Abstract

During the 1990s many Southern African governments liberalized their seed markets. This move initiated an influx of hybrid-maize seeds onto markets through greater involvement of private seed developers. Since then the number of varieties of hybrid seeds has grown considerably. Using an institutional analysis framework, we illustrate the complex system of actors and feedbacks that govern the seed certification process in Zambia. We also examine how smallholder hybrid-seed use has changed over the last decade. We find the Zambian seed certification system allows for frequent certification of new varieties each year without much scrutiny of seed use and performance by smallholders. Smallholders face a complex challenge in selecting seeds due to inconsistencies between the potential yields cited during the seed certification process and the reported yields of smallholders. This inconsistency jeopardizes the goal of food security sought after by both smallholders and policymakers.

1 Introduction

Maize is a vital crop for smallholders throughout Southern Africa. It is the predominant cereal crop in terms of area under production (Smale et al., 2013), and accounts for over 50% of the region's calories (McCann, 2005). As a result of the prevalence and dominance of maize in the region, acknowledgement and consideration of the role of maize is now central to any discussion of regional agricultural development or food security (Shiferaw et al. 2011).

Three primary categories of maize seed are grown in Southern Africa: hybrid, open-pollinated (OPV), and local varieties (Hoogendoorn et al., 2018; Lunduka et al., 2012). Hybrid and OPV varieties are the result of modern breeding techniques, while local cultivars persist through the efforts of farmers (Fisher et al., 2015). Hybrid-maize has the agronomic potential to achieve higher yields and mitigate climate change variability through improved tolerance to prolonged dry periods and shorter growing season duration (Smale & Jayne, 2003; Tester & Langridge, 2010).

Hybrid and OPV varieties in Southern Africa are most often developed by private seed developers, but this has not always been the case in the region. Historically, seed breeding in Southern Africa occurred at a fine scale, with breeders developing varieties for smaller, localized growing areas (McCann 2005; Lynam et al. 2010). However, in the mid-1980s private seed companies began to gain more influence and market share in the region.

The influence of these seed companies increased further in the early 1990s as a result of pressure applied by the World Bank and the International Monetary Fund through structural adjustment programs. Institutions implemented structural adjustment programs in order to decrease government involvement in a number of sectors, while increasing private investments in the same sectors (Kassie et al., 2013; Sitko, 2008; Smale et al., 2013). These changes pushed

policymakers across the region to open national markets and services to regional and multinational entities, including the manufacturing and sale of seed varieties (Smale et al. 2015; Smale et al. 2013; Mason et al. 2013).

FIGURE 1 HERE

Following structural adjustment, the number of companies involved in maize seed development increased 400 percent (Langyintuo et al., 2010). Now most countries have an array of seed companies operating within their borders (Figure 1). The role of multinational companies has expanded further within the past few years as multiple mergers pair large-scale agrochemical firms with seed developing firms at the regional and global level (Bonny, 2017). These mergers created an environment in Southern Africa where seed development is primarily the work of large multinational agri-business firms.

Researchers and policymakers view improved seeds, specifically hybrid varieties, as an important component of improving production and food security (Bonny, 2017; McGuire & Sperling, 2011). The development and use of improved maize seed in small-scale farming systems throughout Southern Africa is done in order to emulate the gains of the 'Green Revolution' that took place in Asia during the 1960s and 1970s. Asia's Green Revolution enabled smallholder farmers to access and cultivate improved varieties of staple crops including wheat and rice, developed through modern breeding techniques (Borlaug, 2000; Evenson & Gollin, 2003). Developments in improved germplasm and chemical inputs are widely considered to be the driver of Asia's Green Revolution and have largely motivated the agricultural policy environment in Africa (Jayne and Rashid 2013; Crawford et al. 2003). The emphasis on improved germplasm and inorganic fertilizer is predicated on the belief that if smallholders can intensify their production and improve yields, they can improve food security. Improvements to

yield will theoretically lead to a production surplus and smallholders will then have the opportunity to sell their surplus on the open market. The influx of supply will then decrease pan-territorial market prices making grains more affordable for net buyers.

In order to achieve this, Southern African policymakers often pair privately developed hybrid-maize varieties with publicly supported rural development initiatives to support widespread adoption. This type of public-private partnership appeals to Southern African governments, because it allows the cost of seed development to be incurred by private firms rather than national governments. National governments will maintain this initiative so long as affordability of the technology does not exclude it from widespread distribution (Crawford et al., 2003). In Zambia, this initiative of public-private partnership is largely carried out through the Farmer Input Support Programme (FISP).

FISP is a large-scale government funded agricultural-input subsidization program first introduced in 2002 that provides subsidized inputs for hundreds of thousands of smallholders nationwide (Mason et al., 2013). FISP is one of the most substantial outcomes of the public-private partnership. FISP bolsters hybrid-maize variety adoption in Zambia by drawing smallholder farmers into the hybrid maize seed market through seed and fertilizer subsidization (Hoogendoorn et al., 2018). The use of hybrids and OPVs by Zambian smallholders is higher than the regional average at roughly 70% of all maize area planted (Langyintuo et al., 2010), largely a result of FISP (Smale et al., 2015). Previous research states the influence of subsidy programs in neighboring Malawi swayed the national seed balance from OPVs to hybrids over the last decade and a half (Hoogendoorn et al., 2018; Kassie et al., 2013). Public-private initiatives such as FISP provide private seed developers a growing market demand for agricultural technologies, and a policy environment that connects smallholder farmers with

improved seeds.

