Hybrid maize production and climate variability in Zambia

Case Study Teaching notes

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Summary: This case study examines the social and ecological implications of widespread adoption of maize and particularly hybrid maize in Africa. Maize was introduced to Africa roughly 500 years ago and now occupies the majority of cultivated land in most countries in Southern Africa. The maize plant is advantageous for African farmers for numerous reasons—it fits well into the farming system, has high grain yield, and all of the parts of the plant can be used. However, Maize is sensitive to changes in sunlight and water, is detrimental to the soil in terms of nutrient requirements, and is particularly susceptible to climatic events. While it provides the vast majority of calories for many African households, it is low in protein and various vitamins. Numerous institutions and policies have contributed to the widespread adoption of maize, particularly hybrid varieties of maize. This case study examines the current model of maize production in Africa, with a focus on Zambia. We assess the tradeoffs involved in wide scale maize cultivation, social and ecological feedbacks in the system, and critically explore the role of institutions in supporting maize cultivation. We focus on the role of institutions: examining how policies and how government, community and private seed companies have contributed to the current social behavior. The goal of the case study is to engage students in debate about a complex socio-environmental topic from the perspective of numerous stakeholders and to determine possible alternative policies at the level of the local and national government.

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Course context

This case study was designed to be taught in a human dimensions of environmental change course at the upper level undergraduate or early graduate level. This case study lesson is designed to be taught in two course hours (with approximately 3-4 hours of outside reading). This will ideally work for approximately 12-30 students. There are no prerequisites but an introductory course in environmental studies or people and the environment would be helpful.

Socio-Ecological Synthesis Learning Goals

1. Distinguish between ecological, agronomic, and socio-political dimensions of maize production in Africa and their interactions;
2. Identify feedbacks and explain the dynamics of subsistence farming as a social-environmental system;
3. Synthesize the implications of policies and institutions to support subsistence farmers given evidence of increased climate variability.

Introduction

This case study follows a Zambian man who is struggling to decide what to do in the coming agricultural season given increasing climate variability in his community and institutional incentives that are pushing farmers towards "intensive" agricultural production. He needs to choose whether to break from his family's tradition of planting local maize seeds and adopt hybrid maize seeds. He is wrestling with the higher stakes gamble of a more expensive but higher payoff method of farming and the unknown future associated with more technologically based farming methods. This exercise would ideally be administered in mid-course, because a baseline understanding of the impact of humans on the environment in a developing world context would be helpful for their comprehension of the role-playing activity.

Learning Objectives

- Understand the context of traditional cropping systems in Africa and how the cropping system relates to social and cultural factors;
- Identify the differences and tradeoffs between traditional and hybrid cropping systems;
- Understand how agronomic dynamics can interact with decision-making and how climatic change adaptation can be a function of behavioral and institutional factors;
- Explain the interdisciplinary connections between human behavior, environmental outcomes, and policies in the context of hybrid crop production.

Classroom Management

This case study includes decision-making simulation from various stakeholder perspectives, small and large-group discussion, and problem-based learning. This case study is designed to take two teaching hours. The first is devoted to giving students the background on agricultural decision-making under uncertainty in sub-Saharan Africa. It involves role-playing in which students have to assume the role of a Zambian farmer struggling to make a planting decision for the next growing season. The second hour focuses more on the physical aspects of agriculture and climate in this context. Students will examine the agronomic tradeoffs involved in different farming systems and technologies and debate the pros and cons of each. They will synthesize the social and physical aspects of the problem in a policy brief.

Day 1: Hybrid maize proliferation in Africa (1 hour)

a) Students should read *Maize and Grace,* Chapter 1 prior to coming to class (in reference list below: McCann, 2001)
b) Introduce students to the Case Study approach and give a brief summary of the topic and activities involved in the case study. Handout cards and ask them to respond to the question: Do you think hybrid crops are good for the environment? Why or why not? Collect the cards (5 minutes).
c) Give a presentation on the history of the "traditional agricultural systems in Africa and introduction of maize" (20 minutes). See slides by the same name.
d) Students should read the story "Protensia's neighbor's maize" found in the student handout (5 min).
e) Divide the classroom into small groups for discussion. Discussion questions for small groups can be found following the story in the student handout (10 mins).
f) Groups report out their main discussion points to the larger group (10 mins) and have a full group discussion (5 mins).
g) Explain homework assignment to students (5 mins). Students should write one paragraph summarizing the group discussion which addresses the agricultural tradeoffs farmers in Africa face. This will be a foundation for the policy brief assignment for day 2. Students should read the following items before the next class.
   Readings: NV Fedoroff (2010), "Radically Rethinking Agriculture"
   http://science.sciencemag.org/content/327/5967/833.full
   D. Tilman et al. (2002). "Agricultural sustainability and intensive production practices".
   http://www.nature.com/nature/journal/v418/n6898/full/nature01014.html

