional arrangements and long-term commitments. As indicated by several experts interviewed herein, perennial sorghum and other “new” perennial crops are only one piece to achieving sustainability in agriculture.

CHAPTER 3

ETHIOPIA AND PERENNIAL SORGHUM: AN OPPORTUNITY FOR COLLABORATION BETWEEN SCIENTISTS AND SMALLHOLDERS?[2]

[2] Brooks, J. T., Navarro, M., Paterson, A., Thompson, J., Hassen, A. M. To be submitted for publication to journal Agriculture and Human Values

Abstract

An ongoing agricultural technology development effort is aimed at breeding perennialized versions of many annual crop varieties. One of the "new" crops being developed is a perennial sorghum hybrid. Sorghum's significance in the agricultural systems of African smallholder farmers and its inherent ratooning ability has led experts working within this perennial technology development effort to theorize benefits for smallholders potentially adopting a perennial/ratooning sorghum in the form of enhanced vigor, labor reductions, and multiple harvests of grain and fodder, in addition to possible ecological and environmental benefits associated with perenniality. Ethiopia is the center of diversity for the Sorghum genus and farmers in the country have been cultivating, developing, and maintaining the crop for millennia, potentially representing a source of germplasm for further perennial/ratooning sorghum technology development. Utilizing the ethnographic methods of participant observation and semi-structured interviews, the farming contexts of smallholder farmers in the Hararghe zones of Ethiopia were investigated to determine the potential fit of a perennial sorghum and possibility of collaboration between scientists and smallholder farmers in the ongoing innovation process. Findings indicate that farmers are extremely knowledgeable about sorghum, sorghum ratooning, and could be allies in ongoing sorghum technology development given adequate protection of their intellectual property rights. Findings also indicate that some farmers already capture many of the benefits of perennial crops through khat production. Improved water access was a universally expressed need by all farmers interviewed across the region investigated. Farmers utilized improvisational farming strategies to cope with climatic uncertainties. It may be that an enhanced ratooning sorghum better meets farmer needs than a truly perennial one because of this need to for flexibility in farming systems.

Introduction

In 2013, a workshop organized by the Food and Agricultural Organization of the United Nations (FAO) and Consiglio per la Ricerca e la sperimentazione in Agricoltura (CRA) brought together the research of, and experts in, plant breeding and agricultural systems based on perennial crops. Titled *Perennial Crops for Food Security: Proceeding of the FAO Expert Workshop*, the published document describes collaborative efforts to develop perennial cereals, legumes, and oil seed crops directed at enhancing agricultural sustainability, poverty alleviation, and food security (Wang & Alonzo, 2014). While many of the technologies being developed as part of this effort are in their nascent stages with development horizons of decades (Glover, 2004), the potential benefits for smallholder farmers are already being considered (Cox, 2014; Dixion & Garrity, 2014; Paterson, Cox, Kong, & Navarro, 2014; Snapp, 2014). Discussing these potential benefits, and the attention these new perennial crops are receiving, the introduction to the document states:

> Recent attention has been focused on the ecological benefits that communities of perennial plants can confer on a landscape: erosion prevention, efficient capture and use of water and nutrients, protection of water resources, carbon sequestration, and maintenance of thriving soil ecosystems. But with food security and rural livelihoods becoming an increasingly serious concern throughout the world, there is growing recognition of the potential benefits that intercropping of perennial grains offers smallholder farmers: reduced expenditure for seed, fertilizer, and other inputs; more reliable stand establishment and early vigour; less effort expended on weed control; extended growing seasons; less transplanting or other stoop labour, especially for women; and protection of biodiversity. (Cox, 2014, p. 1)

One of the individual technologies being developed as part of this larger effort is a "perennial" or "multiple-harvest" sorghum (Paterson et al., 2014). Sorghum is a drought tolerant cereal important in the lives of resource-limited smallholder farmers living in Africa (Belton & Taylor, 2004). Because the interaction between a technology (i.e., perennial sorghum) and what Kranzberg (1986) refers to as the social ecology can have such disparate outcomes and impacts between contexts, it is important to consider the unique qualities of specific context in an attempt to detect potential environmental, social, and human consequences beyond those intended by a technical intervention. This is especially true when considering the introduction of an agricultural technology to potential farmer-adopters living in marginal environments and with limited resource access and allocation.

Prior research elucidated the barriers to realizing perennial sorghum's benefits for smallholder farmers from the "expert" perspective (Chapter 2); namely, the ongoing and long-term nature of the development of perennial sorghum, the nature of perenniality itself, and the uncertain character of the touted benefits of perennial crops for smallholders. Interviewed experts recognized that some smallholder farmers may be experienced and knowledgeable in resource-limited sorghum production, utilize and maintain diverse sorghum germplasm, and potentially already practice semi-perennial and/or ratooning production systems. Based on expert perspectives we assessed the likelihood and nature of smallholders' participation in the ongoing development of this technology.

Whether or not the expert perceptions about smallholders are true depends on the specific context considered, and does not guarantee that a 'new' perennial sorghum technology would automatically benefit farmers possessing these traits. Furthermore, interviewed experts also indicated that the experiences and preferences of targeted end-users (in this case smallholder sorghum farmers) would ultimately determine the acceptability of such a potentially *transformative technology* (see Adebiyi, Olabisi, & Snapp, 2015)—and that their opinions and knowledge would be integrally important to the ongoing development of a perennial sorghum technology for smallholders and possibly users in other contexts as well. The research presented here takes the logical next step: the investigation of a farming context wherein smallholders are likely to possess significant sorghum knowledge to determine the potential fit and acceptability of a perennial sorghum, as well as these smallholders' potential to contribute to the ongoing perennial sorghum innovation process.

Literature Review

Comparing Agricultural Technologies: Past and Perennial

Attempts at diffusing agricultural innovations within the diverse agricultural and environmental contexts of the African continent have often been unsuccessful; and even when considered successful, the reality of this success has been shown to be subjective depending on the question asked and to whom the question is posed (Benzer Kerr, 2008; Nederlof &Dangbégnon, 2007; Röling, 2004; Stoop & Hart, 2005). Röling (2004) explains that as potential adopters of agricultural technology, farmers possess "veto power," or the ability to reject innovations despite the efforts and opinions of those developing, introducing, and diffusing these technologies. Stoop and Hart (2005) say that some in the development and research community view farmers' rejection of technologies as indicating a state of stagnation in African agriculture. However, others argue that past technology pushes, such as the Green Revolution of the mid to late twentieth century, were unsuccessful because they sought to "modernize" farmers by encouraging adoption of improved crop varieties with high yield potentials under relatively high input conditions, while ignoring or not understanding the reality of African farming contexts and the preferences of the farmers (Iles, Garrett, Maywa, & Galt, 2016; Parayil, 2003; Röling, 2010). A brief list of the challenges facing African smallholders includes extreme poverty, historical colonial oppression, the globalization of agricultural commodity trade, increasing population pressures, institutional failure and corruption, environmental degradation, and climatic change (Röling, 2004; Röling, Hounkonnou, Offei, Tossou, & Van Huis, 2004). While considering these realities may seem to impose a deficit model on these farmers and their communities, the ability to merely survive under these conditions suggests remarkable ingenuity and adaptability on the part of these farmers (Röling, 2004)—the exact opposite of stagnanation.

Those who are part of the effort to develop perennial crops distance their efforts from the "productivist" (Iles et al. 2016) forms of agriculture of these earlier technology pushes, stating that their perennial innovations "represent a paradigm shift in agriculture" that "hold great potential to move towards sustainable production systems" (Wang & Alonzo, 2014, p. iii). Reganold (2014) articulates this emerging *perennial paradigm's* vision of sustainable agriculture as having four domains—production, economics, environment, and wellbeing—and others within the paradigm frequently invoke the FAO's concept of "sustainable intensification" (Leakey, 2014; Runck et al., 2014; Snapp, 2014). Whether or not the perennial paradigm's innovations will result in the assumed sustainability improvements remains to be seen and—just as in the case of subjective "successes" of past technology pushes—various stakeholder perspectives may disagree on the extent and reality of this movement towards sustainability. For starters, the use of perennial crops in agriculture is not new, and those within the perennial paradigm recognize this as well (Wang & Alonzo, 2014). It has also been recognized that the smallholder farmers and indigenous communities, who have long known the benefits of perennial crops and utilized them within their agricultural systems, may have much to contribute to the effort to develop "new" and or optimize "old" versions of these crops and farming systems (Cox, 2014). Runck et al. (2014) describe how their "Reflective Plant-Breeding Paradigm" could meet multiple stakeholder objectives to create "win-win scenarios" (p.245). However, in their case study the stakeholders were all in the United States and shared a common language and similar culture.

The difficulties of working across international boundaries and different cultures are more complex. Cleveland (2014, p. 127) explains that differences "between traditional farmer and modern scientific plant breeding is that the former is integrated within the household, community, and local landscape, while the latter is much more isolated, with its goals shaped by mainstream modern industrial society." While—as Runck et al. (2014) points out—the perennial paradigm's efforts are primarily situated in universities and non-profit organizations, and therefore less likely to be motivated by the for-profit goals of the private agricultural industry, there are literally vast distances between the perennial paradigm's proponents and smallholder farmers contributing to the types of misunderstanding previously mentioned. We figuratively refer to these literal distances and the misunderstandings/misalignments between agricultural technology developers/proponents like those in the perennial paradigm and the targeted smallholder end-users as "gaps" (Chapter 2). Additional examples of these gaps appearing in plant breeding efforts, are the choice of environment in which plant breeding takes place, the various conceptions of yield stability, and the resulting potential for yield crossover (Cleveland, 2014).

Cleveland (2014) explains that yield crossovers occur when an improved variety yields less than another variety, often in a marginal environment. This is not supposed to happen. A variety possessing the "mainstream" view of yield stability, what Cleveland (2014) calls "type 2 stability," displays greater yields across selection environments when compared to the average yield of other varieties in the environments considered. Cleveland contrasts this with his definition of "type 1 stability" where, "the rate of reduction in yield with decreasing environmental mean yield is less for a stable variety than for the population mean" (2014, p. 142). Cleveland (2014) explains that these two definitions imply divergent breeding goals— type 1 stability suggesting goals of overcoming the conditions of marginal environments and variability in the factors affecting yields across space and time, while type 2 stability indicates goals of ever increasing yields in response to improved growing conditions. This latter form of plant breeding and its outputs is what Iles et al. (2016) calls productivist. Cleveland maintains that the former type—while criticized by the father of the Green Revolution, Norman Borlaug as "emotional" (2014, p. 143)—is better aligned with sustainability goals prioritizing social and environmental concerns over productivity.

Mekbib (2006) found that the sorghum varieties developed and utilized by farmers in the Eastern and Western Hararghe zones of Ethiopia—the study site of the research presented in this article—had an 132% greater yield than the improved varieties utilized by farmers in these contexts, in what appears to be a clear example of yield crossover. Mekbib (2006) also found that these farmers valued their varieties for purposes beyond grain production, such as fodder, fuel, and construction material. Mekbib also highlighted how only 10% of the improved crop varieties introduced in Ethiopia have been adopted by farmers, and attributed this to "a lack of appropriate varieties and dissemination system that caters [to the] socio-economic and bio-physical environments of the farmers" (2006, p. 168). This same study emphasized the importance of yield stability to farmers where fluctuations in yields between years is dramatic; with weather variability often resulting in a greater than 50% reduction in yield on average, and total crop failures during severe droughts (Mekbib, 2006). Mekbib detailed farmers own conceptions of yield stability, stating that:

> Farmers' perceive yield stability as an adaptation to local production techniques and variable water and soil conditions in combination with a variety of characteristics related to labour, intercropping and weed competition etc.,; [*sic*] food availability and various other consumption purposes opted for. Hence, it is broader than the conventional concept of yield stability. (Mekbib, 2006, p. 172)

One of the goals of Reganold's (2014) model of sustainable agriculture and perennial crop technology is to close the "yield gaps" between the marginal environments that have persisted between smallholder and modern farming contexts. Within the perennial paradigm's FAO and CRA supported published proceedings, Leakey (2014) details a twelve-principle plan utilizing, among other concepts, sustainable intensification to develop and implement perennial agroecosystems to close yield gaps. Cleveland (2014) argues that yield gaps are created in part by yield crossovers resulting from the reliance by many plant breeders on type 2 stability. Cleveland attributes this to plant breeders limited experience with the reality of smallholder contexts, leading to utilizing selection environments that are not representative of the magnitude of environmental degradation and resource limitations under which smallholders actually perform agriculture.

It has been recognized within the perennial paradigm, and among those developing perennial sorghum in particular, that breeding efforts need to move closer to these smallholder contexts (Chapter 2). Cox, Crews, and Jackson (2014) state that the breeding efforts on perennial sorghum to date have largely progressed in North America, and for perennial sorghum to be successful in tropical environments—where many smallholder farmers reside—evaluation of material in these contexts will be essential. They also state that an interim objective to perennial sorghum may be to breed an enhanced ratooning sorghum. As suggested by Paterson et al.'s (2014) article title referring to a "multiple-harvest sorghum," some sorghums possess the ability to regrow from the root and crown portions of the plant after harvest, and therefore possess the potential to be utilized as a ratoon crop (Rogé et al., 2016). This ratooning ability has been suggested to potentially improve both the yield and stability of a sorghum crop's production throughout time (Paterson et al., 2014). While the ratooning of several crop species is known to have been used across the world by various indigenous farming communities throughout history (Hill, 2014), there is little scientific literature and knowledge on smallholder sorghum ratooning systems, and its potential benefits and limitations (Rogé et al., 2016).

Moving Perennial Sorghum Forward: Seeing Smallholders and Farming Systems Anew

Collins and Evans (2002) explain their model on the evolving nature of expertise and experience in science studies as three successive "waves." These authors explain that during the the "first wave" of the 1950s and 1960s (during the emergence of Green Revolution productivist technologies) the public and those who analyzed society did not question the basis of scientific and other forms of technical knowledge and expertise, and bestowed upon the expert class a privileged status. During the ongoing "second wave" of science studies, social constructivist thought questioned the basis of this knowledge and broke down the barriers between those who were traditionally seen as possessing the "truth" in regard to technical matters and the lay public—solving some problems while creating others (Collins & Evans, 2002). Collins and Evans go on to suggest the need for a "third wave" whereby boundaries around those with the experience and expertise to contribute to technical matters are reconstructed in new ways, and both certified and uncertified specialists/experts are recognized based on the authors' three identified types of expertise. These three idealized types of expertise are 1) *no expertise,* 2) *interactional expertise,* and 3) *contributory expertise* (Collins and Evans, 2002). Type one is straightforward and its definition implied by its name, but the authors more subtly distinguish between the second and third types based on an individual's level of capability to either interact interestingly with participants in a field and successfully carry out a sociological analysis (type two), or to possess enough expertise to contribute to and further the field in question (type three).