Despite the extensive research on the agronomic potential of hybrid-maize seed and government initiatives that support its development and dissemination, little research exists investigating the role of national seed certification in the adoption of seed varieties by smallholder farmers. Zambia provides an ideal case study due to the high prevalence of hybrid maize use in the country.

Smale et al. (2015) note how remarkable it is that a country with as small of a population as Zambia is the center of regional breeding activity. As a result of the importance of Zambia to regional breeding, more multinational firms are prevalent in Zambia than other neighboring nations. As a result, the development and testing that occurs in Zambia has implications for agricultural systems elsewhere in Southern Africa. We focus on Zambia as a means to contextualize seed development in the region due to its centrality in the seed industry of Southern Africa. Through examination of the hybrid-maize seed certification process in Zambia, we demonstrate how various institutions influence current maize production outcomes; including a greater number of varieties, widespread use of hybrids, and highly varied seed performance.

2 Materials and Methods

Institutions are constructed by humans to create order and provide opportunities to make individual choices and form outcomes from those choices (McGinnis, 2011; North, 1991). National policies and relationships between actors are both examples of institutions that can influence seed-related outcomes (Akpo et al., 2014). The adoption and widespread use of hybrid-maize seed by smallholder farmers is a product of the institutional environment that drives seed availability through standards, protocols, and rules in use. As a result, studying the national seed certification system as an institution will aid our understanding and contextualization of the

factors that contribute to seed certification and seed adoption.

We present an institutional analysis that builds on the foundation of the Institutional Analysis and Development (IAD) framework, which was developed to explain how institutions operate and change over time (McGinnis, 2011; Ostrom, 2011). We use the New Institutional Analysis of Social-Ecological Systems (NIASES) framework (Cole et al. In Review) to motivate our research into the role of institutional actors on seed use outcomes within Zambia (Figure 2). We acknowledge other mechanisms may be used in order to analyze this institution; however, the ability of the framework to contextualize the role of actors and processes within the system makes it highly useful in our investigation. The NIASES framework highlights the complex institutional arrangements and the role of actors, types of interactions, and environmental attributes of the system. These factors interact within the action arena of the framework - the social space where actors provide feedback to one another through evaluation efforts and institutional interactions (Ostrom, 2011).

FIGURE 2 HERE

We use a mix of quantitative and qualitative data in this analysis in order to understand how the seed certification system has functioned as an institution and affected change over time. Our investigation of the seed certification system in Zambia uses hybrid-maize varietal information from SCCI's 2015 Seed Catalog and seed company publications made available within Zambia. The SCCI seed catalog records the developer and year of certification for each variety since 1960. To examine smallholder use of hybrid-maize seed varieties by Zambian smallholders we use CFS collected by CSO from the 2004 – 2005 (2004/05) growing season to the 2013 – 2014 (2012/13) growing seasons. The CFS is administered annually during the middle of the growing season to about 13,000 small- and medium-scale farmers in Zambia.

Beginning in the 2004/05 growing season, CFS questionnaires included a section about specific maize varieties planted by farmers but prior to that growing season, CFS did not contain maize variety information.

In this analysis, all varieties listed in the CFS datasets are categorized using maturity classifications derived from information provided by the respective developer of each variety. We use the same classification as the Zambian Variety Release Committee (VRC), the committee of mixed stakeholders responsible for evaluation of new seeds, and group hybrid-maize varieties into three distinct classifications: early, medium, and late. In instances where a seed company lists a variety as in between maturity categories we use the earlier of the two classifications. For example, a variety described as 'medium to late' is considered to be a medium maturing cultivar. Few varieties fall within this combined maturity classification. Only varieties developed for domestic production are taken into account.

We also use in-depth key informant interviews with seed developers, distributors, and regulators at different levels of the seed development and certification process to provide both context, as well as insights into the growth of the Zambian hybrid-maize seed industry. The identities of all key informants are anonymous in order to ensure privacy.

2.1 Key actors in the seed certification process

Zambia's seed certification system is comprised of actors that participate in the development, evaluation, certification, and distribution of hybrid-maize seed varieties (Table 1). The first column of Table 1 lists the organizations that maintain positions as actors within Zambia's seed certification process, and the second column describes the function played by each organization.

Table 1. Actors Within Zambia's Seed Certification Process.

Actors	Function
Zambian Agriculture Research Institute (ZARI)	● Develop improved seed varieties for use throughout Zambia
Seed Control and Certification Institute (SCCI)	● Test and certify seeds
Farmer Input Support Programme (FISP)	● Dissemination of hybrid seed varieties
Eight Private Seed Developers: Domestic, regional, and multinational in scope	● Develop seed varieties for use throughout Zambia and Southern Africa ● Apply for seed release through the Variety Release Committee ● Replicate and market seed varieties
Variety Release Committee: Stakeholders from industry, government, higher education	● Review seed application ● Determine suitability of seed Distinctness Uniformity and Suitability (DUS) ● Determine Value of Cultivation and Use (VCU)
Public and Private Agricultural Extension Officers	● Create and maintain variety demonstration plots
Agricultural Input Dealers and Non-Governmental Organizations (NGOs)	● Distribution of seed varieties to smallholders through traditional

	purchasing or program implementation
Farmers	• Selection of varieties for cultivation

Zambia's Ministry of Agriculture (MOA) develops seeds through ZARI, certifies seeds through SCCI, and encourages seed dissemination through the FISP. MOA also supports smallholders through the funding of public agricultural extension officers at the local level. Public agricultural extension officers create demonstration plots on their own or through partnering with private agricultural extension officers to showcase how different maize varieties perform under local growing conditions.