Day 2: Agronomic tradeoffs between cropping systems (1 hour)

a) Give a presentation on the agronomic differences between traditional systems, intercropping, sustainable intensification (15 mins). See slides on "Sustainable Intensification".
b) Divide classroom into 2 main groups: sustainable intensification (1) and intensive cultivation (2). Then have students from opposite groups pair up and discuss the merits of their group's approach (10 mins).
c) Have students read "Reading #1: Institutions and maize subsidies in Africa" in the student handout (15 mins). Lead them in a discussion of the discussion questions that follow.
d) Briefly explain the agroecological zone maps and figures on crop calendar and weather patterns in Zambia in the student handout (5 mins). The section below on "climate variability in Zambia" will help.
e) Discuss the impact of climate variability on farming in small groups. Get in the same groups as earlier and answer discussion questions (10 mins). The discussion questions are found at the beginning of Activity 2 in the Student Handout. The key lessons to distill are that there is a lot of variation in rainfall and dry periods throughout the year. The length of the seasons vary as does the timing of the onset of the rainy season. Southern province lies at the cusp of agrooecological zone 1 and 2 and so the season should be limited to early varieties but possibly some shorter medium varieties. Total annual rainfall seems to be relatively flat although average years are so low that early years can have a significant impact on food security. Farmers perceive the rains to be getting later and this appears to be true in the rainfall figure (a) for the past few years.
f) Explain homework assignment on policy briefs: Students should remain in their groups and meet outside of the classroom to collaborate on policy briefs. Guidelines, outline, and expectations for the policy brief is included in the student handout (5 mins).

Assessment

Learning objectives	Activities	Assessment
Understand the context of traditional cropping systems in Africa and how the cropping system relates to social and cultural factors	1) Background reading "Maize and Grace, Ch1." 2) Presentation on "Maize comes to Africa", 3) Group discussion about agricultural tradeoffs farmers in Africa face	a) Homework assignment on agricultural tradeoffs farmers in Africa face, b) Policy brief.
Identify the differences and tradeoffs between traditional and hybrid cropping systems	1) Background readings (McCann, Fedoroff, & Tilman), 2) Role playing exercise, 3) Presentation on agronomic differences	a) Policy brief
Understand how agronomic dynamics can interact with decision-making and how	1) Presentation on agronomic differences, 2) presentation on	a) Policy brief

climatic change adaptation can be a function of behavioral and institutional factors	Institutions and maize subsidies in Africa, 3) Group activity with maps and figures	
Develop interdisciplinary thinking concerning socio-ecological systems and the connection between human behavior, environmental outcomes, and policies	All activities	a) Policy brief, b) Participation in group activities.

Policy brief rubric

The primary assessment tool for the case study is the policy brief that is the product of the two class periods. In addition to following the outline and having the key elements of a policy brief laid out in the student handout the brief should contain evidence of the learning objectives. Overall, the brief should demonstrate a clear focus on both the social and ecological elements of the decision-making context. In addition, the brief should articulate a clear understanding of traditional cropping systems versus hybrid cropping systems both in terms of social and ecological factors. The policy options section of the brief should demonstrate an understanding of the tradeoffs related to current and proposed policies particularly in light of environmental data on climate variability. And the policy recommendation section should demonstrate clear interdisciplinary thinking.