The Feed the Future Innovation Lab for Climate Resilient Sorghum at the University of Georgia has begun partnering with local institutions in Ethiopia to further the development of perennial sorghum for smallholder farmers (Glover, 2014). Ethiopia is one of the primary centers of diversity of the sorghum genus, and farmers' many centuries of experience with the crop has resulted in a rich indigenous knowledge and cultural heritage in custom and song, as well as the development complex systems of "folk" taxonomies to catalogue the tremendous on-farm diversity of sorghum (Mekbib, 2007, 2009b). Mekbib (2008) explains that it was incorrectly assumed in the 1970s that the introduction and diffusion of improved varieties of sorghum would eventually replace farmers' varieties; Mekbib concluded that while there were several factors contributing to a reduction in the number of sorghum varieties on any one farm, genetic erosion was virtually nonexistent at the regional level. This suggests significant capacity exists within this region to employ existing farmer-maintained germplasm to breed perennial sorghum(s). This capacity to create perennial sorghum and the associated crop systems rests, in large part, with the knowledge and experience possessed by Ethiopian smallholder sorghum farmers themselves.

Research involving Ethiopian smallholder sorghum farmers by Mekbib (2006, 2007, 2008, 2009a, 2009b) indicates an extraordinary level of knowledge and experience relative to sorghum, and one that should perhaps earn them type three status as contributory experts when it comes to developing perennial crop technology based on sorghum for use in environmentally marginal smallholder contexts—especially given the possibility of crop breeders and other traditional agricultural experts possible lack of experience in these contexts, as well as a simultaneous recognition within the perennial paradigm of the need for stakeholder participation (Runck et al., 2014). Recognizing these farmers as experts may have additional benefits and avert possible problems as well. Anderson and Winge (2012) tell the tortuous story of how an agreement on the sharing of teff genetic resources—a culturally significant grain in Ethiopia—ended up as the basis for a protracted legal disagreement between a Dutch-based company and the Ethiopian government on the intellectual property rights (IPR) to this material, eventually earning the Dutch company the Captain Hook Award for Biopiracy. Ezeanya (2013) explains that the "existing global IPR regulatory mechanism is based on Western descriptions of knowledge, and its conceptions of individual intellectual property ownership" (p. 27). Ezeanya (2013) calls for reforming international IPR systems in ways that recognize the more communal nature of indigenous knowledge. Recognizing the expertise of and granting expert status to smallholders may give some protection to and acknowledgement of smallholders' potential contribution to the development of perennial sorghum in a way that those who adhere to Ezeanya's (2013) "Eurocentric" conceptions of knowledge and property ownership can understand.

When describing the differences in the socio-cultural processes that distinguish indigenous knowledge systems from other knowledge systems, Ezeanya states that "indigenous knowledge is based on performance knowledge; data is generated according to the demands of the moment" (2013, p. 27). Richards (1989) encourages the use of the idea of "performance" in agriculture and provides evidence for what he calls a "performance factor," saying that while observing groups of farmers in West Africa he detected a 20% increase in the quantity of work accomplished when music accompanied work activities. Richards claims that this example demonstrates how getting a performance factor right (or wrong) can alter productivity by a magnitude equivalent to adopting the recommendations of agricultural research. The author goes on to explain how various aspects of performance in agriculture are evident in the ways farmers adjust their crops and strategies in real time, often in relation to weather and sometimes experimentally, to maximize available resources and minimize risk under constantly changing conditions. Richards (1989) explained that while farming systems researchers may routinely treat the resulting cropping patterns as part of a prearranged design to minimize risk and uncertainty, it is in fact an ongoing performance, not unlike creative improvisation.

Crane, Roncoli, and Hoogenboom (2011) utilized Richard's agriculture as performance concept to understand famers' agency in Commune of Madiama in Mali, West Africa and Georgia, USA through responses to climate variability and climate change in both technical and social ways. They found that these farmers used available resources to build flexibility into their agricultural performances; whether it was Malian farmers selectively culling either sorghum or millet plants that had been seeded side-by-side based on soil and rainfall conditions and ongoing predictions (this strategy can even include leaving both crops based on available labor and rainfall), or Georgia farmers adapting to sophisticated climate and weather modeling that they may or may not choose to actually trust "not in response to actual circumstances, but in response to anticipated circumstances" (Crane et al., 2011, p. 183).

Cleveland (2014) explains that modern plant breeding's emphasis on wide geographic adaptation, but relatively narrow adaptation to actual growing conditions, leads to selection of a small number of varieties that are subsequently promoted for adoption. Cleveland (2014) contrasts this with smallholder farmers in marginal environments, who he says develop and maintain a wide assortment of varieties possessing unique traits—known as a *varietal portfolio*—to serve multiple purposes under diverse conditions. Mekbib explains how farmers in eastern Ethiopia utilize their portfolios of sorghum varieties:

> Varietal portfolios are manipulated according to the current socio-economic and biophysical environments of the farmers. This change in the micro-environment reduces risk (insect, diseases, and drought) and stabilizes the varietal components and crop ecosystem, and hence prolongs varietal stability. (Mekbib, 2006, p. 173)

This rolling response to environmental conditions through portfolio manipulation, varietal maintenance, and risk reduction echoes Richards (1989) description of agriculture as performance.

A Brief Description of Farming in Ethiopia

Ethiopia is a mountainous country ranging in altitude from -150 to 4,500 meters above sea level (Mulatu & Kassa, 2001). These authors state that within Ethiopian farming systems, uncertainty is steadily increasing and that smallholder farmers must continually adapt their farming systems to cope with these changes and maintain their livelihoods. They state, "between 1985 and 1998, the changes observed include increased incidences of weeds, crop pests and diseases; decreasing crop yield, land, and large stock holdings; and increased human and small ruminant population" (Mulatu & Kassa, 2001, p. 105). Mulatu and Kassa (2001) describe agriculture as the lifeblood of the Ethiopian economy, with approximately 85% of the population reliant on agriculture for their livelihoods, and agricultural products representing over half of all exports and 90% of GDP. Bezu and Holden (2014) state that in Ethiopia the average household farm size is 1.22 hectares, with 57% of households possessing farms under 1 hectare. Mulatu and

Kassa (2001) studied farming systems in the Hararghe regions. They state that agriculture is the primary economic activity in the region and other employment opportunities are generally lacking, but small landholdings often still prevent farmers from meeting self-sufficiency needs.

There is some separation of farming responsibilities by gender, as Mekbib (2009b) indicates that in the Hararghe zones men perform the majority field cultivation and land preparation, but the intricacies of these gender divisions likely vary across Ethiopia's numerous ethnic, cultural, and religious groups. Mulatu and Kassa (2001) described men in Hararghe as being primarily concerned with "long-term" food availability and focusing on sorghum and khat crops, while saying that because of women's primary role in feeding the household they are concerned with "day-to-day . . . short-term food deficit periods . . . [and] bridging the lean season" (p. 88) by focusing on maize and common bean. Mekbib (2009b) explains that farmers in the Hararghe region use herbicides very rarely, and attributes a recent increase in the use of inorganic fertilizers to agricultural extension promotional efforts.

Land tenure and transfer rights have undergone numerous changes throughout Ethiopian history, with the current law being enshrined by the Constitution of the Federal Democratic Republic of Ethiopia (FDRE) enacted in 1995 being somewhat complex and confusing (Gebreamanuel, 2015). Land ownership and the right of transfer is generally held in common by the Ethiopian government for the "Nation, Nationalities, and Peoples of Ethiopia," with the nine regional states determining local land ordinances within the constitutional framework. Farmers are granted "private holdings" through what are essentially usufruct rights to engage in agriculture as a livelihood. The right to an agricultural livelihood and access to land for farmers is prioritized in rural land laws—and while they cannot be sold—these "private holdings" are often passed through inheritance to "family members." This lawful transfer of land, while contributing to land fragmentation, does not allow land holdings to be subdivided beyond a minimum size set by the individual regional states. This often causes backlogs within court systems in a country experiencing relatively rapid population growth, especially in the already highly fragmented highland areas (Gebreamanuel, 2015). Family members, interestingly, are defined not by blood within these rural land laws but as anyone residing with the current land holder and engaged in the same livelihood. Women can be granted access to private holdings and spousal names along with the names of family members are generally included on the land certificates granted to land holders. A second type of rural land holding often utilized by farmers and their communities are "communal holdings," given to communities by the government for common grazing, production of perennials and forestry, as well as social activities—these lands are essentially open access, as long as the user is a member of the designated community (Gebreamanuel, 2015).

Mitiku and Abdu (1995) studied alley cropping and the potential of agroforestry systems in the Hararghe highlands of Ethiopia, and found that population pressures were leading to intensive pressures on land and contributing to degradation. These authors found that while perennial cultivation of coffee (*Coffea arabica*) and khat (*Catha edulis*) was fairly common—khat much more so than coffee, due to its wider tolerance of environmental conditions, annual crop production still dominated. The primary annual crops being produced were sorghum (*Sorghum bicolor*), maize (*Zea mays*), wheat (*Triticum aestivum*), teff (*Erograstis tef*), barley (*Hordeum vulgare*), field peas (*Pisum sativum*), groundnut (*Arachis hypogaea*), and sweet potato (*Ipomoea batatas*) (Mitiku & Abdu, 1995).

Mekbib (2009b) stated that more wealthy farmers may use tractors during land cultivation, while poorer farmers utilize oxen and that this manual land preparation is the norm.

While Mekbib's (2006) research found that at large scales genetic erosion of sorghum was effectively nonexistent in the Hararghe zones, he did identify several factors contributing to on-farm genetic erosion. The top five reasons for this loss as indicated by farmers through surveys and focus groups were: 1) reduction in the benefit received from the varieties (51.7% respondents), 2) drought (41.4%), 3) the expansion of khat (9.7%), 4) reduction in land size (9.2%), and 5) introduction of other food crops—such as maize and other horticultural crops (8.5%) (Mekbib, 2006). This list gives a sense of the types of trade-off decisions Ethiopian farmers are making, as well as the pressures they are facing.

Khat, also referred to as *Abyssinian tea*, is an intriguing and expanding cash crop in Ethiopia—particularly in the Hararghe zones—given its inconstant legal status between nations, and its culturally and socially significant status in the Horn of Africa and the Arabian Peninsula where it has been in use for at least a millennium (Ademe, Coates, Dalsgaard, Brimer, & Lema, 2017; Gebissa, 2004; Lemessa, 2001). Lemessa (2001) indicates that, possibly originating from Ethiopia, this perennial shrub's roots extend 3 to 5 meters into the soil profile, playing a key role in controlling soil erosion. Gebissa (2004) explains that the shrub performs best at elevations from approximately 1,500 to 2,000 meters above sea level, in frost free areas with average temperatures are between 18° C and 29° C, and well-drained soils. Lemessa (2001) says that established shrubs can be harvested 2 to 3 times annually, while Ademe et al.'s (2017) research indicated that farmers harvest up to 6 times annually, and both sources suggest the plants require relatively low labor and input requirements.

Gebissa (2004) highlights khat's significance among adherents to the Islamic faith, but says that its leaves are chewed by members of other religious groups as well. Even within Ethiopia khat's status is complex, and Lemessa states that, "although officially discouraged, *khat* stands among the most important cash crops in Ethiopia" (2001, p. 2, emphasis in original). Gebissa (2004) states that despite efforts in the early twentieth century by the Ethiopian government to eliminate khat production among the farmers, it is the most profitable cash crop of the Hararghe region. The legal and illegal trade in the crop contributes to difficulties assessing its total contribution to the Ethiopian economy, but Ademe et al. (2017) indicate it is often one of the top two or three exports in volume and earnings for Ethiopia. Chewing khat leaves produces an excited, euphoric, and talkative state induced primarily by the amphetamine-like compound cathinone, but this is poorly understood (Ademe et al., 2017; Gebissa, 2004; Lemessa, 2001). Intricate social and cultural rituals have developed around the chewing of khat that often vary by social group, religion, and between rural and urban areas (Gebissa, 2004). Gebissa also states that there is not agreement on the potentially addictive nature of khat, and that "pharmacological, chemical, and medical findings are inconclusive and contradictory" (2004, p.18).

Methods

The research presented here was collected during part two of a two-part master's project. Part one (Chapter 2) of this research centered on the perspective of experts involved in the effort to enhance the sustainability of agriculture by breeding "new" perennial crops and bringing these crops into agricultural systems. In particular, part one sought to illuminate the opinions of plant breeders, agronomists, agroecologists, and extension and development professionals on the barriers facing developing and diffusing perennial sorghum technology to the benefit of smallholder sorghum farmers in Africa. Part two examines the smallholder farming context within the Eastern and Western Hararghe zones of Ethiopia and the expressed needs of the farmers therein. The objective of part two—and this article—is to evaluate the appropriateness of this nascent perennial sorghum technology for the farmers in this context, and the potential contributions smallholders may be able to bring to the ongoing innovation process of perennial sorghum—i.e., to assess the opportunity for collaboration between smallholders and scientists.

Perennial sorghum and other new perennial crops are still in the nascent stages of development, so the assumed benefits for smallholders largely theoretical. This has predisposed research into their acceptability by farmers be based on hypotheticals (e.g., potential benefits and uses) and choice experiments (i.e., measures of participants stated preferences to assess the marginal value of various qualities of a hypothetical product/technology) posed to research participants (Adebiyi et al., 2015; Marquardt et al., 2016; Waldman, Ortega, Richardson, & Snapp, 2017). The approach utilized in this research instead attempts to gain an understanding of the culture, existing farming knowledge and practices, and voiced opinions and needs of the smallholder farmers within the context investigated. Instead of seeking discrete quantified answers to questions and hypothesis testing (Auerbach & Silverstein, 2003), a qualitative approach allows researchers to focus on questioning that cannot easily be answered quantitatively, and generate nuanced understanding of phenomenon or perform important preliminary investigations to future quantitative investigations (Pope & Mays, 1995). Ethnographic research frequently utilizes participant observation (sometimes seen as a methodology in itself) through observation, participation, field notes, and reflective journaling to analyze and interpret a group's lived experience and gain understanding through some level of socialization within that group (Schwandt, 1997). An ethnographic/participant observation approach was utilized during the course of this research.

Various interpretations and critiques of the participant observation method question the ability of an outside researcher to accomplish these tasks, and also disagree with the extent to which one should or should not become socialized within the group's socio-cultural systems

(Schwandt, 1997). These larger debates serve as a reminder to researchers using these methods to be aware of and reflect on their position relative to the group being studied. As Kranzberg (1986) reminds us, potentially socially and culturally disruptive innovations have been and continue to be introduced into dissimilar cultures and societies in our globalizing world. Attempting to consider the socio-cultural x technology interactions though these methodologies may help bring to light potential impacts and opportunities prior to the introduction and diffusion of a technology.

Site Selection and Description

This research was conducted in areas in and around the Eastern and Western Hararghe zones of Ethiopia. Ethiopia is considered one of the primary centers of diversity for the Sorghum genus (Mekbib, 2006, 2007, 2008, 2009a, 2009b), and local institutions are partnering with US based efforts currently working to develop perennial sorghum (Glover, 2014). Within Ethiopia, the Eastern and Western Hararghe zones are some of the principal sorghum producing regions (Bill & Melinda Gates Foundation, 2014). Sorghum is a primary food crop in these zones, and farmers have developed a multitude of varieties having cultivated the crop for millennia (Mekbib, 2006, 2007, 2008, 2009a, 2009b). Also, Mekbib (2009a) indicates that some farmers in this region practice the ratooning of sorghum but says that this important farmer strategy suffers from a dearth of scientific research and understanding.