In addition to ZARI, the University of Zambia and the International Maize and Wheat Improvement Center also develop new varieties of hybrid-maize, but the majority of hybrid-maize seed development in Zambia takes place through the efforts of eight private seed developers. Structural adjustment allowed private seed developers to set the pace and direction of seed breeding activities. While OPVs play larger roles in other African countries, their market share in Zambia continues to be reduced in favor of hybrids (Seed Regulator A Personal Communication 22 May 2016). As the Zambian seed industry has developed, hybrid-maize seeds have consumed the majority of time, money, and breeding expertise allocated by seed producers (A. Seed Breeder, personal communication, May 23, 2016).

The majority of hybrid-maize varieties are developed by large multinational agribusiness corporations (B. Seed Breeder, personal communication, June 6, 2016). The current maize seed market in Zambia is comprised of 8 key companies, with varying levels of market share (Table 2) (B. Seed Distributor, personal communication, August 15, 2016). Private seed developers

differ in geographic scope, with some firms operating domestically, some regionally throughout Southern Africa, while others are multinational and global in scope. Multinational seed developers are typically subsidiaries of larger international agribusinesses from outside the African continent.

Table 2. Top 8 seed developers currently working in Zambia and their market share during the 2013/2014 agricultural season (CFS 2013/2014).

Company	Market Share Percentage
Pannar	18.99%
Seed Co.	18.72%
MRI	8.15%
Zamseed	6.35%
Dekalb	3.48%
Pioneer	2.23%
Kamano	0.41%
Klein Karoo	N/A
Note: During the 2013/2014 agricultural season, Klein Karoo seed use was not recorded by CSO.	

In the certification process, the VRC is the final stage in the formal evaluation process. The VRC is comprised of stakeholders from the University of Zambia, Zambia National Farmers Union, SCCI, MOA, and the Zambia Small Scale and Peasant Farmers Association (Variety Release Committee 2012). The VRC meets every year during September to review Applications for Variety Release and determine whether the variety should be released or withheld.

The final group of actors in the seed certification process are the agricultural input

dealers, non-governmental organizations (NGOs), and farmers. Agricultural input dealers and NGOs interact with farmers during the marketing and selection phase of hybrid-maize varieties. We primarily focus on smallholders because this group comprises the majority of farmers in Zambia. About 1.3 million smallholder farmers cultivate maize in Zambia (Resnick & Mason, 2016).

The selection of varieties by smallholders involves past experiences, perceptions of weather and climate, and a complex decision environment (Waldman et al. 2017). As the adoption of varieties increases, seed developers increase their replication and marketing of preferred varieties. Seed developers phase out varieties as demand wanes or as replacement varieties with greater traits are developed.

2.2 The action situation and evaluative criteria

During hybrid-maize seed certification, seed developers present new varieties for certification, interact with governmental regulators at multiple levels, and provide and receive information for the evaluation of new varieties iteratively through formal feedback loops that occur in the action situation. Feedback loops within the certification process allow actors the opportunity to provide information in order to evaluate the effectiveness of the institution at achieving its mandate. The seed certification system in Zambia features multiple stages of feedback for actors to evaluate new seed varieties in order to ensure productive seed certification, as well as maintenance of the system. Seed developers are able to acquire information from the formal regulatory process through three distinct feedback loops (Figure 3): initial development and internal review, testing through SCCI, and certification evaluation by the VRC.

The certification process of new varieties begins as seed developers identify desirable

traits for propagation. No formal timeframe exists for how long the variety development process takes, but typically four years are required for breeders to identify a line worth developing further (B. Seed Distributor, personal communication, August 15, 2016). If breeders feel the variety needs more work, then additional development through multiple seasons may take place or the variety will be withdrawn from further breeding consideration. Varieties that proceed beyond the internal review are then bred through an additional four to six years of field trials. Once completed the new variety is submitted to SCCI for agronomic field trials.

The guidelines used by SCCI for the evaluation of a new maize variety are a combination of technical plant breeding procedures adapted from European Union standards, registration guidelines from the Southern African Development Community (SADC), and nationally developed breeding protocols. This process ensures a standardized measure of testing all newly developed maize varieties. SCCI evaluates newly developed varieties at seven research sites throughout Zambia. Governmental trials test for the variety's distinctness, uniformity, and stability (DUS) and value for cultivation and use (VCU). DUS and VCU trials are carried out over a period of at least two years for nearly all newly developed varieties. VCU trials are designed to evaluate the agro-ecological suitability of each new variety at six research sites across the three distinct rainfall zones of Zambia. Two VCU trials are completed within each distinct rainfall area in Zambia. DUS trials test whether a variety is unique in at least one physiological trait from other cultivars, while also maintaining trait uniformity and stability. DUS trials are conducted under optimal farm management conditions near Lusaka. Both trial types ensure timely planting and fertilizer application, as well as weed-free growing conditions.

The second information feedback loop occurs when SCCI shares agronomic performance data with the seed developers from all trial stations following the two year trial period. Varieties

are not permitted to enter the commercial seed market without SCCI confirming the DUS and VCU of a variety. This part of the process is critical to ensuring the certification of viable cultivars and maintaining system sustainability but also provides seed companies with technical information about the strengths and weaknesses of the new variety.

FIGURE 3 HERE

After receiving feedback from SCCI, the variety moves to the final evaluative stage, which involves submitting an Application for Varietal Release to the VRC (Figure 3). The VRC determines whether a seed application will be accepted for release onto the commercial market or excluded from entering circulation. If a variety fails to meet national standards, the VRC will provide feedback to the breeder about why the variety failed to meet certifications standards (Figure 3). If rejected, the seed developer is permitted to address the weaknesses identified by the VRC and resubmit the variety for evaluation, or the seed developers will discontinue the line if it seems unlikely to meet the VRC criteria.