Category	Excellent (2 points)	Average (1 point)	Poor (0 points)
Length	2-3 pages (1000-1500 words)	N/A	Paper exceeds or does not meet requirements
Audience	Introduction clearly answers: To, from, date/ title	Includes 2 out of the three items	Only includes 1 or one of the items
Problem statement	a) Problem is clear, b) includes discussion of b) cultural context and c) agricultural tradeoffs	Includes 2 out of the three items	Only includes 1 or one of the items
Policy options	a) should be a minimum of two policy options, b) includes advantages and c) disadvantages of each policy option	Includes 2 out of the three items	Only includes 1 or one of the items
Policy recommendations	a) Make a judgement call about which policy would be the most advantageous and b) articulate why	Includes 2 out of the three items	Only includes 1 or one of the items
Sources or references	a) Includes Author(s), year, title, journal or source, volume number, issue number, page numbers (if applicable), b) Done in a consistent style.	Includes 2 out of the three items	Only includes 1 or one of the items
Grammar and writing	a) Writing is clear and concise, b) does not contain spelling grammar issues	Only includes 1 or one of the items	Does not include either of the items

Formatting	a) Brief looks professional and b) clearly organized	Only includes 1 or one of the items	Does not include either of the items
Grasp of concepts	a) Use terminology introduced in case study, b) includes new concepts, c) synthesizes across concepts	Includes 2 out of the three items	Only includes 1 or one of the items
Interdisciplinary thinking	a) Demonstrates understanding of both social and environmental aspects, b) mentions relationship of social to environmental aspects	Only includes 1 or one of the items	Does not include either of the items

*Total possible points =20.

Sample policy brief at: https://web.stanford.edu/class/siw198q/modelppr/amber2.htm

Background

Corn (Maize) use and development

Crops are amorphous and can change to suit the needs of the society that they function in. For example, ancestral cabbage plants, originally selected for seed oil properties later were selected for leaves (as kale), stems (as kohlrabi), buds (as Brussels sprouts), or flower shoots (broccoli) depending on the society (Diamond, 1999). The history of the maize crop is similar with a single ancestor in Mexico (teosinte) now taking various forms: sweet, pop, dent and flint maize (Doebley, 1990). The majority of maize grown in the US is intended for ethanol production (40%), livestock feed (36%), or exported, while a small fraction is consumed by humans as starch, syrup or sweeteners, or directly as grits, meal or flour (Foley, 2013).

Unlike other cereal crops maize is in an open pollinator which means the stamen and ovaries are separated by as much as a meter or more. The maize plant produces a massive amount of pollen to guarantee propagation. When pollen travels within the same plant the identity of each succeeding generation is identical. But because the method of exchange of genetic material is so promiscuous it is difficult to control (McCann, 2001). The plant is dominated by the wind- pollen grains that travel 10s of meters and can self-fertilize which means that it can carry other dubious traits. But with controlled cross pollination the new generation can be bred to have desirable traits. Hybrids are the results of crossing (once or twice) two or more inbred (self-pollinated) genetic lines to produce the desired traits. The interaction of favorable genetic materials as manipulated by maize breeders to produce hybrids is known as hybrid vigor or *heterosis*.

Maize is the dominant crop in the corn belt of the United States (including Illinois, Iowa, S. Minnesota and Michigan, Eastern Kansas and Nebraska). Since the 1850s, corn has been the predominant crop, replacing the native tall grasses. By 1950, 99% of the corn was grown from hybrids (USDA, 2017). Hybrids are particularly responsive to higher levels of fertilizer inputs and this method of farming has come to be known as “intensive agriculture”.

History of maize in Africa

Maize was introduced into Africa around 1500 and by the early 1900s had replaced sorghum to become the dominant staple crop in southern Africa (Smale and Jayne, 2003). Wide-scale continuous maize cultivation requires fertilizer inputs that many farmers in the region struggle to afford and can deplete soils over time (Lal, 1997). Over the last one hundred years maize achieved rapid growth and in many areas replaced traditional cereals like sorghum and millet (Smale & Jayne, 2003). In Africa, 95% of maize is consumed by humans, occupies 85% of arable land, and provides over 60% of the calories (Denning, 2009). This may be due to advantages such as the very high grain yield potential of maize, a C4 grass adapted to high heat and light that can produce approximately twofold more grain than other staple food crops, when provided sufficient fertility (Egli, 2008). Further, maize is one of the most labor efficient staple food crops with plant traits that include a weed suppressing architecture, and an ear covering that protects the grain from birds and other pests.