Four districts or *woredas* (Babile, Fedis, Haramaya, and Meiso) within the Eastern and Western Hararghe zones and one administrative region/chartered city (Dire Dawa) were selected based on information provided by key informants at Haramaya University (Figure 3.1). Key informants indicated that these areas produced significant amounts of sorghum and that the farmers residing therein would be highly knowledgeable about sorghum and experienced in sorghum production. For simplicity, the words "district" and "woreda" will be used interchangeably to refer to all five of these research sites.

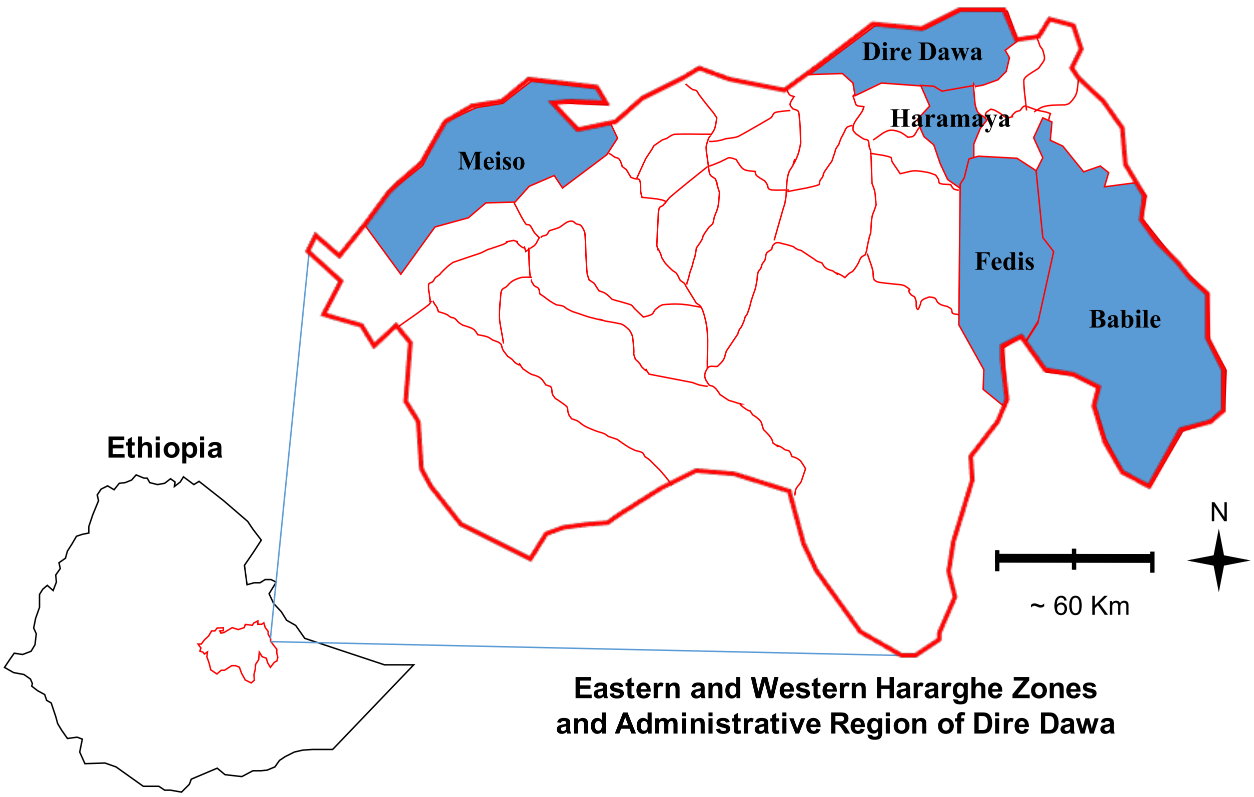

Figure 3.1. Map of Research Sites Within Ethiopia. Indicates the fours districts/*woredas* of Eastern and Western Hararghe zones (Babile, Fedis, Haramaya, and Meiso) and administrative region/chartered city of Dire Dawa in which farmers were interviewed.

Ecology.

Based on Mekbib (2006), the five districts selected come from either the lowland or intermediate ecology divisions found in eastern Ethiopia; however, the mountainous nature of the country means that elevations actually vary within woredas. The elevations provided in Table 3.1 give an approximate altitude of the areas where interviews were conducted in each district. Mitiku and Abdu (1995) indicate that the rainfall totals given in Table 3.1 occur in a bimodal distribution; with the earlier "short rains" starting at the beginning of March and continuing into

Table 3.1

Approximate Elevation, Climate, Rainfall, and Temperature for Districts Where Farmer Interviews Were Conducted. Information on the ecology type, climate, and average annual rainfall amounts and temperature ranges are based on the approximate elevation recorded at interview locations when compared with the elevation ranges stipulated by Mekbib (2006).

District or Chartered City	Approximate Elevation at Interview Locations (m)	Ecology Type	Climate	Average Annual Rainfall (mm)	Average Annual Temperature (°C)
Babile	1700	Intermediate	Cool and sub-humid	800-1200	17.5-20
Dire Dawa	1385	Lowland	Warm and semi-arid	200-800	20-27.5
Fedis	1810	Intermediate	Cool and sub-humid	800-1200	17.5-20
Haramaya	2050	Intermediate	Cool and sub-humid	800-1200	17.5-20
Meiso	1320	Lowland	Warm and semi-arid	200-800	20-27.5

May, and the later “long rains” beginning in July and ending in September. Mulatu and Kassa (2001), who also conducted farming system research in the Haraghe zones, describe the bimodal distribution of rainfall slightly differently, referring to “small” rains in March and April, and “big” rains from June to September. Mulatu and Kassa (2001) also state that during the October to February dry season, precipitation is less than half of the potential total evapotranspiration.

Demographics and culture.

After the fall of the military socialist dictatorship known as the Derg in 1991, new administrative divisions were created based largely on ethnic groups and commonality of language (Ficquet, 2015). The Eastern and Western Hararghe zones are within the large regional state of Oromiya, named after the region’s majority ethnic group the Oromo who speak Afaan Oromoo (Ficquet & Feyissa, 2015)—or simply Oromo. The Oromo, of which 93.5% live in Oromiya, make up 34.5% of the Ethiopian population as of 2007; and despite their demographic majority in the country, are described by Ficquet & Feyissa (2015) as having a subaltern political role in the country as a whole. Ficquet (2015) says that the 2007 census states that 33.9% of Ethiopians are Muslim, and that 51% of all Muslims are Oromo and are primarily concentrated the eastern zones. This includes the zones of Eastern and Western Hararghe. Ficquet (2015) also indicates that the official accounting of Muslim Ethiopians is possibly an underestimation of their true numbers, as statistical surveys since the 1960s have all suggested that the proportion of Muslims in Ethiopia is approximately one in three. The multifarious historical, political, and social interactions between Ethiopia’s numerous cultural, ethnic, and religious groups is beyond the scope of this article, but the realities of this situation are inescapable and must be considered at least in part when conducting ethnographic research.

Data Collection

Over the course of five weeks in June and July of 2016, 31 smallholder farmers (N=31) participated in semi-structured interviews conducted by JTB and AMH, a coauthor and native speaker, occasionally with the aid of additional translators. AMH was a PhD candidate in plant pathology at Haramaya University at the time of this research who grew up on a farm within the zones investigated. AMH was able to provide cultural and social guidance as well as first-hand experience on local sorghum production and use to JTB.

Interviewed farmers were assigned aliases consisting of a letter and a number, with the letter indicating the first letter of the name of the district in which they were interviewed. The number of farmers interviewed in each district was as follows: Five farmers in Babile and Dire Dawa, seven farmers in Fedis, four farmers in Haramaya, and ten farmers in Meiso. Table 3.2 provides additional information on the farmers interviewed. The semi-structured interview protocol asked farmers to describe their farms/land, livelihoods, and farming practices, as well as their needs as farmers and issues within their community (Appendix E, contains English and Oromo). Follow-up probes were centered on the production, use, and possible sale of sorghum, other crops, and livestock, as well as the farmer's contact with farmer organizations and other non-farmer sources of information. Following interviews, debriefing conversations between JTB and AMH served to discuss farmer responses to interview questions and provide context to facilitate understanding by JTB. Farmer interviews were audio recorded and later transcribed by AMH to capture key content for later analysis and coding by JTB. To assist with data collection activities, key informants were often recruited from locally embedded agricultural research stations within the district being investigated. These informants were able to serve as district guides and provided access to farming communities for interview activities.

Table 3.2

Description of Farmers Interviewed. The letter in farmer aliases indicates the district where interviewed.

Farmer	Gender	Typical Crops Grown	Has Used Non-Family Labor	Sells Any of Food Crops Produced	Has Used Chemical Fertilizers	Has Used Pesticides and Herbicides	Has Ratooned Sorghum (Fodder or Grain)
B1	M	sorghum, groundnut, maize, khat	Yes	Yes	Yes	Yes	Yes
B2	M	sorghum, groundnut, maize, sweet potato	Yes	No	Yes	No	Yes
B3	M	sorghum, groundnut, maize, "vegetables", khat	No	Yes	Yes	No	Yes
B4	M	sorghum, maize, khat, sweet potato, hot pepper	Yes	Yes	Yes	Yes	Yes
B5	M	sorghum, maize, groundnut	Yes	Yes	Yes	Yes	Yes
D1	M	sorghum, maize	No	No	No	No	Yes
D2	M	sorghum, maize	No	No	Yes	No	Yes
D3	M	sorghum, maize, lentils	No	No	No	No	Yes
D4	M	sorghum, maize	No	No	No	No	Yes
D5	M	sorghum, maize, beans, sweet potato	No	No	No	No	Yes
F1	M	sorghum, maize, onions, beans, potato, barley, wheat, khat	No	No	Yes	No	No
F2	M	sorghum, maize, onion, potato, beans, groundnut, khat	Yes	No	Yes	Yes	Yes
F3	M	sorghum, maize	Yes	Yes	Yes	No	Yes
F4	M	sorghum, maize, beans	Yes	No	No	No	No
F5	M	sorghum, maize, beans, groundnut, khat	Yes	No	Yes	Yes	No
F6	F	sorghum, maize, beans, potato	Yes	No	Yes	Yes	No

F7	F	sorghum, beans, maize, wheat, barley, groundnut	No	No	Yes	Yes	Yes
M1	M	sorghum, maize, beans, pepper, teff, barley, wheat	No	Yes	Yes	No	Yes
M2	M	sorghum, maize, beans, sesame	No	Yes	No	No	Yes
M3	M	sorghum, maize, beans, sesame, groundnut, wheat	No	Yes	Yes	No	Yes
M4	M	sorghum, maize, beans, groundnut, sweet potato	No	Yes	Yes	Yes	Yes
M5	M	sorghum, maize, beans, chickpeas, sesame, sweet potato, khat	No	No	Yes	Yes	Yes
M6	F	sorghum, maize, wheat, sesame, groundnut	No	Yes	Yes	Yes	Yes
M7	F	sorghum, maize, sesame, caster beans, groundnut, sweet potato	No	Yes	Yes	Yes	Yes
M8	F	sorghum, maize, beans, chickpeas, sweet potato	No	Yes	Yes	Yes	Yes
M9	F	sorghum, maize, wheat, sesame, onions, teff, beans, peppers, tomatoes	Yes	No	Yes	Yes	Yes
M10	F	sorghum, maize, beans, chickpea, sesame, khat, sweet potato, groundnut, wheat	Yes	No	Yes	Yes	Yes
H1	M	sorghum, maize, sweet potato, beans, "vegetables", khat	No	No	Yes	Yes	Yes
H2	M	sorghum, beans, beets, maize, onions, potato,	Yes	Yes	Yes	Yes	No
H3	F	sorghum, maize, potato, onions, beets	Yes	No	Yes	Yes	No
H4	F	sorghum, maize, chickpeas, peas, broad bean	Yes	No	Yes	Yes	No

Individual smallholder participants were recruited by convenience sampling along roadways, farms, and within villages in the five districts. The timing of this research coincided with the Islamic holy month of Ramadan. This meant that the majority Muslim population in the region was abstaining from food and drink during daylight hours, and consequently most of the farmers encountered were resting in their fields, villages, and homes. While this limited the ability to directly observe many farming activities, it also meant that farmers were repeatedly more than willing to be participate in interviews. Additional observations were recorded in the form of field notes and a reflective journal. Supplementary informal interviews were conducted with key informants working on development projects in the area investigated and documents on development programs were collected and reviewed. The University of Georgia IRB approved this research along with all contact, interview, and questionnaire materials; and local approval for research was obtained through the University of Haramaya prior to the commencement of data collection activities.

Data Analysis

Data analysis, in qualitative research, is an ongoing and reflective process that occurs throughout data collection and encourages the researcher to be aware of their subjective experience and position relative to what or who is being studied (Auerbach & Silverstein, 2003). Analysis began with the journaling process, reflection on notes and interviews, as well as conversation with those assisting during the research process. The translated and transcribed transcripts were read several times to become familiar with the data before beginning coding. After the leaving the research site and the cessation of data collection activities, the qualitative data analysis software ATLAS.ti (ATLAS.ti Mac, Version 1.6) was utilized to organize and code collected data. This software aided the coding process to facilitate the identification of patterns emerging during analysis. Structural and descriptive coding (Saldaña, 2009) were primary coding techniques used to index and identify data during analysis. The filter feature of ATLAS.ti allowed for this indexed data to be further examined and farmer-participants' answers compared and organized into categories. The resulting categories depict the smallholder farming systems and smallholder livelihoods in Eastern and Western Hararghe zones of Ethiopia, with an emphasis on the production practices and uses of sorghum. This coding and analysis process was conducted exclusively by JTB; however, ongoing communication with the AMH helped when the data seemed unclear or confusing.

Limitations

Language and cultural barriers between JTB and the farmers and informants at the site, as well as reliance on JTB's analysis to interpret the phenomenon explored, are the major limitations of the research presented here. For example, cultural barriers limited the number of women participating in farmer interviews; however, an explicit effort was made to interview some women during data collection. These limitations do not mean that the results and conclusions of this research are not useful for facilitating understanding of the context and livelihoods of smallholder sorghum farmers in the Eastern and Western Hararghe zones of Ethiopia, the appropriateness of a perennial sorghum technology for these farmers, or their ability to participate in its innovation process.

Results

In the following sections, the results of this research are presented. Subheaders are used organize this section and present readers with an understanding of smallholder farming systems in the Hararghe zones of Ethiopia, including the relevant knowledge they may possess to the ongoing perennial sorghum innovation process, and to assess the potential fit of a perennial sorghum in this farming context. The following five subsections occur under the main heading of Farming in the Hararghe Zones of Ethiopia: 1) Households, livelihoods, labor, and land; 2) Farming strategies, crop and livestock management; 3) Sorghum utilization, storage, and ratooning; 4) Khat and instances of conflict; 5) Farmer's voiced needs, cooperatives, and access to information and technology. Taken together these sections paint a picture of smallholder farming and livelihoods at the time of this research.