Although feedback loops are in place between seed system actors, the existing feedback loops do not meaningfully generate feedback to improve the system. Rather, the rules in place involve feedback about whether varieties meet performance standards used by regulators which do not reflect farmer preferences or needs. The current process evaluates the agroecological suitability at central research stations through VCU, but fails to reproduce field-level management conditions of smallholders, such as with participatory breeding methods (Witcombe et al., 1996). Without evaluating new hybrid-maize varieties on farmers fields, there exists a disconnect between how seeds are marketed and the average performance observed by farmers in Zambia.

Once approved, developed seeds may face a lag time of two years between final approval

and the initial stages of distribution for commercial use (Kassie et al., 2013). Once distributed, the purchase and use of hybrid seeds by farmers provides an informal avenue of evaluation beyond the regulatory processes of SCCI and the VRC, but is complicated by the nuances of farmer preferences and new technology adoption. Adoption of new varieties by farmers is not guaranteed, as farmers may exhibit a path dependency, favoring the use of long standing, known cultivars. Research shows farmers significantly discount the inability to replant hybrid seeds and this is an important barrier to adoption of other crops including rice (Ward et al. 2014) and sorghum (Waldman & Richardson, 2018). The higher input costs required by hybrids relative to OPVs is another significant barrier to adoption of hybrid seeds (Kassie et al., 2013).

Previous research identifies the inability of private firms to certify seed varieties across national boundaries as a barrier to the development of agriculture across Southern Africa (Kassie et al., 2013; Langyintuo et al., 2010). Over the last decade and a half, interest by stakeholders in harmonizing regional seed guidelines has grown. Harmonization of seed certification guidelines would allow companies to develop and release varieties more widely for greater adoption in Southern Africa (Smale et al., 2013), even beyond what has currently occurred as a result of structural adjustment. Under harmonized guidelines, only two of SADC's 15 member nations would need to certify a variety for use throughout all member nations (A. Seed Distributor, personal communication, June 6, 2016). Less stringent guidelines may lead to more favorable outcomes for seed firms in breeding and widely releasing varieties. Currently, there is a range of seed development across SADC nations, with some countries having multiple seed developers and others have none.

2.3 Biophysical conditions in Zambia

Changing climatic conditions are expected to impact agriculture globally, with

disproportionately more severe impacts on smallholders dependent on rainfed systems within tropical and subtropical regions (Mendelsohn, 2008; Vermeulen et al., 2012). Africa, more than any other continent, will be impacted by climate change induced droughts (Li et al., 2009). Under medium scenarios, the average annual temperature over much of the African continent is expected to increase by 2°C by 2050 (Barros et al., 2014). Increases in temperature, paired with decreased precipitation, will have detrimental effects on crop production in Southern Africa (Boko et al., 2007; Funk et al., 2008).

Seasonal precipitation patterns in Southern Africa are influenced by the movement of the Inter-Tropical Convergence Zone, an area of low pressure that roughly corresponds to the latitude where solar radiation is strongest in the tropics. The seasonal shift in solar radiation and subsequent atmospheric circulation creates two distinct seasons in the region: typically wet from November to March and dry from April to October (McCann, 2005).

Smallholder agricultural production in Southern Africa is characterized by repeated drought stress, and its effect can cause yield losses of 10 - 25% (CIMMYT, 2014). One solution to mitigate changing climate conditions is to breed crop varieties that have a higher tolerance to environmental stresses. The use of hybrid-maize seed varieties bred for environmentally-stressed growing conditions may reduce climate-associated risks for smallholders (Lunduka et al., 2017), and previous research found that hybrids yield 40% more during drought conditions (Setimela et al. 2012). The cultivation of hybrid-maize varieties may increase further as the effects of climate change intensify, although maize is likely to be one of the most severely affected crops due to the impacts of climate change (Jones & Thornton, 2003).

In Zambia, the wet season creates three distinct precipitation zones (Figure 4): Agro-Ecological Zone (AEZ) I (located in the south, with less than 800 mm of rainfall annually); AEZ

II (spans the center of the country, between 800 mm to 1,000 mm of annual rainfall; AEZ III (Zambia's northern portion, over 1,000 mm of rain per year) (Aregheore, 2009). The precipitation amounts create a natural gradient from north to south, which coincides with approximate length of the growing season. Changing growing conditions for maize within Zambia are likely to produce negative production outcomes. An analysis of future maize production scenarios in two AEZs estimates maize yield losses between 2 to 12% (Wineman & Crawford, 2017). Seed companies are faced with the challenge of developing varieties with physiological traits amenable to the unique growing conditions within each AEZ, while also ensuring new varieties align with the preferences of farmers and are capable of mitigating future effects of climate change.

FIGURE 4 HERE

The development of new varieties is not for the sole purpose of increasing the potential grain yield of hybrid-maize varieties; rather, breeders pursue improvements in a wide-range of traits: disease and pest resistance, poundability and grain type, stability, and the time to reach maturity (McCann, 2005). Of particular importance in Southern Africa is the maturity period, or the time it takes for a variety to reach physiological maturity. Varieties with shorter maturity periods can mitigate rainfall variability by minimizing the effect of dry periods during vital stages of plant development (Cairns et al., 2013).