The development of modern varieties in conjunction with the implementation of subsidy programs for maize and fertilizer has led to broad access to hybrid maize seeds among smallholder farmers (Lunduka, Fisher, & Snapp, 2012). Maize has been heralded as providing an engine for growth, and the foundation for the green revolution in Africa (Byerlee & Eicher, 1997). Despite all the benefits maize has brought to Africa, there have also been many tradeoffs. The maize plant is highly sensitive to deficiencies in water, and nitrogen. The grain does not store well and is attacked by weevils and other pests and diseases. Wide-scale production of maize has slowly mined the soil of nitrogen, and ultimately created a reliance on external inputs to maintain previous yields (Snapp et al., 2010). Moreover, maize has one of the highest erosivity factors (C-values) among crops grown in the region, contributing significantly to soil loss on susceptible slopes (Lewis, Clay, & Dejaegher, 1988). The crop is largely grown without irrigation in a single growing season and is particularly susceptible to dry spells during flowering, rainfall variability, and growing season length (Rao, Ndegwa, Kizito, & Oyoo, 2011). Additionally, maize lacks essential amino acids, vitamin A, and can be associated with poor nutritional outcomes.

Sustainable intensification

High demand for food coupled with input-intensive conventional agricultural intensification practices that are increasingly common in Africa are potentially leading to agricultural land degradation, land conversion, and exacerbating climate change. National policies often promote input-driven intensification, which strives to increase agricultural output through increased use of inputs. Input-driven agricultural systems will experience an increase in yields and productivity, but this increase is often unsustainable. Unsustainable agricultural practices render the soil unproductive (Giller et al., 1997) and contribute to land degradation (Barbier, 1997; Sanchez et al., 1997; Symeonakis, 2007). Once land becomes degraded and scarce farmers put more pressure on protected areas and marginal hillsides (Headey and Jayne, 2014). Unsustainable practices can also force smallholders to acquire new fertile lands (often marginal forests) through land conversion or extensification. The transition to intensive agriculture may also reduce total soil carbon stocks, and increase emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide thus exacerbating climate change. The net effect of unsustainable agriculture intensification is a reduction in the food security and resiliency of agricultural households and the landscapes on which their livelihoods depend.

In response to the perceived shortcoming of the Green Revolution in Africa a scientific debate has emerged about how the sustainability of the intensive methods promulgated during the green revolution in Africa. Sustainable intensification (SI) of agriculture, integrates the dual and interdependent goals of using sustainable practices to meet rising human needs while contributing to resilience and sustainability of landscapes, the biosphere, and the Earth system to sustain the future viability of agriculture (Rockstrom et al., 2017).

Sustainable intensification has the potential to mitigate the impact of agriculture on the landscape by intensifying agricultural production without increasing deforestation or the cultivation of more land and without reducing biodiversity (The Royal Society, 2009; Garnett et al., 2013; Keating et al., 2013). It is common to think of intensification in terms of land as the key input and improving yields (productivity of the land) as the key objective. Pretty et al. (2011) define SI as (i) production of more food, feed, fiber, and/or fuel per unit of land, labor, and/or capital used; (ii) maintained and or improved natural resource base, including enhanced ecosystems services; and (iii) resilience to shocks and stresses, include climate change. SI practices could reduce agricultural encroachment into forests, preserving biodiversity and soil carbon stocks (Phalan et al., 2011; Pretty et al., 2011). Thus, SI approaches can potentially minimize environmental and long-term economic costs by increasing the efficiency of agricultural systems and by contributing to household and ecosystem resilience. SI approaches must include higher yields overall because most arable land consists mainly of forests, wetlands, or grasslands, whose conversion would greatly increase emissions of greenhouse gases (Garnett et al., 2013), which is not sustainable in the long term. Increasing the land area in agriculture would also have significant environmental costs in terms of wildlife conservation, carbon storage, flood protection, recreation, and other ecosystem services.

Institutions and maize subsidies in Africa

Once hybrid varieties were introduced to Africa, grain production increased particularly since the 1960s, yet Africa is still struggling to achieve a Green Revolution. Since the initiation of market reforms in sub-Saharan Africa in the 1970s and 1980s, numerous African governments have responded to food deficits by implementing costly and ambitious fertilizer and hybrid crop subsidy programs with limited success (Denning et al., 2009; Mason et al., 2013). Maize continues to be the target of breeding programs in Africa (McCann, 2009). Investment in the maize sector during the colonial period led to maize breeding success in countries like Kenya and Zimbabwe, particularly during the 1970s and 1980's (Smale and Jayne, 2003). Innovations in technology, smallholder- oriented policies and institutions, and breeding of improved crop varieties were at the core of this success. Coupled with improved seeds were investments in extension, seed distribution and delivery, and later fertilizer subsidies and delivery and access to credit.