It is necessary to include a note on use of the word *variety,* when used throughout the remainder of this article it will generally be referring to *farmers' varieties*. The term *improved varieties* will be used to refer specifically to what Cleveland (2014) calls modern crop varieties resulting of formal breeding efforts often taking place in institutions and laboratories removed from farmers' fields, households, and communities. Also, while the term variety will be used in this article as a blanket term, Mekbib (2007) explains that farmers have their own "folk" taxonomic system with a hierarchal classification similar to the more familiar family, genus, species, and so on. Mekbib (2007) goes on to explain that there can be inconsistencies in the naming of farmer varieties, as when names vary from place-to-place or the same name is applied to a variety due to morphological or other trait similarities of what might otherwise be considered separate varieties. However, the scientific classification system likely relied upon by those reading this article is not without its own errors, inconsistencies, and disagreements, as Mekbib (2007) points out.

Farming in the Hararghe Zones of Ethiopia

Households, livelihoods, labor, and land.

Interviewed farmers primarily described their households as consisting of their spouses and children. Many described being born and growing up in the woreda they were interviewed in, and had typically resided on their land multiple decades, depending on their age. Table 3.2 summarizes some key characteristics of farmer interview participants. Two female farmers described themselves as widows (farmers F6 and H3). Farmer D4 said that his family had only lived in the area two years (this may have been tied to the fact that he said he worked off-farm in "multiple ways"), and farmer B3 described himself as a 50-year-old man who had only been in the area for three years after coming to live with his nephew. It was unclear whether this latter farmer was widowed, but he indicated that he had moved to his nephew's farm to produce vegetable cash crops with the aid of irrigation.

The majority of farmers interviewed stated that farming was their sole livelihood. Two farmers (D4 and D5) said that they also worked various "labor" jobs, and a single farmer (H1) said he was employed at Haramaya University for approximately 800 ETB per year (at the time of data collection 1 USD was equivalent to approximately 22 ETB). More than half of the farmers interviewed (N=17) said that they relied solely on the labor provided by their families and themselves on their farms (Table 3.2). Farmer H2 explained that he was only 28 years old, not yet married, and still living and working on his family's farm. H2 described how the family farm had hired extra labor so that he could attend school, but that at "grade 10" he had to leave school because of labor shortages. Some farmers described using hired labor only very rarely (M10), only in case of ample rainfall (M9), or that they no longer used hired labor because of increasing costs (F4).

Three forms of labor arrangements besides family-based labor were described by farmer interview participants. These included: 1) group labor—where farmers work on each other's farms in groups; 2) day labor—ranging in cost between 30 and 100 ETB per day per laborer, with 70 ETB per day being common and sometimes including providing meals; or 3) a sort of contractual labor arrangement on an annual basis. This latter form could be paid in an agreed upon sum for the year, with farmers describing payment ranging between 3000 and 5000 ETB. Payment was also sometimes provided in livestock (which farmer M9 valued at more than 3000 ETB), or through a sort of crop share arrangement. Crop sharing also took multiple forms, with farmer F2 saying he has provided 400kg of sorghum per year in exchange for labor, and other farmers describing giving these annually contracted laborers the harvest from a portion of land. Farmer F2 described this as being very costly at ½ hectare of groundnuts or sorghum harvested by the laborer for a year's work, and farmer F4 described exchanging the harvest of sorghum or groundnut from ¼ hectare for a year's worth of labor.

Two women farmers (F6 and H3) described having to rely on additional hired labor as they were widows. Farmer H3 explained that typically men perform the majority of the field work and land preparations. Observational data indicated that women are typically not perceived as or referred to as "farmers" per se. Despite this, farmer H3 described the intercropping of her fields, her use of fertilizers and chemicals, issues surrounding irrigation water access in her community, and the timing of planting of certain crops based on rainfall, pest, and disease patterns. Farmer F6, whose late husband received awards from the Ethiopian government for being a "role model farmer," said she has also received this award—twice. Farmer F6 explained how she already bore heavy work loads associated with collecting water and wood and preparing food, in addition to taking on her late husband's customary farm work duties. As these two women were older widows, their traditional childcare responsibilities may have been somewhat reduced; however, while farmer H3 was encountered alone walking on a road, farmer F6 was encountered within her village and children swarmed around her and us during the interview. Farmer F6 also described owning her own tractor—the only farmer interviewed to make this claim. Several of the farmers interviewed described performing their initial tillage by tractor when they possess sufficient money to rent one, and informants indicated that one of the primary ways they gain access to this equipment is through renting it from other wealthier farmers.

Despite farmer F6's ownership of a tractor, she did not sell any of the food crops she produced. This was a common characteristic of over half of the farmers interviewed (N=18). Those farmers who did sell some of the food crops they harvested discussed how and to whom they usually sold these crops, and how they attempted to obtain the best prices. It was typical of the farmers interviewed to transport threshed grain and other products to markets and towns to sell to market vendors and traders. Farmer H2 discussed how vegetable traders would come directly to farmers' fields to see the produce in the field and negotiate purchase prices. Most farmers who described taking their products to market explained that they would search for the best price available by talking to different buyers or asking other farmers what prices they were able to obtain. Many farmers described trying to time the market by storing sorghum and other grains until prices were at a premium, and farmers such as M2 described following commodity price information broadcast on the radio for periods and locations with the greatest prices. Farmer M3 described how he generally obtained the best prices by selling his products to the farmer association in which he was a member. Farmers who sold their grain to traders explained that these traders often either stored the grain to also try and time the market, or transported it to areas without sorghum production to obtain better prices. Farmer B5 described how the government purchased grain from him at premium to be distributed/sold as certified seed of a variety of sorghum called Teshale. He explained that the seed for the initial crop was provided to him through a government program known as Integrated Seed Sector Development (ISSD).

During data collection activities transportation to the Babile site was shared with ISSD personnel transporting seed to the local agricultural research center to be distributed to farmers.

Farmers' landholdings varied in size between and within the woredas investigated. Typically, areas with higher population densities (outside of population centers this was typically at higher elevations) had smaller farm sizes, as land holdings customarily passed down through families caused these landholdings to fragment and reduce in size over time. Farmer B1 described his farm as being ¾ hectares in size, commenting that additional land would help him produce more crops—a sentiment shared by farmer M7. Farmer B1 described how farm land is becoming more limited due to population issues and changing weather patterns, such as ongoing extreme drought events that he attributed to deforestation. As indicated, the land issue varied by location, and farmer F6 described their community as having "wide farm lands." Farmer F6 stated that productivity on her farm and in her community was primarily being limited by ongoing and increasing drought problems. The lack of titled land ownership generated tensions that emerged during farmer interviews. Farmer M1, who said he had been living in the area for over 59 years, explained how Meiso woreda is known for livestock production, but complained that this was being hampered by the Ethiopian government's lack of support of his people (Oromo), and that some of their land had been appropriated and given to Somali ethnic populations.

Farming strategies, crop and livestock management.

All farmers interviewed said they produced sorghum, maize, and livestock. Cattle and goats were the only livestock specifically mentioned by farmers, but camels were frequently observed in fields within Meiso woreda. Despite farmers all indicating that they produced livestock, farmer B3 explained that he does not own the animals on his farm, and has an agreement to take care of other people's livestock providing him the ability to plow and obtain milk.

The crops that farmers said they have grown are listed in Table 3.2. This list is likely not a complete accounting of the crops produced by these farmers as farmers often indicated they were talking only about the most prominent crops grown or that the crops listed were examples of what they produced. It is also conceivable that not all the farmers interviewed included khat production in their accounting of the crops they grew because of the researcher's primary interest in sorghum and food production, as well as the social stigma associated with the crop. The variations in elevation and the corresponding divergent rainfall patterns between and within the woredas explored were closely linked to varieties and species of crops produced. For example, when farmer M1 discussed the types of sorghum he produces, he remarked that he primarily produces red sorghum varieties "like Mastsugi, Abdalota, and white sorghum" and stating that "Muyra varieties are common around high or mid-lands of our district but not here." Khat was another example of this pattern as it was visibly more abundant in areas of higher elevation that received greater rainfall, and absent from low-lying semi-arid areas like Dire Dawa.

Interviewed farmers described how they would begin each season of grain production by removing any remaining crop residues from their fields and plowing either by tractor or ox. More often than not, farmers who used a tractor described using this equipment only for their initial plowing and when they felt they had the capital to do so. Farmer B4 commented that using the tractor helped conserve higher moisture content in the soil. Interviewed farmers typically mentioned performing a total of two or three separate tillage events, with planting typically coinciding with the last tillage. However, farmer D3 explained that while he typically plowed two or three times prior to planting, crop failures the previous year created a shortage of animal feed that forced him sell his male ox used for plowing to purchase supplemental feed for his remaining livestock. This lack of male ox meant that farmer D3 was unable to “pre-cultivate” and was forced to use “direct planting.”

Farmers explained that these multiple tillage events served to expose the seed bank and encourage germination of weeds, which could then be killed in subsequent cultivations. There were two general patterns to the land preparation practices described by farmers: 1) the first tillage occurring as early as January or February before the beginning of seasonal rainfall; or 2) farmers waiting for the first rainfall before plowing in March or April. Rainfall was by far the most frequently cited factor that farmers considered when determining not only when to undertake practices such as tillage and planting, but what varieties were selected for planting in any given year. Yet, the majority of farmers interviewed indicated that there has been a change in these rainfall patterns over their lifetimes, namely an overall lack of rainfall and more erratic deviations from typical patterns. Farmers and local informants described a historical pattern of bimodal rainfall—generally first peaking in April and May, and then peaking again in July and August. However, farmers indicated that presently the early rains were either sporadic or non-existent, and that irregular later rains could cause problems during key crop development stages. Many farmers discussed this, but farmers B3 and F6 described both occurrences of no rain during the critical grain filling period leading to a lack of harvestable grain, and too much rain at grain maturity leading to moldy grain heads. Several of the farmers interviewed referenced the severe droughts in the previous year (2015) as causing widespread crop failures and issues of food insecurity within their households and communities.

To cope with these climatic uncertainties farmers discussed various strategies. The most frequently cited being the shift from *long-season* sorghum varieties to *short-season* varieties of sorghum and other short-season crops such as maize. Farmers described how these short-season crops allowed them an option to fall back on when the early rains do not materialize. Some farmers, such as M5 who said he had lived in Meiso for more than 60 years, described using his long experience to predict what the rainfall amounts and patterns for that season would be and then planting the corresponding crops/varieties. The timing of crops to rainfall events meant there were significant deviations from what might be considered the usual cropping calendar and the general land preparations patterns described previously. For example, farmer D1 described planting crops as early as January when he received what he believed to be adequate rainfall. Farmer B1 also said that he plants immediately when the rains begin, stating that waiting until May which he described as the traditional "right time of major cropping seasons" can leave farmers unable to plant because of a lack of rainfall. Farmer B1 explained that the farmers who prefer to wait for this "right time" are concerned that planting too early might expose crops still in a susceptible growth stage to army worm outbreaks. Farmers H1, H2, and H4 indicated that in Haramaya (which H1 said does not suffer as much as other areas form erratic rain problems) they utilize wind direction as an indicator of coming rainfall and in turn what crops to plant—with Haramaya farmers saying that moist air blowing from north to south indicates a chance of significant rainfall.

Rainfall patterns even seemed to influence the use of other farming strategies. For example, farmer M10 stated that an April rain would mean that on her family's farm they would plant a sorghum variety called Matsugi intercropped with maize, but no April rain would mean another plowing and later planting of a short-season variety of sorghum. Intercropping was a repeatedly observed strategy within many farmer's fields in the region investigated. While clearly often done intentionally, in some instances it seemed more passive, with plants from a previous crop being allowed to mature within a current crop. Farmer H2 was the only farmer that specifically stated using the practice of crop rotation, stating that he rotates between maize and sorghum every year, occasionally including potatoes in his rotation.

Only nine of the farmers interviewed (B4, B5, F2, F3, F4, D5, H4, M3, M6) indicated that they faced soil related issues. While most of these were related to decreasing soil fertility, farmers M6 and D5 indicated that their soil problems were related to erosion. A few other farmers described past issues with erosion, but stated that by terracing their fields they had solved these problems. A majority of the farmers interviewed indicated that they have used chemical fertilizers (Table 3.2). Farmers referred to these as “white” (urea) and “black” (diammonium phosphate) fertilizers. However, farmer D2 indicated that this was a very rare occurrence and farmer M1 said he prefers using fertilizers derived from animal manure. Farmers said that they generally obtain chemical fertilizers through the locally-embedded district agricultural offices and research stations, local farmer cooperatives that they may or may not be a member of, as well as a few farmers living in or close to Haramaya purchasing these products from a farmer’s shop in town. Access to chemical pesticides, herbicides, and fungicides followed a similar pattern, but fewer farmers claimed to have used these products (Table 3.2). Farmers who said they had used pesticides/herbicides/fungicides were often unable to name the chemical used (B1, B5, F5, F7, M5, M6, M7, M8, M9, and M10), and also said they used chemicals infrequently, typically only when faced with a severe pest outbreak—often this was army worms. The chemicals that farmers were able to name included DDT, malathion, mancozeb, and endosulfan.

Farmers F2, F5, F6, F7, H4, D3, and D4 all mentioned purchasing “furishka” as a supplemental food for their livestock. Furishka was described by informants as an animal feed made from the leftover material when grains were ground into flour. These farmers indicated that they only relied on this strategy once they had exhausted their own supply of livestock feed that they had built up from their fields. Farmers explained that during the cropping season livestock were often a fed a combination of weeds pulled by hand from their fields and the non-salable portions of crops like maize, groundnut, and sorghum. Some farmers indicated that instead of furishka, they traveled to areas of higher elevation (and higher rainfall) to purchase fodder often consisting of sorghum. Several farmers indicated that of the crops produced, sorghum provides the most livestock feed—especially the long-season varieties that farmers said take can take eight or more months to produce mature grain.

Farmers like B4, D1, D2, and M7 indicated that weeds were one of the less troublesome challenges to crop production since they were often utilized as livestock feed, but farmers described performing frequent cultivations throughout the season in their fields to control weeds. “Sargo” (*Parthenium* sp.), “Aram Azab” (*Striga* sp.), “Burana” (*Cyperus rotundus*) were the three most common weeds mentioned by farmers. Farmers also listed local names of weeds that may apply to different weeds in different regions. Examples of this included “Wanjali” translated as “criminal,” and “Nmale” translated as “selfish weed.”

The majority of farmers interviewed indicated that droughts and shifting rainfall patterns have pushed them towards short-season varieties of sorghum that they said take as little as three months to mature. However, many farmers indicated a preference for long-season varieties because of their enhanced livestock feeding capabilities. Farmers strip the leaves from maturing sorghum stalks, drying and piling these leaves in a conical structure made from the bare sorghum stalks (Figure 3.2). Farmer B2 stated that while he should be planting short-season varieties of sorghum because of rainfall pattern changes, he prioritizes livestock food production over human food and prefers to plant long-season varieties. Farmers indicated that the ratooning of long-

Figure 3.2. Sorghum Stalks Stacked in a Conical Structure with Sorghum Leaves Piled Inside for Livestock Fodder.

season varieties when young to obtain additional animal fodder. The young shoots and leaves of these ratooned plants were fed whole to livestock. Several farmers shared knowledge on livestock health problems associated with young sorghum shoots, particularly under drought conditions and when invaded by an ant-aphid complex. Farmers explained that older plants typically caused no such issues, and that these issues could be mitigated by drying the young shoots and leaves—although farmers disagreed on whether young shoots should by dried in the sun or under shade. Farmer B4 also said that he used plants removed during thinning and those invaded with stock borer pests to feed his livestock.