Generally, four maturity classifications exist in Southern Africa: very early, early, medium, and late maturing. Late varieties have the highest yield potential, but require more days to develop fully. Alternatively, very early and early varieties mature quicker but with lower yield potential, but greater suitability for farmers in regions with shorter growing seasons or areas with delayed seasonal rains. Time to physiological maturity is dependent on many environmental

factors; but broadly speaking, very early varieties mature in less than 125 days, early maturing varieties mature between 110 to 130 days from planting, medium maturity varieties mature 120 to 140 days from planting, while late maturing varieties reach maturity 140 days after planting (B. Seed Breeder, personal communication, June 6, 2016). Current trends in variety development indicate a shift toward the development of earlier varieties capable of reaching physiological maturity in environments of reduced precipitation (Maddison, 2007).

3 Results and Discussion

3.1 Seed development

The seed industry in Zambia has undergone substantial growth in the certification of improved varieties from the mid-1990s to present, as compared to the preceding three decades (Figure 5). The upward trend is a direct result of the structural adjustment programs implemented during the early 1990s, which expanded the seed industry throughout Southern Africa (Kassie et al., 2013). Decreased public expenditures on seed development led to increased involvement of private firms in the seed certification process beginning in the mid-1990s. From the 1960s to 1990s African maize yields improved, on average, by just 1% annually; however, during the period of structural adjustment, yields increased by nearly 3% (Heisey & Edmeades, 1999). The increase in yields across the region is almost certainly related to improved varieties (Evenson & Gollin, 2003), although the magnitude is unclear.

FIGURE 5 HERE

Despite past criticisms regarding an overly conservative seed certification process, we find the bureaucratic process does little to deter the development and certification of maize varieties. The seed certification system in Zambia may be more thorough than those of neighboring nations, but that does not indicate over restriction of the certification of hybrid-

maize seed. Should harmonization occur, it is unclear how the seed certification system for the region would operate. The use of more lenient seed certification guidelines would inundate seed markets, contributing to an already complex decision environment that smallholders must contend with when selecting seeds.

Previous research finds an average of 16 new maize varieties are certified and released annually in Zambia, and a nationally representative survey conducted in 2011 found over 100 varieties being used by smallholders throughout Zambia, with only two varieties cultivated on more than 5% of the country's cropland (Smale et al., 2015). However, the addition of more cultivars to the market may have an adverse effect as a result of market saturation through promotion of varieties that are only marginally different.

While research has found that hybrid-maize varieties can augment smallholder farming systems (Mason & Smale, 2013), the use of hybrid-maize varieties varies throughout the Southern African region (Langyintuo et al., 2010). Overall, hybrid-maize seed use has remained relatively constant, despite the increase in development and release of new varieties (Smale et al., 2013). In contrast to critiques about the seed certification system being too restrictive or suggestions that hybrid-maize has limited appeal, hybrid-maize has reached near universal adoption. This trend is due in large part to the influence of subsidization programs like FISP, which continue to shape farmer behavior through subsidized seeds and fertilizers.

3.2 Increasing use of early maturing maize

Variety acceptance or new technology adoption by smallholders is often a slow process. Encouraging farmers to cultivate new seed varieties is a constant challenge for seed companies, as they must contend with farmers' perceptions of new varieties, budget constraints, low information exchange about new agricultural technologies, and heterogeneous and uncertain

growing conditions (Fisher et al., 2015; Fisher & Snapp, 2014).

Using CFS data from the 2004-2005 to 2013-2014 growing seasons we find a marked shift between the selection of maize maturity classes planted by Zambia's smallholders over a ten-year period (Figure 6). Cultivation of late maturing varieties remains fairly stable at approximately 12% of all seed varieties used by small- and medium-scale farmers over the ten-year period. Medium maturity seeds are the most common variety planted, but decline from about 70% of all maize cropland planted during the 2004-2005 agricultural season to just above 44% nine years later. Inversely, use of early maturing varieties increased from 16% to 44% of maize cropland during the same period, slowly supplanting medium maturing varieties

FIGURE 6 HERE

Uncertain growing conditions are likely to affect farmers who cultivate varieties with little drought tolerance or varieties that take longer to mature and are thus exposed to greater variation in rainfall. Choosing an adequate seed for cultivation is a complex process. Smallholders face a challenging decision environment with little guidance in terms of site-specific information from seed companies and agricultural extension (Waldman et al., 2017). Smallholders must evaluate trade offs related to various maize traits based on incomplete information often communicated locally by word of mouth.

Planting data from the CFS shows a clear trend towards adoption of earlier maturing hybrid varieties by Zambian smallholders but the underlying causality is unclear. Is the trend due to greater availability of early maturing varieties or due to farmer preferences and increased demand for this type of seed? Past research from Malawi shows that farmers prefer hybrids over OPVs at a margin of slightly more than three to one (Dorward et al., 2008), and as long as prices for hybrids are held relative to that of lower cost OPVs, it appears farmers will actively seek out

this seed type (Denning et al., 2009). Given that farmers have so little information to evaluate the tradeoffs between differing hybrid-maize varieties, it is also likely that the decrease in cultivation of medium maturing hybrid varieties is the result of greater abundance of earlier maturing varieties on the market, and reinforced through farmer preference for hybrids.

The decrease in preference for medium maturing varieties in favor of early maturing varieties is potentially problematic considering the wide differences in growing season length across the country. Medium maturing varieties are the most suitable throughout much of the mid-rainfall regions of Zambia, where average season length is 120-150 days with 800-1000 mm of rainfall over that period. Early maturity varieties mature more quickly and are most suitable in the drier portion of Southern Zambia, where growing season length is typically less than 120 days and less than 800 mm of rainfall. Planting an early variety in an area that receives more than three months of rain means that farmers are not maximizing the rainfall and thus achieving lower potential yields. Receiving rainfall late in the season can also create problems with pest and disease or even crop failure as excess moisture may rot the plant before it is harvested.