In recent years, numerous countries in SSA including Ethiopia, Ghana, Kenya, Malawi, Nigeria, Tanzania, and Zambia have all implemented input subsidy programs at substantial cost to government and donor budgets (Mason and Ricker-Gilbert, 2013). Fertilizer subsidy programs have existed in almost every year for decades in Malawi and Zambia. The majority of these programs focus on providing inorganic fertilizer to small farmers at subsidized prices although many of the programs also expanded to provide subsidized seeds, particularly hybrid maize seeds. While the majority of countries experienced a decline in absolute maize production during the 1990s, others (such as Malawi) experienced an increase due to input support programs (Smale and Jayne, 2003).

One notable breeding development in this period was the establishment of shorter-season hybrid varieties that were tolerant of late planting. By creating varieties that were able to flourish despite late planting, maize breeders allowed smallholders to adapt to changing climatic conditions by planting later into the season. The new varieties combined with subsidized credit for seed and fertilizer led to a doubling of maize area (in Zambia) during the 1970s and 1980s (Smale et al., 2015).

The government of Zambia (along with numerous other African countries) liberalized the seed market in the 1990s as a result of pressure from the International Monetary Fund and the World Bank through the Structural Adjustment Program. During this process, Zamseed was privatized, and new regional and international seed companies entered the market. The number of hybrids and improved open pollinated varieties (OPVs) doubled between 1992 and 1996 (Howard and Mungoma, 1997). Since then hundreds of new varieties have been released in Zambia by 14 different companies and research institutions, and the rights of almost all these varieties are held by private seed companies (Smale et al., 2015).

At the time of market liberalization, the government of Zambia was building an agricultural support program focused on hybrid maize seed and fertilizer. During Zambia's 52 years of independence, there was only a brief period in the early 1990s where there were no agricultural subsidies in Zambia (Mason et al., 2013). Prior to liberalization, the government of Zambia provided farmers with subsidized fertilizer and seed on credit and purchased their harvest through the parastatal National Agricultural Marketing Board (NAMBOARD) (Smale and Jayne, 2003). The government abandoned NAMBOARD due to its high operational costs but found it politically infeasible to stop subsidies. The Fertilizer Credit Program (FCP), started in 1997, was an input loan until the end of the season but loan default was high and the FCP morphed into the Fertilizer Support Program (FSP) in 2002 (Mason et al, 2013). The name of the program was changed to the Farmer Input Support program (FISP) in 2009 but the goal remained the same.

Originally FISP allocated maize varieties to farmers that were members of participating cooperatives based on an assessment of agroecological suitability made by the FISP, leaving farmers no choice among cultivars. These varieties were targeted to various regions based loosely on agroecological needs and the seed and fertilizer was delivered directly to the cooperatives. Over time FISP allowed farmers to choose between more varieties of hybrid maize and gradually offered more seed variety choice to farmers each year. With the introduction of the e-voucher program in the 2015-2016 growing season farmers are now able to choose from any hybrid maize seeds available from agro-dealers using electronic vouchers from the FISP.

Through investment, liberalization, and subsidies the Government of Zambia effectively institutionalized hybrid maize production among small-scale farmers in Zambia over the last few decades. Adoption of hybrid maize in Zambia is the highest of all African countries and most of this is focused on earlier maturing varieties.

Climate Variability in Zambia

Changing weather patterns and increasing frequency and intensity of weather events contribute to the riskiness of farming and pose a threat to food security, particularly in developing countries (Field and IPCC, 2012, Campbell et al., 2016). Climate change disproportionately impacts poorer nations and poorer, agrarian households within those nations who rely on rainfall for agriculture (Jarvis, 2011). The impact of climate change on crop production is expected to constitute a significant threat to food security, particularly with crops like maize in more marginal parts of sub-Saharan Africa (SSA) in this century (Lobell et al., 2011; Rippke et al., 2016).

In Zambia there is a distinct growing season from roughly November to April. Figure A (in the Student Handout) depicts daily precipitation over the growing season from a weather station in Southern Province for the last four growing seasons. Intermittent periods of no or low rain are common—such as the dryspell that occurred during the first three weeks of March in the 2014/5 season. Dryspells can be particularly damaging during the flowering and early grain filling stages and can sometimes result in total crop loss or require replanting. Most traditional varieties of maize generally take five to six months to reach maturity so farmers need to utilize the entire rainy season to produce them. Early and medium maturing varieties can reach maturity in three to four months and are critical when the rainy season is delayed or characterized by dryspells.