Farmers explained that while livestock were prevented from entering fields during the normal cropping season, during the off-season everyone's livestock were generally free to graze within anyone's fields. Farmer B5 explained that this *free-grazing* period generally starts after harvest and extends until the first rains, saying this is typically from December until March. However, some farmers (F2, F3, F5, F6, F7, H1, H3, H4, and M10) said that livestock never grazed in their fields. Farmer B4 clarified that livestock were never allowed to graze in vegetable and khat fields—and this may explain the concentration of farmers who indicated there was no free-grazing in their fields in Fedis and Haramaya (districts where both khat and vegetable production was more common).

Sorghum utilization, storage, and ratooning.

The farmers interviewed indicated that sorghum was a multi-use food crop, providing sustenance for both for humans and livestock. Observations indicated that sorghum was also utilized as a cooking fuel source—especially important in deforested areas—and for construction purposes, such as fences and shade refuges in farmers' fields. Even of those farmers who stated that they sold some their food crops, all indicated that they saved a significant proportion of the sorghum produced for household consumption. Farmer H2, whose family produced many crops to sell, stated that sorghum was not sold and utilized solely within the household. Farmers indicated that prices for sorghum grain fluctuated over time and by region, but Farmer M6 explained how the prices obtained for sorghum differed by variety as well. Table 3.3 details the varieties of sorghum mentioned by the farmers interviewed, and whether farmers indicated they could be used for ratooning.

Table 3.3.

Sorghum Varieties Mentioned by Farmers. Table indicates which farmers mentioned the variety and whether farmers indicated the variety was useful for ratooning.

Variety	Farmers Mentioning	Farmers Indicating Variety Can Be Used for Ratooning
Abdalota	M1, M2, M3, M4, M5, M6, M7, M9	M1, M3, M4
Adi	F2, H1	
Ashenafi	D5	
Bedukanni	B4	
Bele Melik	D2, D4	
Bube	M3	
Bullo	B2, B3, B4, B5	B3, B4
Butene	F1, F2, F3, F4	F2
Chamme	B2, B5	
Cherchero	F6, F7	
Dhaqab	M6	
Dimma	F1, F2, F3, H1	F2
Dukun	D3, D5	D3
Eja	F3, F4	
ESES[a]	M4	
Fechee	F7	
Fendisha	D5, H1, H2, H3, H4	D5
Gambela	M2, M9	
Hafare	F3	
Haji Ali	D1, D2, D3, D4	D1, D5
Hitibile	H1	H1
Jabeyis	M2, M3	M2, M3, M6, M9
Jaldi	D2, D3, D4	
Jaldu	D1	D1
Jeldi	D1, D2	D1
Keyla	H1, H2	
Kuffa kassa	B3	
Masengo	D4	
Matsugi	M1, M2, M3, M4, M5, M6, M7, M8, M9, M10	M1, M2, M3, M4, M6, M8, M9, M10
Meko	M6, M8, M9	
Meleta	M5	
Melkam	M2, M3, M4	
Misikir	M3	
Muyra	D1, D2, D3, D4, D5, H1, H2, H3, H4	D5

Sarude	M6, M7, M9, M10	M6, M7, M10
Shashatu	D5	
Shashe	D3	
Taabelaa	B4	
Teshale	B1, B2, B5, F4, F7, D1, M2, M3, M4, M6, M7, M8, M9	
Wacila	M7	
Wegere	B3, F1, F2, F5, F6, D1	
Yubiye	M2, M4	

Note. To the extent possible, variety names mentioned by farmers have been spelled according to English language conventions. Some of the varieties listed here are farmers' varieties that are supplied to farmers as certified seed.
[a]This sorghum variety is most likely an improved variety that has been made available to farmers; however, it is unknown if this name is correct as many improved varieties also have number designations following these letters.

Farmers listed several food products produced and consumed in their households made from sorghum. The most commonly cited of these were porridges blended with sorghum grains called "afelama", boiled sorghum grains called "shumo" (often described as mixed with beans), a soft pancake-like food locally called "tuftufa", and a flatbread and staple of Ethiopian cuisine called "injera". Injera is perhaps the more famous and ubiquitous of these foods, but locals explained that it is traditionally made from the more expensive teff—another grain produced in Ethiopia. Teff seemed to be the preferred grain for eating and making injera as it is more pliable and spongy, and therefore holds up better when pieces of the flatbread are torn and used for grasping and eating food. Injera can be made exclusively from sorghum, other grains besides teff and sorghum, or as a blend of flours made from different grains.

Farmer H3 explained that when sorghum grain heads are reaching maturity they are bound together to keep them from lodging, once mature the stalk and grain head are removed together and piled between two closely spaced plants to dry for a few days before the grain heads are removed. Once these heads are removed they are all moved to an area where they can be threshed by hand before being stored. Most farmers described storing their harvested and threshed grain in underground pits, but some described storing the grain in the home. Farmer M4 said that they preferred to store their grain in a "gotara"—a large basket-like vessel made from wood and/or bamboo, animal manure, and covered on top with grass.

Of the farmers interviewed, 24 farmers (Table 3.2) said that they have employed the ratooning properties of sorghum to produce either livestock fodder or human food with some indicating that these plants sometimes stay in place into the off-season. Those farmers who had not utilized ratooning themselves were sometimes familiar with the practice. Farmers H2 and H3 said they had heard of the practice's use in lowland areas, and farmer F4 said that he heard the practice could decrease soil fertility and make plowing difficult from the mass of fibrous roots generated. Farmers that did utilize the practice were split on whether or not it caused soil fertility declines. Many of these farmers indicated that they only suspected fertility declines, and that it depended on how long the crop remained in the field. Farmer M3 said that he believed the practice was very draining on soil fertility, while farmer D5 said that up to two years is not problematic but longer than this might result in soil fertility declines. Famers F2, F3, H1, and M2 indicated that through the addition of fertilizers they can address soil fertility issues. Farmer D1 thought there might be reductions in fertility after a single year of ratooning, but also claimed that with good moisture he had been able to ratoon sorghum for five years on his farm.

For the farmers that said they utilized the ratooning ability of sorghum to produce grain, they almost universally remarked that good rainfall and soil moisture levels were essential to get a successful grain yield. This was true even for those farmers who said they only used the technique to produce livestock fodder, as they explained that a drought stressed crop can result in the livestock health issues discussed earlier. Farmer F1 expounded on his ratooning method, saying that it requires planting in March or April, and a cutting in May to prevent stock borer damage. Farmer B4 said that he once used early rains in January to plant Bullo sorghum, which he then cut in June for animal feed and to promote suckering, and that this allowed him to obtain 18 grain heads from a single plant.

The farmers that utilized ratooning to produce grain frequently commented on how much grain they had been able to produce from the technique. Farmer F2 explained that to obtain good grain yields late season rains need to last until October, and farmer F3 said that he harvested 200kg of grain from ratooned sorghum. Some farmers expressed strong interest in the promotion of the practice among farmers and farming communities, saying that damage from birds and livestock often occurs when its use was limited to a small area such as a single field or farm. Farmer D4 stated that if neighboring communities could work together to produce these types of sorghum, bird and livestock damage could be reduced. When discussing her use of ratooning, Farmer M6 commented that she would like improved varieties of ratooning sorghum to be supplied to farmers.

The challenges that farmers described relative to the production of ratooning sorghum were some of the same challenges they cited in reference to sorghum production in general. Frequently cited issues with sorghum production in general, included pests such as birds, striga, stalk borer, and army worms. However, the most frequently cited challenge to both sorghum production in general and the ratooning of sorghum, were issues of drought and erratic rainfall.

Khat and instances of conflict.

There was a clear tension between the ubiquitous and culturally significant nature of khat within the region investigated and observed social stigma against its use among certain social groups. This is likely exacerbated by its prohibition in most countries outside the Horn of Africa and the Arabian Peninsula. In the region investigated khat chewing was a quite ordinary occurrence, and its production a primary source of income for many farmers. Farmer H1, who made an 800 ETB annual salary from his work at Haramaya University, explained that he makes more than 2000 ETB annually from his khat production. However, several local informants expressed concern that khat expansion is overtaking lands and limiting food production, as well as expressing concerns over the plants misuse and abuse by habitual users. Local informants and informal conversations indicated that many people used the stimulant properties of the plant to enhance their wakefulness, energy levels, and ward off hunger while working—whether farming or driving vehicles. Farmer F2 explained that while khat is the main cash crop in his area, food crop lands are being limited by khat production. Khat fields were observed being intercropped with sorghum between the rows of this perennial woody plant making the most of limited land.

Within all the population centers visited (e.g., Harar), the remnants of chewed twigs frequently littered the ground, and entire side-streets and market areas were devoted to vendors selling nothing but the bundles of branches and young green leaves. On the roads between towns, vehicles were frequently seen with their roofs piled high with large bundles of khat. Khat chewing was a social affair, and while its use by men seemed more culturally and socially acceptable, men and women were both observed partaking in its use. Observations indicate that there is a common preconception by some that khat users are lazy, of lower social status, or otherwise uneducated. The classification of khat as a controlled substance in many countries that provide monetary and development aid to Ethiopia was cited by key informants as the primary reason why no funding is dedicated to formal research on khat in Ethiopian universities.

The khat issue and farmer M1's perceived lack of support from the Ethiopian government were not the only instances of conflict observed between the majority Oromo Muslim inhabitants of the study site and interests from outside the region. Upon arrival to the study area, Haramaya University was under lockdown due to outbreaks of student protests, and the blue and black camouflage uniforms of the armed Ethiopian Federal Police were a common sight around campus and in the surrounding community. Data collection activities were sometimes prevented by protest events within the communities under study. These protests were appeared to frequently be carried out by Oromo youth (re)affirming their cultural and ethnic heritage and often spurred into action by instances of perceived police brutality, government oppression, and lack of opportunity.

Farmer's voiced needs, cooperatives, and access to information and technology.

While discussing aspects of their communities, livelihoods, farm management, and sorghum production and use, farmers often reflected on the issues they faced as farmers and community members. However, farmers were also asked directly about their needs as farmers and the needs of their communities, and what they believed would help in fulfil these needs. When answering these other questions every farmer interviewed, at some point, mentioned issues related to water. While this was frequently in relation to drought and erratic rainfall patterns hampering crop production and decreasing yields, it was also in connection to their community's, household's, and livestock's access to drinking water. Farmer M9 described how in the mornings children on their way to school regularly stop at her house to solicit drinking water. Although concerned for these children, she explained that if she gives these children water it encourages more to come to her house, and she already has to devote significant time and travel long distances to obtain her family's drinking water.

Farmers' strategy of adjusting the timing and varieties of crops to the current season's rainfall patterns while moderating risk, often meant that farmers did not plant their preferred crops and varieties. Observations and interview data indicated that farmers with access to irrigation and in areas receiving higher levels of rainfall often fared better economically and had greater food security. Several of the farmers interviewed discussed how irrigation would, or does, permit them to produce greater yields, multiple crop successions, and higher value crops such as vegetables. Several farmers (F2, F4, D3, M3, M6) specifically mentioned the need to construct ponds for irrigation and drinking water near their fields and in their communities. Additional farmers (M7, B3, F4, F5, D3) said they were also in need of pumps to facilitate the irrigation and move water to their fields. Farmers H1 and H2 who indicated they had some access to water and even a pump, explained that they often had difficulty accessing and affording fuel for these pumps. Farmer H1 commented that while the farmers in Haramaya are relatively wealthy because of their water access and ability to produce vegetable cash crops, he had faced instances where even these ponds dried up. In fact, farmer H1 was interviewed while overlooking a large area consisting of vegetable fields and common grazing land that had been the bottom of Haramaya Lake. Informants disagreed over what caused the lake to disappear—unsustainable use by farmers, a now defunct brewery, and nearby population centers—but the ever-present need for water among all the farmers interviewed was clear.

Farmers' proposed solution to the need for greater irrigation access often centered around assistance from the government or NGOs in the form of access to credit and interest-free loans. Farmers often cited credit access as possibly improving other expressed needs, such as access to fertilizers and improved and/or certified seeds as well. Farmers B1 and M7 indicated that they needed more land while farmers B5 and M2 said that more and improved breeds of livestock would improve their livelihoods. Several farmers simply indicated that they needed to increase their yields and income, and that this could help with issues of food security. While some farmers indicated that outside assistance would help these expressed needs, several others simply stated that they needed to keep working hard or work even harder. Some of these latter farmers indicated that they hoped their efforts would improve the opportunities and access to education for their children, and farmer D5 said that by saving his money he hoped to start a business as a trader or merchant.

During interviews, farmers were asked both about their contact with development personnel, researchers, NGOs, as well as membership in or contact with farmer organizations. All farmers from Haramaya (N=4), and all but one farmer from Dire Dawa (N=4), as well as farmer B3 from Babile said that they never or only rarely have contact with these individuals and organizations. This was surprising in relation to the Haramaya farmers, as the waterless lakebed of the vanished Haramaya Lake was the only thing that separated the interviewed farmers from Haramaya University a major agricultural university. Most of the farmers indicating they had little to no contact with these agricultural knowledge, input, and technology sources said that they relied on their own indigenous/farmer knowledge for their livelihood. However, Farmer H2 did say that his education allowed him read, and he used the information published annually by the Ministry of Agriculture in the form of a newspaper to learn about new farming information and practices.

Among farmers who indicated they had contact with district agricultural offices, development professionals, and researchers from local universities, such as Haramaya University, provided examples of the types of information they received. Farmers cited things like planting and harvesting information for crop species and varieties, information on the benefits of planting in rows versus broadcast methods, as well crop management and varietal demonstrations. Farmers also discussed how these organizations provided access to and information on fertilizers and chemical controls, as well as access to seed varieties with traits like striga resistance.

Farmers B1, B5, and M6 discussed their participation in the ISSD project mentioned earlier. These farmers and program personnel explained how the ISSD project worked in communities generally in collaboration with locally-embedded research centers and through farmer cooperatives to assist with organizing and monitoring farmers and their fields for the production of certified seed. This certified seed obtains significantly higher prices than if it was simply sold as grain. Informants explained that seed shortages and limited access to improved cultivars and certified seed was an ongoing issue in the country, and several farmers (B2, B5, F1, F7, H2, H3, H4, M7, M9) explicitly mentioned the need for access to improved varieties and certified seed during interviews. Farmers D1 and D3 explained that they were provided sorghum seed through the government but that it was not provided at the right time for planting, and both farmers said that they instead used this sorghum seed as food within their households.