3.3 Potential yields vs. actual yields

Farmers value crop varieties for a multitude of production and consumption traits, although the most predominant attribute farmers desire tends to be yield (Fisher et al., 2015; Waldman et al., 2017). Yield can be a deceptively complex metric in developing countries. Equipment for measuring farm level yields is not common and farmers usually only receive 'potential yield' estimates from seed companies. Often the potential yield reflects an optimal growing conditions scenario that involves healthy soil, irrigation, timely weeding, and fertilizer application, which does not resemble the conditions faced by smallholder farmers. The stated yield potential of varieties in circulation in Zambia ranges between five and ten metric tonnes per

hectare, yet smallholders within the region tend to produce less than 2 tonnes/hectare (Mason et al. 2013; Burke et al. 2012).

Using variety yield data from SCCI, CFS, and seed developers we examine the yield range of five hybrid-maize varieties during the 2011/12 growing season (Figure 7). While more than five varieties were used during this agricultural season, we only have SCCI trial data and farmer reported yield data for these five varieties. The other varieties reported in the 2011/12 CFS were not included in SCCI-provided data.

FIGURE 7 HERE

The potential yield estimated by seed developers is highest for each variety, and no variety has a potential yield below eight metric tonnes per hectare. Results from field trials completed at the six SCCI research stations are substantially lower than the potential yield estimates from the seed developer, yet smallholders often only see seed company estimates and not SCCI recorded estimates. Estimates from both SCCI trials and seed companies are so different than farmer actual yields that they bear little resemblance, demonstrating that the growing conditions from these field trials do not simulate smallholder growing conditions well. The inability of the certification system to connect farmer achieved yields with SCCI trial data and seed company performance data highlights the lack of feedback from smallholders that is needed to truly improve the existent seed certification system. FISP effectively normalizes the disconnect between the yields marketed to farmers and the performance achieved by farmers. Hybrids can play an important role for some farmers, but the current seed certification process does not facilitate meaningful feedback which could develop a more sustainable solution to the increasingly variable rainfall patterns farmers face.

While the varieties may be distinct from one another based on guidelines of SCCI and

the VRC, it is not clear that smallholders are able to distinguish the differences. One reason for this is that various growing conditions are more important determinants than the seed variety such as the underlying soil quality, the date planted, and the weather pattern during the sensitive early growth phase of the plant. The annual addition of new varieties that result in highly variable yield raises the question of whether there are too many varieties of only marginal differences available. This can ultimately be more detrimental than helpful to farmers, by creating an overabundance of choices they must sift through in order to find suitable varieties for their farm and field conditions in a given year.

Institutions involved with the seed certification process, and the structure of the system, bolster the development and use of hybrid-maize seed. Regulation from VCU and SCCI involves accepting or denying new varieties, but has little influence over the direction of seed development or market orientation. For breeders in Zambia the existent public-private partnership shifts decision-making power to the seed companies and effectively makes the FISP program and agro-dealers their target audience, as opposed to the farmers. This allows breeders to influence the direction of the national seed market by continuing or discontinuing particular traits and lines of breeding. Farmer seed choice may impact the replication and continuation of lines by seed companies, but seed companies appear to be driving the technology development rather than farmer preferences.

Policymakers in Southern Africa institutionalized and embraced hybrid-maize varieties by liberalizing seed markets and championing large-scale input distribution programs of seed and fertilizer. These policies drove demand for hybrids by Zambian smallholders, which would otherwise not exist given the monetary barriers to entering the hybrid seed market. Unfortunately, these programs have only marginally succeeded in improving the agricultural

systems of smallholders, beyond the improvements that come from typical technological advancements. Much of the yield improvements from hybrids appears to be muted by factors other than the potential of a particular germplasm. It is unlikely certifying more new varieties, or harmonizing of regional seed certification practices, will lead to greatly improved food security outcomes for smallholders or a Green Revolution, if other determinants are not addressed simultaneously. One of the primary ways to address these problems is through information dissemination to farmers about best crop management practices at the farm level, which is not built into the current seed certification process.

Heisey and Edmeades (1999) argue that because maize is often grown in marginal or unfavorable environments, the need for improved varieties is not the single most important factor in improving yield. Rather, the strongest impetus for increasing production should come through efforts aimed at improving management. Improvements in food security require the pairing of new varieties with the provision of extension services (through government, non-governmental organizations, or agri-businesses), improved management practices, and increased access to inputs (Shiferaw et al., 2011; Smale et al., 2013).

4 Conclusion

Zambia holds a prominent position within the regional seed sector of Southern Africa, as a result of a liberalized seed development sector and a large-scale government-sponsored seed subsidy program. Liberalization allowed the growth of the private seed sector, while the seed subsidy program has institutionalized hybrid-maize seeds as a key component for programs aimed at alleviating rural poverty and agricultural development in the country. However, the development of new hybrid-maize varieties in recent years has led to a proliferation of seed options.

The frequent certification of varieties means smallholders have greater choice in seeds than ever before, however more choice may complicate the already complex process of seed selection faced by smallholders. Smallholders become inundated with recently certified hybrid varieties that are more similar than different from pre-existing varieties. The chasm between potential yields reported by seed developers and the actual yields achieved by farmers is problematic for the certification system. Without testing of varieties under realistic conditions and inclusion of this information in the certification process, farmers will continue to harbor unrealistic expectations about the performance of newly released maize varieties over those that are already in existence. This mismatch may enhance food insecurity in a way not intended through the promotion of hybrid-maize varieties. By not enabling inclusion of smallholder yield data or enabling information exchange between smallholders and the seed certification system, an important feedback loop is not used.