Hybrid maize production and climate variability in Zambia

Zambia has a range of agroecological zones which follow a rainfall gradient from the Northwest to Southeast of the country (see figure B in student handout). The driest agroecological region or zone is AER1 in the South East which received less than 800 mm of rainfall per year. The second AER runs through the middle of the country and receives slightly more rainfall, from 800 to 1000 mm annually. Northern Province and Northwest province receive the most rainfall which typically exceeds 1000 mm per year. The amount of total annual rainfall in each AER also reflects the length of the growing season. The shortest growing season is in AER1 where the growing season is less than 4 months on average, AER2 ranges from 4 to 5 months on average, while AER3 ranges from 5 to 7 months. AER1 is only long enough to sustain early maturing varieties which reach maturity in 3-4 months, while AER2 can support early maturing varieties that reach maturity in 5 months and AER3 can support all seed maturity classes.

Zambian farmers face significant climate variability (see figure C in student handout). In the part of Southern Province, which lies in AER 2 where the total annual rainfall average is often reported to be 1000 mm per year, only reached 1000 mm of rain in one of the last 15 years. The actual average for the last 15 years is 789 mm. In a low rainfall year such as the 2004/5 season there was an extreme food security crisis, demonstrating that small deviations from the mean can be disastrous for farmers. In addition to wide variation in annual rainfall there is a slight declining annual rainfall trend. In many years this simply means that rains arrive later. Farmers perceive the onset of the rainy season to be getting later every year (see figure D in Student Handout). The shifting of the onset of the rains is one indication that the length of the growing season is effectively becoming shorter for farmers.

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References

Barbier, E. B. (1997). The economic determinants of land degradation in developing countries. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 352(1356): 891–899.

Byerlee, D., & Eicher, C. K. (Eds.) (1997). Africa's emerging maize revolution. Lynne Rienner Publishers.

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., Loboguerrero, A. M., … Wollenberg, E. (n.d.). Reducing risks to food security from climate change. *Global Food Security*. https://doi.org/10.1016/j.gfs.2016.06.002

Doebley JF. 1990. Molecular evidence and the evolution of maize. Econ Bot 44 (3 supplement): 6-27. Summarized here: https://teosinte.wisc.edu/questions.html

Diamond, J. (1999). *Guns, Germs, and Steel: The Fates of Human Societies*. W. W. Norton & Company.

Denning, G., Kabambe, P., Sanchez, P., Malik, A., Flor, R., Harawa, R., … Sachs, J. (2009). Input Subsidies to Improve Smallholder Maize Productivity in Malawi: Toward an African Green Revolution. PLoS Biol, 7(1), e1000023.

Egli, D.B. (2008). Comparison of corn and soybean yields in the United States: Historical trends and future prospects. Agronomy Journal, 100:S79–S88.

Field, C. B., & Intergovernmental Panel on Climate Change (Eds.). (2012). *Managing the risks of extreme events and disasters to advance climate change adaption: special report of the Intergovernmental Panel on Climate Change*. New York, NY: Cambridge University Press.

Foley, J. (2013). It's Time to Rethink America's Corn System. March, 5, 2013. Scientific American. https://www.scientificamerican.com/article/time-to-rethink-corn/

Garnett, T., Appleby, M. C., Balmford, A., Bateman, I. J., Benton, T. G., Bloomer, P., B. Burlingame, Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P. K., Toulmin, C., Vermeulen, S. J., Godfray, H. C. J. (2013). Sustainable intensification in agriculture: premises and policies. *Science* 341(6141): 33–34.

Giller, K. E., Cadisch, G., Ehaliotis, C., Sakala, W. D., Mafongoya, P. L. (1997). Building soil nitrogen in Africa. In: Buresh, R.J., Sanchez, PA., and Calhoun, F. (eds.), Replenishing soil fertility in Africa. *Soil Science Society of America*, Madison, WI, USA, pp. 151-191. SSSA Special Publication No. 51.

Headey, D. D., Jayne, T. S. (2014). Adaptation to land constraints: Is Africa different? *Food Policy* 48: 18–33.

Howard, J. & Mungoma, C. (1997) Zambia's stop and go maize revolution. In D. Byerlee & C.K. Eicher (Eds.), *Africa's Emerging Maize Revolution* (pp.4-62). Lynne Rienner Publishers.