Farmers that were members of or had contact with farmer cooperatives also described the benefits these organizations provided. This included information, technology, and input access similar to the benefits received from contact with development personnel, NGOs, and the district agricultural offices. However, farmers also described how they were able to obtain credit as well as household staples like sugar and flour at reduced costs through their membership in these organizations. Farmer M6 explained that there were farmer associations for both males and females, and that her union shares the generated profits back with its farmer members.

Discussion

Ethiopian smallholder farmers were found to often face dire immediate needs (e.g., food insecurity), growing populations, shrinking landholdings, erratic weather, and a general lack of opportunity. This is leading to increasing uncertainty, growing political instability, and even civil unrest. However, the farmers interviewed utilized extensive farming knowledge (regardless of gender), to attempt to mitigate these circumstances. Farmer knowledge even sometimes extended to the varietal uses, preferences, and practices in areas distant from a particular farmer's fields despite the highly variable nature of environments across relatively short distances. Farmers made the most of the resources available to them within the limitations of their context through the use of annual (i.e., vegetables) and perennial (i.e., khat) cash crops, limited irrigation access, livestock production, an extensive varietal portfolio of sorghum, several sources of information and inputs, and strategies such as intercropping, ratooning, and creative on-the-fly adjustments to what might be considered the regions normal cropping calendar.

This improvisation strategy emerged as a principal method to cope with the increasing uncertainty faced by farmers. Whether through the ratooning of sorghum, adjustments of planting dates and tillage practices, or use of extensive experience and environmental cues to predict weather and rainfall, these decisions were made creatively and often in the moment analogous to the creative improvisation described by Richards (1989). Mekbib (2006) found that the primary reasons farmers cited for adopting improved varieties of sorghum was early maturity (~100%) and drought resistance (~90%)—yield, the primary goal of most modern plant breeding efforts, was only cited by approximately 20% of farmers. This can be explained by realizing the need of farmers to *improvise* their farming every year and draw upon an assortment of traits that will get them through rapidly changing and erratic conditions. While farmers frequently mentioned shifting to short-season sorghum varieties, they did this in response to these changing and erratic conditions; and their expressed preference for their varieties—also indicated by Mekbib's (2006) measured low adoption rate of improved varieties—indicates that when they deem it possible they will gladly shift back to their long-season sorghum varieties. The Ethiopian smallholder's need for flexibility suggests that experts working with the development perennial grains and the associated cropping systems may benefit from considering Richards (1989) performance concept, emphasizing the improvisational strategies farmers use to manage uncertainty.

It is unclear in what ways a perennial sorghum might restrict the ability of farmers to perform agriculture under these conditions. It may be that Cox et al.'s interim goal of a "super-ratooning sorghum" may be a better fit within the explored context than a truly perennial one. Under Ethiopian law farmers are entitled to compensation for improvements made on their lands (and legally required to not degrade their land) should the land be expropriated (Gebreamanuel, 2015). Would a perennial sorghum that could grow and yield in place for several years be considered such an improvement? Article 13(3) of the FDRE constitution also states that when water and soil conservation "works have been undertaken a system of free grazing shall be prohibited and a system of cut and carry feeding shall be introduced" (Gebreamanuel, 2015, p. 49). This could unintentionally increase farmers' labor and forage needs if perennial sorghum is considered a "work" to improve water and soil conservation and grazing is restricted. While the interviewed farmers recognized this need for erosion control, this point serves to illustrate how planting a truly *perennial* sorghum for erosion control or unrelated reasons may have possible legal ramifications.

Certainly, perennial sorghum will best meet smallholder farmer needs if it can fulfill multiple-use (food, fodder, and fuel) needs and withstand drought conditions. The ability to withstand drought will be paramount for a perennial or "super-ratooning" (Cox et al., 2014) sorghum, as farmers indicated that both successfully ratooning and simply obtaining grain from a ratooned (or any) sorghum was highly dependent on the presence of moisture during both grain filling and other important growth stages. Different uses would be prioritized under the specific environmental and local contexts, likely necessitating the development of more than one variety of perennial sorghum. As Cleveland (2014) and Mekbib (2006) emphasize, smallholder farmers prefer to maintain a portfolio of varieties to draw upon when the moment presents itself. For example, the development of a perennial sorghum with a tall woody stalk for cooking fuel and construction purposes would be particularly useful in deforested areas, and a sorghum with enhanced ratooning and livestock nutrition/palatability/silage characteristics would be particularly useful in areas where livelihoods are geared towards livestock production. Farmers clearly viewed sorghum as a culturally and traditionally significant grain that was important for food security in farming households along with the other food crops produced. However, given the choice and opportunity Ethiopians did not necessarily prefer sorghum's use in one of the country's most iconic foods—injera. Those with the ability to afford it, seemed to prefer teff over sorghum to produce this flatbread-like staple of essentially every meal. This may be an indication that at least some in the country associate a stigma of poverty with sorghum, as in restaurants and urban areas the injera encountered was always made from teff.

The environmental and resource/input benefits of a new perennial crop are at least partially captured through the perennial crops already in production by some Ethiopian smallholder farmers. However, observations indicated that khat (the most frequently encountered perennial crop in the region investigated) research goes unfunded for political and social reasons. Overcoming this barrier will require engagement with the Ethiopian and other international governments. Incorporating a perennial sorghum or super-ratooning (Cox et al., 2014) sorghum as an intercrop into existing perennial khat systems—as well as other perennial crops, like coffee—could further enhance ecological systems and environmental benefits while addressing smallholder needs. Although, the extent may not be as transformational as many within the perennial paradigm have hoped considering the practices already in use.

Furthermore, considering the pressures facing the region's farmers (population growth, land fragmentation, climate change, and conflict) it is unclear as to how much more sustainable a perennial sorghum will actually make these farming systems if the situation is by definition already unsustainable. Gebissa (2004) explains that khat maintains a significant price advantage over the majority of crops produced in the region, including coffee; and while the many international legal prohibitions against the crop will limit any real market expansion, Gebissa explains that smallholders recognize that khat production is not a long term solution to their and their country's agricultural problems. Gebissa (2004) clarifies that price is not the only consideration farmers facing food insecurity and increasing uncertainty weigh when deciding which crops to plant each year as strategic risk mitigation through multiple crops is paramount. However, the income earned from khat can afford farmers the ability to shift livelihoods—often into small entrepreneurial activities—and relieve some of the pressure on fragmented and degraded lands. Discussing the khat production in the Hararghe region, Gebissa articulates the realities of this point well:

> In this regard, khat did what the policy planners would never have imagined they could do for farmers, that is, moving them to nonagricultural occupations, thereby easing demographic pressure on land and agricultural resources. It is interesting to note that farmers pursued diversified occupational strategies to cope with the challenges of agriculture whereas policy-makers sought to fix the existing problems of agriculture and perpetuate smallholder farms. (Gebissa, 2004, p.183)

There is no reason to assume that simply adding a perennial sorghum to the mix would solve these complex social issues or do anything besides also perpetuating smallholder agriculture. However, the fact that smallholder farmers are highly knowledgeable and experienced with the immense diversity of sorghum varieties found in Ethiopia and the ratooning capabilities of these varieties, indicates that these farmers will be an important ally in the continued development of perennial sorghum. Further research into this indigenous and farmer knowledge could greatly contribute to the development of perennial sorghum(s) and the agronomic systems based on them. It is difficult to say from the sample and results of this research whether there was a difference between men's and women's interest in or use of the ratooning capabilities of sorghum as both genders indicated knowledge on sorghum ratooning. However, if Mulatu and Kassa's (2001) assessment of the differences in men's ("long-term") and women's ("short-term" and "lean season") focus on food availability and crops is valid, then perhaps women would be interested in taking over men's ratoon/perennial sorghum crops for grain production during the typical off-season. This is largely speculation however. During further research on farmer's sorghum ratooning, issues related to gender could be explored more fully.

The so-called "third wave" in science studies on experience and expertise (Collins & Evans, 2002) views those with contributory expertise—such as smallholder sorghum farmers—as experts in their own right, and this thinking could shift the way these farmers are viewed. It will also be very important to consider how the IPR of these individuals and communities can be protected to insure that their contribution is recognized, and benefits returned. Accomplishing this will necessitate the development of new and innovative systems of IPR protections (Ezeanya, 2013). Partnering with these farmers and farming communities could enhance local opportunities and livelihoods while improving the future sustainability of agriculture globally. Perhaps this is where the real benefit for farmers exists—Ethiopian smallholder farmers receiving financial remunerations for a successful and globally adopted perennial sorghum technology based on their expertise and the germplasm they have developed and maintained for millennia.

The efforts of projects like ISSD indicates that farmers can be organized into cooperative units across areas to produce certified seed—a product with enhanced income earning potential. This is necessary because of the issues associated with cross pollination that occurs when producing seed on small fragmented farms. This program’s evolving successes indicates that farmers are more than willing to cooperate on larger scales when they receive real benefits. Large scale cooperation potentially addresses some of the farmer identified issues associated with livestock grazing and bird damage when isolated crops of semi-perennial and/or ratooning sorghum are produced. At least some of the farmers interviewed did express an interest in growing more perennial-like ratooning sorghum when moisture availability allows, and a few even explicitly stated an interest in varieties possessing improved ratooning capabilities. As suggested and implied by farmers, perennial and ratooning sorghum projects in farmers’ fields would be most successful and best meet farmers’ expressed needs if they were partnered with efforts to enhance access to water resources—both for irrigation and consumption. All the grain in the world cannot save someone from thirst.

Conclusion

The Ethiopian farmers in the region investigated employed many varieties of sorghum and other crops on their farms, and demonstrated expertise relative to crop production under significant resource limitations. This included considerable knowledge on the ratooning of sorghum to enhance fodder and grain production, and further research specifically on farmers use of sorghum ratooning and sorghum ratooning varieties is needed. Recognizing and valuing farmers' expertise in these areas could certainly assist with moving the development of perennial sorghum forward; however, protecting the intellectual property rights of these farmers and returning benefits to them must be a priority. This would likely require participatory negotiations on methods to return benefits that recognize the communal and culturally significant nature of this knowledge.

Farmers use their available resources and strategies in an improvisation-like manner to cope with the annual and day-to-day uncertainty they face with regard to erratic weather causing crop failures and exacerbating food insecurity. It is unclear whether a perennial sorghum potentially occupying land for an extended period of time would limit this adaptive strategy, and in what ways its perennial nature could cause issues with the off-season grazing of farmers' fields or even land tenure and rural land law. Many of the farmers within the region investigated already take advantage of the ecosystem enhancing properties of perennial crops, such as the culturally significant but socially stigmatized cash crop khat. There may be additional environmental benefits from the intercropping of a perennial sorghum with khat or other perennials grown in the country. However, it remains uncertain whether ratooning/perennial sorghum will truly enhance the sustainability of smallholder farming long term in the context investigated given the complex overarching issues of water shortages, climate change, political conflict, population growth, and increasingly fragmented land holdings; as well as the limited alternative economic and livelihood opportunities available and accessible to farmers beyond a continuing persistence in smallholder agriculture.

Still, farmers expressed interest in the potential of improved ratooning/perennial cultivars of sorghum, along with a universally expressed need for improved water access. Farmers may receive greater benefit from an improved ratooning sorghum over a truly perennial one given their need for flexibility. Either way, to mitigate risk and cope with uncertainty developing multiple types/varieties of ratooning/perennial sorghum for smallholder contexts will be essential given the extent of environmental and climatic variability across space and time, divergent farmer priorities between areas, and the farmer practice of varying combinations of crops with various growth and maturity timeframes. The contextually specific nature of these conclusions are obviously not generalizable to all smallholder farming contexts across Africa or even in Ethiopia; however, these conclusions do elucidate how the appropriateness and consequences of agricultural technology are contextually dependent. As the technology historian Melvin Kranzberg states, "technology is neither good nor bad, nor is it neutral," (1986, p. 545).

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

This thesis document contains two individual manuscripts presented in Chapter 2 and Chapter 3. The findings and conclusions of each of these manuscripts are revisited here in succinct form to avoid excessive repetition. Subsequently, the overarching recommendations for this thesis as a whole are presented considering the combined findings and conclusions of each of these individual manuscripts.

Manuscript One

[Summary of the findings and conclusions for the first manuscript. Please refer to pages 18-82 to review this manuscript in its entirety.]

Interviews with experts developing perennial crops and systems, as well as experts in smallholder contexts helped to outline the potential barriers to developing a perennial sorghum that would benefit smallholder farmers. These barriers were directly connected to the *pre-analytic choices* (Röling, Hounkonnou, Offei, Tossou, & Van Huis, 2004) being made, meaning that they were rooted in problem chosen to be addressed, the assumptions on the theoretical functioning of these crops in agricultural systems, and the hypothetical benefits for smallholders. These barriers were organized into three interconnected constructs: the innovation process, the technology, and the end-user.

Within the first construct, the potentially decades-long research and development timeframe for breeding newly perennialized crops contributes to the largely hypothetical nature of perennial sorghum, other perennial crops, and their theorized benefits. Barriers related to the gaps between the environments where development has taken place thus far and where smallholders actually practice agriculture only exacerbate research and development timeframes and the uncertainty surrounding the final outcome. The physical distance separating many of those within the push to develop "new" perennials and smallholders meant that misunderstandings of contextual realities emerged. What might be considered an advantage under certain circumstances, or from a distant perspective (e.g., asynchronous flowering), could be a disadvantage for target end-users. While explaining that moving breeding and other research efforts closer to smallholder contexts is underway, experts expressed concern over maintaining funding and research over long timeframes.

In the second construct on the technology, the possible alterations to and consequences of growing a crop in place for an extended period of time—possibly several years—caused some experts to express concerns regarding changes in pests, diseases, and other crop management considerations. An example of these expert concerns was a potential conflict arising from the common smallholder practice of communally grazing livestock in farmers' fields during what otherwise would be the off-season. This also highlights the ramifications the protracted crop season of perennial sorghum may have with regard to established social and cultural norms. Perhaps most importantly for smallholders, experts discussed how perennials might be uniquely susceptible to crop loss during their establishment period, entailing a period of higher risk for smallholders. Questions around soil fertility were also raised; however, some experts indicated a potential for soil fertility enhancing abilities in perennial sorghum hybrids.

The third construct on the end-user, focused on barriers related to the acceptability and preference of potential adopters, as well as barriers related to promotional efforts. While a perennial technology based on sorghum might be more familiar to those already producing sorghum, some advocated for these new perennial crops to be given new names at looked at entirely differently. The fact that some of the current material is hybridized with the invasive weed Johnson grass presented additional problems related to acceptability. Experts discussed how in many contexts smallholder farmers may already grow some crops, like sorghum, in perennial-like systems and use ratooning to enhance yields. One expert explained that smallholders' use of perennial and ratooning systems went initially unnoticed by researchers working directly with them because of agricultural science's deep-seated predisposition toward annual production systems and the timeframe restrictions surrounding research. Mirroring the issues surrounding agricultural research, introduction and diffusion efforts to bring perennial sorghum technology to farmers must navigate the complex realities of international development while respecting the intelligence and agency of smallholders.