References

Akpo, E., Crane, T. A., Stomph, T.-J., Tossou, R. C., Kossou, D. K., Vissoh, P. V., & Struik, P. C. (2014). Social Institutional Dynamics of Seed System Reliability: the Case of Oil Palm in Benin. *International Journal of Agricultural Sustainability*, *12*(3), 214–232.

Aregheore, E. (2009). Country Pasture / Forage Resource Profiles. Retrieved March 1, 2017, from Food and Agriculture Organization website: http://www.fao.org/ag/agp/agpc/doc/counprof/zambia/zambia.htm

Barros, V. R., Field, C. B., Dokken, D. J., Mastrandrea, M. D., Mach, K. J., Bilir, T. E., … Others. (2014). *IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Boko, M., Niang, I., Nyong, A., Vogel, C., Githeko, A., Medany, M., … Yanda, A. P. Z. (2007). Africa. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, & C. E. Hanson (Eds.), *Climate Change 2007: Impacts, Adaptation and Vulnerability.* (pp. 433–467). Cambridge University Press.

Bonny, S. (2017). Corporate Concentration and Technological Change in the Global Seed Industry. *Sustainability: Science Practice and Policy*, *9*(9), 1632.

Borlaug, N. (2000). *The Green Revolution Revisited and the Road Ahead*. Retrieved from The Norwegian Nobel Institute website: http://www.biologyjunction.com/green%20revolution.pdf

Burke, W. J., Jayne, T. S., & Black, J. R. (2012). *Getting More "Bang for the Buck": Diversifying Subsidies Beyond Fertilizer and Policy Beyond Subsidies*. Retrieved from

Michigan State University, Department of Agricultural, Food, and Resource Economics website: https://ideas.repec.org/p/ags/midcpb/123209.html

Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting Maize Production to Climate Change in Sub-Saharan Africa. *Food Security*, *5*(3), 345–360.

CIMMYT. (2014). *Drought Tolerant Maize for Africa Country Report: Zimbabwe*. Retrieved from International Maize and Wheat Improvement Center website: http://dtma.cimmyt.org/index.php/about/background

Crawford, E., Kelly, V., Jayne, T. S., & Howard, J. (2003). Input Use and Market Development in Sub-Saharan Africa: an Overview. *Food Policy*, *28*(4), 277–292.

Denning, G., Kabambe, P., Sanchez, P., Malik, A., Flor, R., Harawa, R., … Magombo, C. (2009). Input subsidies to improve smallholder maize productivity in Malawi: Toward an African Green Revolution. *PLoS Biology*, *7*(1), e1000023.

Dorward, A., Chirwa, E., Kelly, V. A., Jayne, T. S., Slater, R., & Boughton, D. (2008). *Evaluation Of The 2006/7 Agricultural Input Subsidy Programme, Malawi. Final Report* (No. 97143). Retrieved from Michigan State University, Department of Agricultural, Food, and Resource Economics website: https://ideas.repec.org/p/ags/midcwp/97143.html

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

Fisher, M., Abate, T., Lunduka, R., Asnake, W., Alemayehu, Y., & Madulu, R. (2015). Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. *Climate Change*, *133*(2), 283–299.

Fisher, M., & Snapp, S. (2014). Smallholder Farmers' Perceptions of Drought Risk and

Adoption of Modern Maize in Southern Malawi. *Experimental Agriculture*, *50*(4), 533–548.

Funk, C., Dettinger, M. D., Michaelsen, J. C., Verdin, J. P., Brown, M. E., Barlow, M., & Hoell, A. (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. *Proceedings of the National Academy of Sciences of the United States of America*, *105*(32), 11081–11086.

Heisey, P. W., & Edmeades, G. O. (1999). *CIMMYT 1997/98 world maize facts and trends–Maize production in drought-stressed environments: Technical options and research resource allocation*. Retrieved from http://repository.cimmyt.org:8080/xmlui/handle/10883/759

Hoogendoorn, J. C., G., Audet-Bélanger, Böber, C., Donnet, M., Lweya, K. B., Malik, R. K., & Gildemacher, P. R. (2018). Maize seed systems in different agro-ecosystems; what works and what does not work for smallholder farmers. *Food Security*, *10*(4), 1089–1103.

Jayne, T. S., & Rashid, S. (2013). Input subsidy programs in sub-Saharan Africa: a synthesis of recent evidence. *Agricultural Economics* , *44*(6), 547–562.

Jones, P. G., & Thornton, P. K. (2003). The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environmental Change: Human and Policy Dimensions*, *13*(1), 51–59.

Kassie, G. T., Erenstein, O., Mwangi, W., MacRobert, J., Setimela, P., & Shiferaw, B. (2013). Political and economic features of the maize seed industry in southern Africa. *Agrekon*, *52*(2), 104–127.

Langyintuo, A. S., Mwangi, W., Diallo, A. O., MacRobert, J., Dixon, J., & Bänziger, M. (2010). Challenges of the maize seed industry in eastern and southern Africa: A compelling case for private–public intervention to promote growth. *Food Policy*, *35*(4), 323–331.

Li, Y., Ye, W., Wang, M., & Yan, X. (2009). Climate change and drought: a risk assessment of crop-yield impacts. *Climate Research*. Retrieved from http://www.jstor.org/stable/24870421

Lunduka, R., Fisher, M., & Snapp, S. (2012). Could farmer interest in a diversity of seed attributes explain adoption plateaus for modern maize varieties in Malawi? *Food Policy*, *37*(5), 504–510.

Lunduka, R., Mateva, K., Magorokosho, C., & Manjeru, P. (2017). Impact of adoption of drought-tolerant maize varieties on total maize production in south Eastern Zimbabwe. *Climate and Development*, 1–12.