Keating, B. A., Carberry, P. S., Dixon, J. (2013). Agricultural intensification and the food security challenge in sub- Saharan Africa. In *Agroecological Intensification of Agricultural Systems in the African Highlands*. Edited by Vanlauwe, B., Van Asten, P., and Bomme, G. New York: Routledge (Earthscan).

Lal, R. (1997). Long-term tillage and maize monoculture effects on a tropical Alfisol in western Nigeria. II. Soil chemical properties. Soil and Tillage Research, 42(3), 161–174. doi:10.1016/S0167- 1987(97)00007-X.

Lewis, L. A., Clay, D. C., & Dejaegher, Y. (1988). Soil loss, agriculture and conservation in Rwanda: Toward sound strategies for soil management. Journal of Soil and Water Conservation, 418–421, Sept– Oct.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing Climate Change Adaptation Needs for Food Security in 2030. *Science*, *319*(5863), 607–610. https://doi.org/10.1126/science.1152339

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. doi:10.1016/j.foodpol.2012.05.001.

Mason, N. M., Jayne, T. S., & Mofya-Mukuka, R. (2013). Zambia's input subsidy programs. *Agricultural Economics*, *44*(6), 613–628. http://doi.org/10.1111/agec.12077

Mason, N. M., & Ricker-Gilbert, J. (2013). Disrupting Demand for Commercial Seed: Input Subsidies in Malawi and Zambia. *World Development*, *45*, 75–91. https://doi.org/10.1016/j.worlddev.2012.11.006https://doi.org/10.1016/j.worlddev.2012.11.006http://ageconsearch.umn.edu/bitstream/246951/2/FSP_Research_Paper_28.pdf

McCann, J. (2001). Maize and Grace: History, Corn, and Africa's New Landscapes, 1500–1999. *Comparative Studies in Society and History*, *43*(2), 246–272.

Mubanga, K. (2014). Assessing seed breeders recommended maize varieties for Southern Zambia: How small-scale farmers have adapted. Presented at the International Conference on Agricultural, Environmental and Biological Sciences, Phuket, Thailand: International Institute of Chemical, Biological & Environmental Engineering. https://doi.org/10.15242/IICBE.C414017

Phalan, B., Onial, M., Balmford, A., Green, R. E. (2011). Reconciling food production and biodiversity conservation: Land sharing and land sparing compared. *Science 333*(6047): 1289–1291.

Pretty, J., Toulmin, C., Williams, S. (2011). Sustainable intensification in African agriculture. *International Journal of Agricultural Sustainability* 9(1): 5–24.

Rao, K. P. C., Ndegwa, W. G., Kizito, K., & Oyoo, A. (2011). Climate variability and change: Farmer perceptions and understanding of intra-seasonal variability in rainfall and associated risk in semi-arid Kenya. Experimental Agriculture, 47(2), 267–291.

Rippke, U., Ramirez-Villegas, J., Jarvis, A., Vermeulen, S. J., Parker, L., Mer, F., … Howden, M. (2016). Timescales of transformational climate change adaptation in sub-Saharan African agriculture. *Nature Climate Change*, *advance online publication*. https://doi.org/10.1038/nclimate2947

Rockström, J., Williams, J., Daily, G., Noble, A., Matthews, N., Gordon, L., … Smith, J. (2017). Sustainable intensification of agriculture for human prosperity and global sustainability. *Ambio*, *46*(1), 4–17. https://doi.org/10.1007/s13280-016-0793-6

The Royal Society. (2009). Reaping the benefits: science and the sustainable intensification of global agriculture, London: The Royal Society.

Sanchez, P. A., Buresh, R.J., Leakey, R.R.B. (1997). Replenishing soil fertility in Africa. Philosophical Transactions of the Royal Society B352: 949.

Smale, M., & Jayne, T., (2003). Maize in Eastern and Southern Africa: 'Seeds' of Success in Retrospect, International Food Policy Research Institute, Washington, DC. EPTD Discussion Paper No. 97.

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. http://doi.org/10.1002/agr.21384

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., & Kanyama- Phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. Proceedings of the National Academy of Sciences, 107(48), 20840–20845.

Symeonakis, E., Calvo-Cases, A., Arnau-Rosalen, E. (2007). Land Use Change and Land Degradation in Southeastern Mediterranean Spain. *Environmental Management* 40(1): 80–94.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*(6898), 671–677.

USDA (2017). United States Department of Agriculture Economic Research Service. Corn Production. https://www.ers.usda.gov/topics/crops/corn/