The pre-analytic choice of the technological solution (i.e., perennial sorghum and other perennial crops) to the pre-analytically identified problems of agricultural systems dominated by annual production was made without the input of a target end-user group (i.e., smallholder farmers). The pre-analytic choice to not obtain this input restricts the nature of participation between stakeholders—including both those developing perennial technologies and smallholder farmers—in the ongoing innovation process even though the interviewed experts agreed that the participation of smallholder farmers would be key to the ongoing development of perennial sorghum. Therefore, we conclude that the future innovation process of perennial sorghum is limited to either consultative participation (Johnson, Lilja, & Ashby, 2003; Lilja & Ashby, 1999)—where scientists use farmers' knowledge and opinions how they see fit during the innovation process—or collaborative participation (Johnson et al., 2003; Lilja & Ashby, 1999)—

where farmers and scientists come together to share their knowledge and opinions and mutually make decisions as the innovation process advances.

Manuscript Two

[Summary of the findings and conclusions for the second manuscript. Please refer to pages 83-139 to review this manuscript in its entirety.]

Interviews with Ethiopian farmers and observational data collected in Eastern and Western Hararghe zones of Ethiopia showed that farmers, regardless of gender, were highly knowledgeable and experienced in sorghum production under resource limitations and environmental/climatic uncertainty. Farmers often faced limited access to water, improved seed and other technology, land, labor, credit, education, and opportunity beyond smallholder farming. Within the area studied, elevation and climate varied, often dramatically, across relatively small spatial scales. This sometimes caused a particular resource limitation to be exacerbated in a particular area; however, issues related to water (e.g., drought/rainfall and irrigation) were the resource limitations most often voiced by farmers across the areas investigated.

To cope with these constraints, Ethiopian farmers utilize a variety of farming practices, crops, and crop varieties to produce food and generate income on small landholdings. These farming practices included the production of perennial cash crops (i.e., khat), the ratooning of sorghum, intercropping, pest and weed control, and livestock production. Farmers frequently discussed changing weather patterns and erratic rainfall as deviating from the historical bimodal rainfall patterns of the region. In another coping strategy, farmers frequently altered farming practices on-the-fly, deviating from what might be considered the normal crop calendar to take advantage of rainfall events and soil moisture or to guard against the possibility of drought and pest outbreak.

Among the farmers interviewed, sorghum was a culturally significant food crop important for food security. Sorghum was utilized in the home to produce several types of food items, although its use in certain foods (i.e., injera) was not necessarily preferred. Farmers utilized many varieties of sorghum and alternated between *long-season* and *short-season* varieties depending on rainfall timing and magnitude. Farmers explained that they obtain food, fodder, fuel, and fabrication material from sorghum plants. Some farmers explained that utilizing sorghum's ratooning abilities enhances livestock fodder production and can produce additional grain for human consumption. These farmers cautioned that adequate soil moisture was necessary for successful sorghum ratooning. Farmers also discussed how livestock grazing and bird damage often limited the success of ratooning sorghum in a perennial-like system that extended beyond the normal crop season. Some farmers suggested that encouraging multiple farming communities to utilize the practice might disperse bird damage and encourage livestock control during the off-season. Some farmers discussed their participation in a government program known as Integrated Seed Sector Development (ISSD) project to produce certified seed and enhance farmer income through its sell at a premium. ISSD personnel monitored farmers' and certified crops by working with farmer associations and communities to organize farmers to cooperatively produce seed thus preventing cross-pollination.

The research presented in Chapter 3 indicates that Ethiopian sorghum farmers possess *contributory expertise* (Collins & Evans, 2002) relevant to the ongoing development of perennial/ratooning sorghum for smallholder contexts. Through recognizing this expertise and the expert status of smallholder farmers it is hoped that their intellectual property rights (IPR) might be better protected.

Overarching Recommendations

The following recommendations are suggested to facilitate the continued development and future diffusion of perennial/ratooning sorghum technology to benefit smallholder farmers; specifically, those smallholder farmers in the major sorghum producing regions found in and around the Hararghe zones of eastern Ethiopia. The following italicized list of six recommendations for stakeholders in the ongoing innovation process of perennial/ratooning sorghum build on each other to assist benefit realization and allocation.

1) Enhance awareness of and reflection on the pre-analytic choices of the perennial paradigm among stakeholders and how these limit the types and directions of agricultural technology development. Myopic focus on technologies considered "perennial" may exclude the development of other possibly more beneficial technologies for smallholders. Examples include enhanced ratooning sorghums or sorghums in symbiotic relationships with microbes that fix nitrogen and increase phosphorus availability. An early commitment to the development of perennial technologies and their assumed benefits may once again lead agricultural scientists to not recognize the reality of smallholder farming contexts and continue a pursuit of technologies unsuitable to smallholders' situations or that do not address primary causes.

2) Consider the ways in which the diverse knowledge systems and worldviews of stakeholders to the development and diffusion of perennial technologies may contribute to gaps in communication and understanding and how these might be bridged. Those involved in the ongoing development of perennial/ratooning sorghum, and the perennial paradigm as a whole, should explicitly pursue an effort to build effective communication among stakeholders and acknowledge diverse perspectives and ways of knowing. This necessitates an interdisciplinary approach that includes expertise from fields such as communication, an ongoing evaluation to monitor progress, and new research on how to achieve the bridging of physical and philosophical gaps. Also, allowing for more international experience and interaction between all stakeholders to this effort could facilitate the co-production of knowledge and technology.

3) Consider how perennial sorghum projects in smallholder contexts might be designed to include addressing farmers expressed needs beyond improved crop varieties, such as access to resources and enhanced prospects for opportunities beyond smallholder farming. Despite perennial/ratooning sorghum's potential to survive under adverse conditions, its adoption will not guarantee grain production under extreme drought conditions or provide opportunity beyond a continuation of smallholder farming livelihoods. Effective program development and ongoing evaluation can help assess stakeholder's needs, design projects, and monitor outcomes as they occur so that mutually identified goals can be obtained.

4) Utilize a collaborative effort to develop multiple perennial/ratooning sorghum(s) for smallholder farmers. The continued development of perennial/ratooning sorghum and the interaction of farmers and scientists is likely to occur as one of two types of participation in the innovation process: consultative or collaborative (Johnson, Lilja, & Ashby, 2003; Lilja & Ashby, 1999). Through consultative participation, farmers' knowledge and experience is extracted and utilized how scientists see fit; whereas, the collaborative process combines the knowledge and experience of both scientists and farmers and shares decisive agency. Collaborative participation can result in the co-production of knowledge and technology in a process contrary to the majority of past agricultural technology development efforts.

To mitigate risk and adapt to a variety of needs and circumstances smallholder farmers utilize a varietal portfolio. Sorghum is a multi-use crop for smallholder farmers who obtain food, fodder, fuel, and fabrication material by utilizing more than just the plant's grain. These various uses are prioritized in different regions often under varying environmental conditions. More than one type of perennial/ratooning sorghum would enhance farmers' options and add to this portfolio.

5) Develop an appreciation of the improvisational nature of agriculture to better understand the effects of perennial crops on farmers' strategies, especially in farming contexts marked by relatively high uncertainty and risk. Working with farmers in a collaborative effort will entail crossing the physical and philosophical gaps mentioned earlier and necessitates challenging the predominant ways agriculture is seen by most agricultural scientists: a well-thought-out and adhered to plan. In reality, farmers must improvise in the face of constantly changing situations, including everything from erratic rainfall to existential threat. Not having too much invested in any one undertaking and having the flexibility to make adjustments on-the-fly is essential.

6) Recognize the expertise and expert status of Ethiopian smallholder farmers during the development of perennial/ratooning sorghum and protect the intellectual property rights (IPR) of these farmers and communities. Smallholder farmers are the experts at smallholder farming. Ethiopian farmers, like those interviewed in Chapter 3, have developed vast knowledge and experience related to the production of sorghum for millennia. They have produced and maintained numerous varieties of sorghum during that time, which represent a source of germplasm that can be used to develop additional improved varieties of annual, ratooning, and/or perennial sorghums. An important direction for future research is the continued cataloguing of these varieties and wild relatives focused on their ratooning and perennial traits, as well as a more in-depth study of farmers' use of ratooning and perennial-like sorghum systems. However, protection of the IPR of these farmers is essential and likely necessitate the creation of new ways to share and return benefits—financial and otherwise—from the development of sorghum technologies using farmer varieties and knowledge to farmers and their communities.

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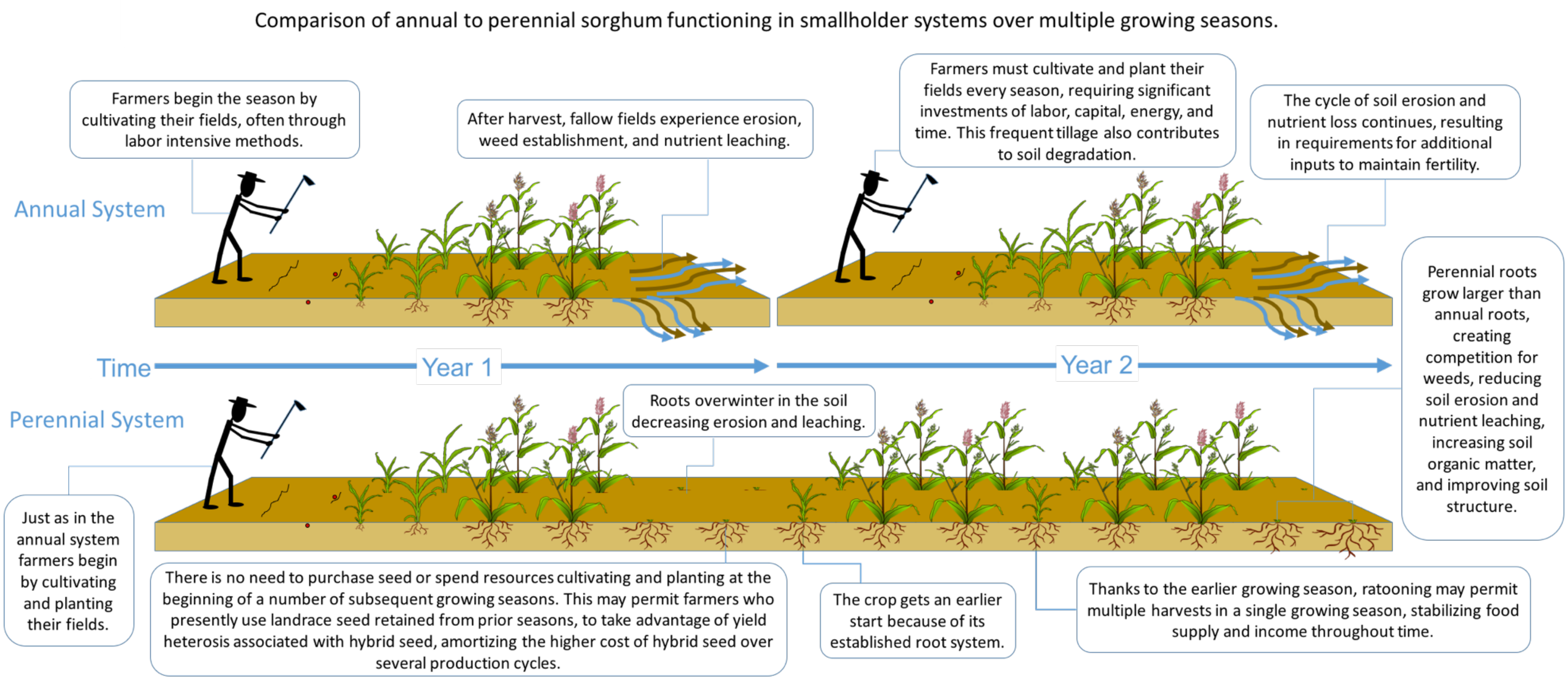
APPENDIX A

Model Summarizing Benefits Suggested in the Literature on Perennial Sorghum for Smallholder Farmers



APPENDIX B

Information and Consent Form for Interview

I agree to participate in a research study titled "The Appropriateness, Acceptability, and Potential Barriers to the Introduction of Perennial Sorghum into the Context of Resource-Poor African Farmers of the Semi-Arid Tropics," conducted by Justin Brooks, graduate student from the department of Agricultural Leadership, Education, and Communication at the University of Georgia (ALEC-UGA) (ty1707@uga.edu; 720-400-1213), under the direction of primary investigator Dr. Maria Navarro, UGA Associate Professor (mnavarro@uga.edu; 706-583-0225).

My participation is completely voluntary; I can refuse to participate or stop taking part at any time without giving any reason, and without penalty or loss of benefits to which I am otherwise entitled. If I decide to stop or withdraw from the study, the information collected from or about me up to the point of my withdrawal will be kept as part of the study and may continue to be analyzed, unless I make a written request to remove, return, or destroy the information. Written requests can be mailed to: Justin Brooks c/o Maria Navarro, 131 Four Towers Building, UGA Campus, Athens, GA 30602-4355. Requests can also be emailed to: ty1707@uga.edu or mnavarro@uga.edu.

To contribute to this research, I am a researcher with knowledge and experience pertaining to perennial grains, their development, and/or their growth and production systems; or I am an extension or change agent with experience and knowledge related to resource-poor, smallholder farmers in the African semi-arid tropics and/or the agricultural context of this region. I must be at least 18 years old in order to be eligible.

Purpose of Research:
The purpose of this research is to identify the potential barriers to the introduction and adoption of perennial sorghum, as well as the relative appropriateness and acceptability of perennial sorghum to smallholder farmers in the context of the African semi-arid tropics. This research will also seek to identify potential key stakeholders to the diffusion of perennial sorghum in this context.

Potential Benefits:
I will not directly benefit from this research; however, the results of the study may be used in the advancement of existing and future agricultural development projects that seek to benefit smallholder farmers in Africa and potentially build cooperation and understanding between key stakeholders.

Procedures:
If I volunteer to take part in this study, I will be asked to participate in an interview that will last approximately 30-minutes to an hour—depending on my preference and availability—answering

open-ended questions about my experience, expertise, and views about perennial sorghum—and perenniality in general—and its use in agricultural development within the context of smallholder farmers in the African semi-arid tropics. A copy of the interview questions is attached for my review. There is a possibility that I may be contacted by the researcher for an additional 15-minute interview for follow-up questioning for clarification or elaboration purposes only.

If I participate in the interview, the conversation will be audio-recorded unless I state otherwise. The interview will be conducted face-to-face, telephone, or via Skype or other video/audio-chat technology, depending on my or the researcher's preference, location, and availability.

Discomforts or Stresses
No discomforts or stresses are expected.

Risks
No risks are expected

Confidentiality
My identity will be kept confidential to the extent provided by law. My name and identifying information will be kept confidential and will not be reported unless I verbally indicate that I grant permission for my identity and the results of this participation to be made public. My identifying information will only be used if follow-up questions are needed, unless I agree to public participation. Public participants' contact information will be kept confidential, and will not be published.

All audio-recordings will be transcribed/analyzed and then destroyed or modified to ensure participants cannot be identified, unless I agree to public participation. I can request access to the transcription or recording by contacting the researcher.

If I participate in an interview via online audio/video chat technology, I understand that Internet communications are insecure and there is a limit to the confidentiality that can be guaranteed due to the technology itself. However, once the researcher receives materials, standard confidentiality procedures will be employed.