Lynam, J., Gilbert, E., & Elliot, H. (2010). *Evolving a Plant Breeding and Seed System in Sub-Saharan Africa in an Era of Donor Dependence*. A report for the Global Initiative on Plant Breeding (GIPB). Rome: Food and Agriculture Organization of the United Nations.

Maddison, D. (2007). *The Perception Of And Adaptation To Climate Change In Africa*. The World Bank.

Mason, N., Jayne, T., & Mofya-Mukuka, R. (2013). Zambia's input subsidy programs. *Agricultural Economics* , *44*(6), 613–628.

Mason, N., & Smale, M. (2013). Impacts of subsidized hybrid seed on indicators of economic well-being among smallholder maize growers in Zambia. *Agricultural Economics* , *44*(6), 659–670.

McCann, J. (2005). *Maize and grace: Africa's encounter with a New World crop, 1500-2000*. Harvard University Press.

McGinnis, M. D. (2011). An introduction to IAD and the language of the Ostrom workshop: a simple guide to a complex framework. *Policy Studies Journal: The Journal of the Policy Studies Organization*, *39*(1), 169–183.

McGuire, S., & Sperling, L. (2011). The links between food security and seed security: facts and fiction that guide response. *Development in Practice*, *21*(4-5), 493–508.

Mendelsohn, R. (2008). The impact of climate change on agriculture in developing countries. *Journal of Natural Resources Policy Research*, *1*(1), 5–19.

North, D. C. (1991). Institutions. *The Journal of Economic Perspectives: A Journal of the American Economic Association*, *5*(1), 97–112.

Ostrom, E. (2011). Background on the institutional analysis and development framework. *Policy Studies Journal: The Journal of the Policy Studies Organization*, *39*(1), 7–27.

Resnick, D., & Mason, N. (2016). *What Drives Input Subsidy Policy Reform? The Case Of Zambia, 2002-2016* (No. 1572). Retrieved from International Food Policy Research Institute website: https://ideas.repec.org/p/ags/midamp/246951.html

Seed Breeder, A. (2016, May 23). [Letter to Jordan Blekking].

Seed Breeder, B. (2016, June 6). [Letter to Jordan Blekking].

Seed Distributor, A. (2016, June 6). [Letter to Jordan Blekking].

Seed Distributor, B. (2016, August 15). [Letter to Jordan Blekking].

Seed Regulator, (2016, May 25). [Letter to Jordan Blekking].

Setimela, P. S., MacRobert, J., Atlin, G. N., & Magorokosho, C. (2012). Evaluation of regional on-farm variety trials in eastern and southern Africa 2011. *Harare, Zimbabwe: CIMMYT*.

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security*. Retrieved from https://link.springer.com/article/10.1007/s12571-011-0140-5

Sitko, N. (2008). Maize, food insecurity, and the field of performance in southern Zambia. *Agriculture and Human Values*, *25*(1), 3–11.

Smale, M., Byerlee, D., & Jayne, T. (2013). Maize Revolutions in Sub-Saharan Africa. In K. Otsuka & D. F. Larson (Eds.), *An African Green Revolution* (pp. 165–195). Springer Netherlands.

Smale, M., & Jayne, T. (2003). *Maize in Eastern and Southern Africa: "seeds" of success in retrospect* (Vol. 97). Retrieved from IFPRI website: https://www.researchgate.net/profile/Thomas_Jayne/publication/5056187_Maize_in_Eastern_and_Southern_Africa_Seeds_of_Success_in_Retrospect/links/09e4151144e3befba8000000.pdf

Smale, M., Simpungwe, E., Birol, E., Kassie, G. T., de Groote, H., & Mutale, R. (2015). The changing structure of the maize seed industry in Zambia: Prospects for orange maize. *Agribusiness* , *31*(1), 132–146.

Tester, M., & Langridge, P. (2010). Breeding technologies to increase crop production in a changing world. *Science*, *327*(5967), 818–822.

Variety Release Committee (2012). VRC Meeting Notes. Lusaka: Seed Control and Certification Institute.

Vermeulen, S. J., Aggarwal, P. K., Ainslie, A., Angelone, C., Campbell, B. M., Challinor, A. J., … Kristjanson, P. (2012). Options for support to agriculture and food security under climate change. *Environmental Science & Policy*, *15*(1), 136–144.

Waldman, K. B., Blekking, J. P., Attari, S. Z., & Evans, T. P. (2017). Maize seed choice and perceptions of climate variability among smallholder farmers. *Global Environmental Change: Human and Policy Dimensions*, *47*(vember 2017), 51–63.

Waldman, K. B., & Richardson, R. B. (2018). Confronting Tradeoffs Between Agricultural Ecosystem Services and Adaptation to Climate Change in Mali. *Ecological Economics: The Journal of the International Society for Ecological Economics*, *150*, 184–193.

Ward, P. S., Ortega, D. L., Spielman, D. J., & Singh, V. (2014). Heterogeneous Demand for Drought-Tolerant Rice: Evidence from Bihar, India. *World Development*, *64*, 125–139.

Wineman, A., & Crawford, E. W. (2017). Climate Change and Crop Choice in Zambia: A Mathematical Programming Approach. *NJAS - Wageningen Journal of Life Sciences*, *81*(Supplement C), 19–31.

Witcombe, J. R., Joshi, A., Joshi, K. D., & Sthapit, B. R. (1996). Farmer participatory crop improvement. I. Varietal selection and breeding methods and their impact on biodiversity. *Experimental Agriculture*, *32*(4), 445–460.