Further Questions
The researchers Justin Brooks, assistant researcher, and/or Dr. Maria Navarro, Principle Investigator, will answer any further questions about the research, now or during the course of the project, and can be reached by email (ty1707@uga.edu; mnavarro@uga.edu), or telephone at: 720-400-1213 or 706-583-0225).

Additional questions or problems regarding your rights as a research participant should be addressed to: The Chairperson, Institutional Review Board, University of Georgia, Telephone: (706) 542-3199; E-Mail Address: IRB@uga.edu

APPENDIX C

Semi-Structured Interview Protocol: Researchers and Change Agents

The purpose of this interview is to obtain your perspective on the opportunities and barriers to diffusion, as well as the relative appropriateness and acceptability of a perennial variety of sorghum and the associated cropping and farming system for the lives of resource-poor, smallholder farmers in the context of the African semi-arid tropics. This interview also seeks to understand any relevant experience, knowledge, and ideas you have that may be useful to this research. To obtain an accurate record of your answers this interview will be audio recorded.

[Top question is asked first, and sub-questions are used as needed to probe further for additional information.]

1. CONFIDENTIALITY CONSENT: If you are willing, we would like to be able to use your name and professional affiliation to attribute your comments to you as an expert in your field—your contact information will not be disclosed. However, you can choose to participate confidentially, and a pseudonym will be used in all materials and any identifying information will be altered. We cannot guarantee that other individuals working in your field will not be able to deduce that you participated in this research because of the relatively small community of practitioners involved in these fields. Do you grant permission for your identity and results of this participation to be made public?

2. BACKGROUND AND EXPERIENCE [If interviewee is in the Change Agent category use bracketed inserts]: I would like to begin with some background information related to your experience with perennial grains [farmers]. What is your job title and organization?

a. What is the nature of your work with perennial or ratooning crops [farmers]?
b. How long have you been working with sorghum (other grains and/or perenniality) [farmers]?
c. Could you tell me how you got involved working with perennial sorghum (grains/crops) [farmers]?
d. Have you been involved with related work in the past? How does that work compare with the work you do now?
e. (For Researchers) Do you have experience with farmers or extension agents? Could you please describe this experience?
f. f. (For Change Agents) What is your experience with the researchers tasked with developing agricultural innovations? How familiar are you with the development of perennial sorghum (grains) for use by farmers?
g. I am interested in understanding how perennial sorghum might affect farmers living in the context of the African semi-arid tropics and in particular resource-poor, smallholder farmers. How you would you describe these farmers? Do you have experience working

with these farmers? Could you tell me about this experience?

3. PERENNIAL PRODUCTION SYSTEMS: Do you have experience and/or knowledge related to the planting, growing, and harvesting of perennial crops (sorghum/grains)?

a. [If relevant] Approximately how much experience? Could you tell me about this experience and how you were involved?
b. How does growing perennial crops differ from growing annual crops?
c. Would there be differences in the planning and regular tasks required throughout the growing season in a perennial vs an annual system? What and how?
d. What resource investments are required in the establishment and subsequent growth and maintenance of perennial crops (sorghum/grains)?
e. Are there special or specific knowledge, skills, and/or tools needed to grow these crops successfully?
f. What might an ideal perennial production system look like? What metrics do you believe are useful for determining success in a perennial cropping system?
g. What would be the benefits of this system (and crop) compared to annual production system and crop? What would be the challenges?
h. [If they have specific knowledge of perennial sorghum] What specific issues would a farmer face when growing perennial sorghum?

4. AGRICUTURAL DEVELOPMENT: What is your experience with agricultural development?

a. [If relevant] What countries have you worked in? Could you describe some of your experiences with this work?
b. [If relevant] What would you say you have learned through this work? Biggest success? Biggest failure?
c. Has your approach to or understanding of agricultural development changed over time? How?
d. What need(s) do you think perennial grains (sorghum) address in agricultural development and in the lives of farmers, especially in the context described?
e. What do you think are the most important issues and needs agricultural development should seek to address?

5. AFRICAN CONTEXT: Do you have experience or knowledge about farming in the semi-arid tropics of Africa?

a. Do you have experience working with extension workers or farmers in this region or others? If so, could you describe your experiences with these individuals and/or communities?
b. Can you give me one or two examples within this context (or other context) that you would consider a successful agricultural development project/innovation? Why do you believe they were successful?
c. Can you think of an example of an agricultural development project/innovation in this context (or other context) that you consider unsuccessful? Why?
d. Are you aware of any other perennial crops currently being grown in the African semi-arid tropics? What and how? Are there unique issues associated with these crops and directly related to their perenniality? To your knowledge, how would growing perennial sorghum compare to these crops?

e. From your perspective, what qualities and traits would perennial sorghum need to be a successful crop in this context? Do you think that these farmers might use different qualities and traits to evaluate perennial sorghum? (If there is a difference)
f. Why do you think your evaluation and the farmer's evaluation methods differ?
g. What do you think would be appropriate strategies to introduce perennial sorghum (or other perennial grains/crops) to the farmers in this context? (If you don't think this introduction is a good idea, why?)
h. If the introduction and adoption of this innovation were successful, what do you think would be possible impacts? (If this is overly positive, ask about negatives and vice versa.)
i. What, to your knowledge, is the most pressing need of farmers in this context? How do you think perennial sorghum (grains) relates to or addresses this need?
j. Who do you think would important to involve in the introduction and diffusion of perennial sorghum in this context? Who do you think are the important individuals or groups to consult when planning to introduce this type of innovation in a community?

6. CULTURAL AND SOCIAL EFFECTS AND RELATIONS: How do you think the cultural and social lives of these individuals, including women farmers, would be affected by this innovation's introduction and diffusion?
a. What about the larger scale effects on the communities/region where the introduction and adoption of perennial sorghum (grains) would take place?
b. Based on your experience, could you describe the relationship between (women) farmers and (change agents/extension agents/experts)?
c. How do you think the relationship between these experts and (women) farmers could be improved?
d. We often cite impending environmental problems, such as climate change, as reasons for this sort of agricultural innovations introduction. What do you think these farmers think about these environmental problems? Do you think that there are social factors that affect this?
e. What other barriers to the introduction and adoption of perennial sorghum (or other perennial grains/crops) can you into this context?
f. [Use this list to stimulate thinking on topics not already mentioned:]
    1. Land tenure and perenniality (land tenure in general)
    2. Gender labor divisions and other gender issues
    3. Education needs/issues
    4. Biotic and abiotic conditions and constraints—pests and diseases, etc.
    5. Acceptability by these farmers
    6. Appropriateness for these farmers
    7. Scalability
    8. Market accessibility
    9. Extensive vs intensive agriculture
    10. Desirable or undesirable varietal traits
    11. Others?

7. CLOSING: Is there any other information that you would like to share with me before we end the interview?

APPENDIX D

Open-Ended Questionnaire Instrument: Researchers and Change Agents

The purpose of this questionnaire is to obtain your perspective on the opportunities and barriers to diffusion, a well as the relative appropriateness and acceptability of a perennial variety of sorghum and the associated cropping and farming system for the lives of resource-poor, smallholder farmers in the context of the African semi-arid tropics. This questionnaire also seeks to understand any relevant experience, knowledge, and ideas you have that may be useful to this research. If you feel any of these questions do no apply to your area of expertise, feel free to skip that question.

1. CONFIDENTIALITY CONSENT: If you are willing, we would like to be able to use your name and professional affiliation to attribute your comments to you as an expert in your field—your contact information will not be disclosed. However, you can choose to participate confidentially, and a pseudonym will be used in all materials and any identifying information will be altered. We cannot guarantee that other individuals working in your field will not be able to deduce that you participated in this research because of the relatively small community of practitioners involved in these fields. Do you grant permission for your identity and results of this participation to be made public?
2. What is your job title and organization?
3. What is the nature of your work with perennial and ratooning crops and/or with resource poor, smallholder farmers?
4. Could you please describe your experience working with extension/change agents and/or farmers? [If you are an extension/change agent, could you describe your experience with researchers and farmers?]
5. This questionnaire is particularly interested in resource-poor, smallholder farmers living in the semi-arid tropics of Africa. How would you describe these farmers?
6. What do you think would be the benefits of a perennial crop and production system when compared to an annual production system and crop?
7. Could you please explain what you think would be some of the specific challenges when growing perennial sorghum or another perennial grain in this context?
8. What needs do you believe perennial grains, like sorghum, address in agricultural development and in the lives of these farmers?
9. What do you think would be appropriate strategies to introduce perennial sorghum (or other perennial grains) to the farmers in this context? (If you don't think this introduction is a good idea, why?)
10. What might be some specific challenges/barriers to the successful introduction and adoption of perennial sorghum in this context?
11. What do you think would be the impacts of the introduction and diffusion of perennial sorghum within this context?

12. Who do you think would be important to involve in the introduction of perennial sorghum in this context?
13. What traits, qualities, characteristics, etc. would you use to evaluate the successfulness of perennial sorghum in this context?
14. What methods might a farmer in this context use to evaluate the relative success of this crop? (If there is a difference between your evaluation methods and the farmer's, why do you think these evaluations differ?)
15. Please feel free to provide any additional information or comments that you think is relevant to this research and potential diffusion efforts of perennial sorghum into the context of these farmers.

APPENDIX E

Semi-Structured Interview Questionnaire for Farmers:
Casalee- gafii fi debisaa qonnaan bulaf dhiyatuu:

Tell me about your farm.

- Wa'ee oyruu ketii natii himi:

1. How long have you/your family been here? What do you produce? Who lives/works here and what do they do throughout the year? Tell me about what you do and who helps you? Have you ever paid/exchanged goods/work with anyone to help you in the farm?
   - Yeroo hangam takaf atii/matin kee as turtan?; mal omishtuu?
   - Enyutuu lafaa kana/ edo kana jirata/ hojata, waga guttuu mal hojacha jiratu?
   - Mal akka hojatu nati himi?; Enyutuu sii gargara?
   - Kanan durati nama oyru kee sif hojatuf, kafaltidhan/jijiradhan hojasifte nii bekta?

What is the biggest need you have as a farmer?

- Aka qote bula tokotii wanii atii ira-calati barbadu mali?

1. What do you think would be helpful to address this need?
   - Wan barbade san arkachuf, mal yoo tahee garidha jetee yadda?
2. What is the biggest issue you and your family face?
   - Wanti ijoon /guddan akka rakotii sifi matii kee mudatee malii?
3. What about your community?
   - Hawassa nanno ketii hoo?

Possible follow-up questions:

How about changes in the land since you have been farming it?

- Ergaa atii qotuu egalte jijiramni lafaa kana iratii mulate mali?

2. Tell me about soil. Do you have any type of soil or water problems?
   - Wa'ee biyee kanaa natii himii. Rakoo biyee ykn bishani sii mudate nii qabda?
3. Tell me about the weather and rainfall here. Has it changed over time? How?
   - Hala qillensa fi robaa nanno kana naf ibsii. Yeroo fi yeroo tii nii jijirama? Akamin jijirama?

How do you decide what you are going to grow each year? Tell me about…

- Maal akka qotuu qabdu wagga wagga dhan akamin murteysita ykn tilmamata? Wa'e sanii balilan naf ibsii?.

1. What other crops have you grown?
   - Dabalatan midhan gosaa kamii qotaa?
2. Have you ever grown any perennial crops?
   - Kanaan duratii midhan waqtii lamaf turuu/ hamaa waga tokko turuu qotee bekta?
3. How do you get the seed for your crops?

    - Shanyii midhan qotuu eysaa arkata?
4. Have you ever acquired seed from private companies, NGOs, or government agencies?
    - Kanan duraa sanyii midhanii dhabbata dhunfa, dhabbata mitii motuma ykn dhabbata motuma iraa arkate bekta?

Have you ever grown any sorghum?

- Kanan dura gosaa Bishinga kamiyu qotee bekta?

1. What do you use the sorghum you grow for?
    - Midhan bishinga qotuu kana calla ykn omisha isaa akkaam gotaa?
2. What do you do with it after you harvest it? (processing, storage)
    - Yeroo omishtee bodaa akkam gotaa? (mall itti fayadamtan, mal gota, moo nii kufataa?.
3. What is challenging about growing sorghum?
    - Bishinga qotuuf rakkon isin mudatuu malii?
4. How do you manage weeds and pests on your farm and in your fields?
    - Wantotaa akaa harammaa fi ilbiisota ykn dhukuba oyruu teeti fi eddo ketira akamin ittifta?

Do you use any fertilizer or sprays for your crops?

- Xa'oo ykn dawalee bifamuu kamiyuu midhan ketif nii fayadamta?

1. What kinds of fertilizer and sprays do you use?
    - Yoo Fayadamta tea'e; Xa'oo gossaa kam? Dawa bifamuu gosaa kam?
2. If so, where do you get your fertilizer and/or sprays from?
    - Yoo arkata ta'e, Xa'oo ykn dawa bifamuu san eysa arktaa?

Do you raise any animals on the farm?

- Horii kamiyuu nii gudifta oyruu ketiratii?

1. Do you or others graze animals at any time of year in the fields where you grow your crops?
    - Horrin kee ykn kaan nama birra lafaa atti qotuu ykn oyruu kee keysa dhedde nii bekaa, wagatii yeroo kamiiyuu ykn yeroo fedhetii?
2. (If they have animals) How do you meet the animal's food needs throughout the year?
    - Horii yonif qabatee, akamiin nyata isaan barbadan wagaa gutuu nyachisuu dandeysa?

Do you sell any of the crops that you grow?

- Midhan atti qotuu kana keysa, tokolee kan gurgurtuu nii qabda?

1. Where or to whom do you sell your crops?
    - Eysatii ykn enyuf gurgurta midhan kee?
2. How do you determine what is a good price for your crops?
    - Akamiin gatii garii omishaa ketiif ta'uu baruu dandeysa?
3. (If they sell sorghum) What do the people who buy your sorghum use it for?
    - Bishingaa kan gurgurtuu yoonif ta'e, namnii isiniraa bituu san mal itii godha ykn faydaa maliraa olchaa?

Do you have any contact with university researchers or development agents? How did you get in contact with them?

- Waraa University keysa qoranoo gageysanii ykn oggeysa missoma qonaa wajin-hariroo ykn walitii hidhata nii qabduu?
- Akamiin hariro kana umuu dandeysaan?

1. What sort of information or assistance do they provide you?
   - Odeyfanoo gosaa akamii ykn gargarsaa akamii siif dhiyesuu?
2. Do you belong to any farmer organizations? (If yes) What benefits do you receive as a member?
   - Missensa waldayale qonnan bulla tokkolee keysa nii jirta? Yoo jirataa ta'e, akka misensatii faydan atii iraa arkatuu mali?
3. Where or to whom do you go to find out new information about farming?
   - Wa'e qonaa keettii ykn akata itiin qotaan oddefanolee haraya eysa arkata?

Do I have your permission to contact you again for a follow-up interview (no more than 30 minutes) if I need clarifications?

- Debi'ee sii arkachuf naf hayamtaa, iraa debine marii kenyaa hordofuf (daqiqqa 30 kan hin caleef) oddefanoo balaa'a yonin barbade?

Thank you!
Galatomaa!