LUND UNIVERSITY
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Effectiveness of Climate-Smart Agriculture in Uganda: Evidence from Micro-Level Data

by

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Abstract

I examine the climate-smart agricultural (CSA) practices of intercropping, inorganic fertilizer application and improved seeds use for their effects on crop yields in Uganda. Based on panel data from the Uganda National Panel Surveys (UNPS), I use a correlated random effects model and propensity score matching to explore the general effectiveness of CSA, the changing effects of CSA with climatological conditions and potential differences of the impact across Ugandan regions, agro-ecological zones and crop types. The empirical analysis indicates that the CSA practices of intercropping and improved seeds use are associated with higher agricultural productivity levels, increasing yields by around 48 to 56 percent according to the sample, whereas inorganic fertilizer application does not have a general significant effect. The impact of an intercropped cultivation system is particularly strong or at least still positive when farmers are exposed to critical weather stress, while the positive effect of improved varieties is conditioned by climatic variables. Further, I find substantial differences in terms of effectiveness of CSA between agro-ecological zones of Uganda and crop types. My findings have important policy implications for targeted agricultural programs to improve the productivity and resilience of Ugandan smallholders being confronted with the adverse consequences of climate change.

Keywords: Climate Change, Climate-Smart Agriculture, Food Security, Uganda

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1 Introduction

Despite of some people still denying it, it is a fact that climate change is an unavoidable reality and recent studies have stressed that meeting the goal of keeping global warming to a maximum of 1.5°C is unlikely in the long run and we will have to deal with the far-reaching consequences of this, spanning various dimensions (IPCC, 2018). Climate change becomes visible through various channels such as longer and more frequent drought spells, rising temperatures, as well as heavier and erratic rains (Below et al., 2010). Both heavier rains and persistent droughts increase soil erosion and vegetation damage, affecting agriculture and sustainable livelihoods. Additionally, increasing temperatures and prolonged droughts lead to faster loss of soil moisture and foster the spread of pests and diseases (Nyasimi et al., 2014). These changing conditions that many parts of the world increasingly experience have severe impacts on ecosystems and human development. This is also why *Climate Action* is part of the United Nations Sustainable Development Goals, being intrinsically related to all 16 of the other Goals of the 2030 Agenda for Sustainable Development such as for example *No Poverty* or *Zero Hunger* (UN, 2020).

The negative impact of climate change is unevenly distributed. People who are affected the most are also the least equipped to tackle the problems, both from a macro and micro perspective (Barrett, 2013). This is especially the case for vulnerably located developing nations in Africa. A feature that makes these countries even more vulnerable is their dependence on income from agriculture (Busby et al., 2014) combined with political, economic and social conditions being unfavorable to the well-being and safety of inhabitants, buildings, the economy and the environment (Murray and Ebi, 2012). One can conclude that the direct negative effects of climate change are most visible in regions which engage in activities dependent on favorable climate outcomes, such as the rainfed agriculture that is practiced in most parts of Sub-Saharan Africa (McCarthy et al., 2001).

My research focuses on the East African country Uganda. Implications of climate change have been identified as integral components of the overall constraints to agricultural productivity and consequently to a sustained growth and development trajectory of this nation. The economy and the well-being of the people are tightly bound to the environment and climate since about 80 percent of the population lives in rural areas and is dependent on rainfed agriculture. The magnitude and frequency of unpredictable climatic variability and extreme weather events is expected to increase, thereby increasing food insecurity, the spread of diseases, soil erosion and land degradation leading to landslides, damaged infrastructure and settlement as well as lower output from agriculture and natural resources. Recent years' experiences include more frequent droughts, heavy rains, floods, landslides and the outbreak of associated diseases, already indicating the magnitude of the problem (Government of Uganda, 2020c).

The combination of the adverse impacts of climate change and the weak adaptive capacity of African households implies that sustainable adaptation strategies have to come to the fore in policy analysis and debate. The implementation of climate-smart agricultural practices seems particularly relevant since agricultural productivity is crucial for economic growth, bearing potential to stimulate structural transformation, and also in terms of food security on a national level.

The overall goal of climate-smart agriculture (CSA) is to build resilience and adaptation to climate change, by increasing agricultural productivity in a sustainable manner (FAO, 2018). Practices with CSA potential include minimum soil disturbance, crop rotation, legume intercropping, the use of inorganic fertilizers and improved seeds, (inter alia) agro-forestry, improved livestock/grazing management and joint crop-livestock systems (FAO, 2014; Arslan et al., 2015). All of these practices theoretically have the potential to increase productivity, incomes and resilience and/or to reduce greenhouse gas (GHG) emissions stemming from agriculture.

However, if the impact of CSA practices is positive in the end is context-dependent and can thus not be generalized. While it is clear that CSA practices have the technical potential to increase or at least maintain yields of Ugandan farmers, the magnitude of this effect, how much of that can be associated with the practice itself (rather than changes in inputs and timing of cropping operations) and how it interacts with variables measuring changing climatic conditions requires further research. To quantify this effect is crucial for policy makers in order to be able to implement targeted policies aiming at improving the productivity and resilience of smallholder agriculture in Uganda in the face of the threat of climate change. My research question is therefore *Is the use of climate-smart agriculture practices by smallholders in Uganda effective for increasing agricultural productivity, particularly regarding changing climatic conditions?*

To approach this research question I implement a step-wise analysis, going from a general perspective to the specifics of the country. Based on theoretical considerations, the hypotheses being examined in my research are the following:

H1: CSA practices increase agricultural productivity.
H2: CSA practices increase agricultural productivity, especially when exposed to climatic shocks.
H3: The effect of CSA practices might differ across regions, agro-ecological zones (AEZs) and crops.

To investigate my hypotheses, I follow the approach of Arslan et al. (2015) and examine a set of potentially climate-smart agricultural practices (intercropping, inorganic fertilizer application, improved seeds use) for their effect on agricultural productivity in Uganda. Using household-level panel data from the Uganda National Panel Surveys (UNPS), covering approximately 3,200 households and the time period from 2009 to 2011 including two growing seasons per year, a correlated random effects model and subsequently a propensity score matching approach is applied.

The key results of the empirical analysis indicate that the CSA practices of intercropping and improved seeds use are associated with higher agricultural productivity levels, whereas inorganic fertilizer application does not seem to have a general significant effect. The impact of an intercropped cultivation system is particularly strong or at least still positive when farmers are exposed to critical weather stress, while the positive effect of improved varieties is conditioned by climatic variables. Further, I find substantial differences in terms of effectiveness of CSA practices between agro-ecological zones of Uganda and crop types.

The rest of the paper is structured as follows: sections 2 and 3 provide the necessary contextual framework and essential findings from academic literature. Section 4 includes a description of the data used, the econometric model and the selection of variables. In section 5 the empirical findings are analyzed and discussed. Section 6 concludes.

2 Contextual Framework

In order to understand the relevance of my research topic, it has to be clear which role agriculture has for the economy and the livelihoods of Uganda's population, and how the phenomenon of climate change is expected to affect prevailing climatological conditions and agricultural output. This section therefore provides the necessary contextual framework, explaining the significance of the agricultural sector, geographical as well as agricultural characteristics and the impact of climate change.

2.1 Uganda's Economy: The Role of Agriculture

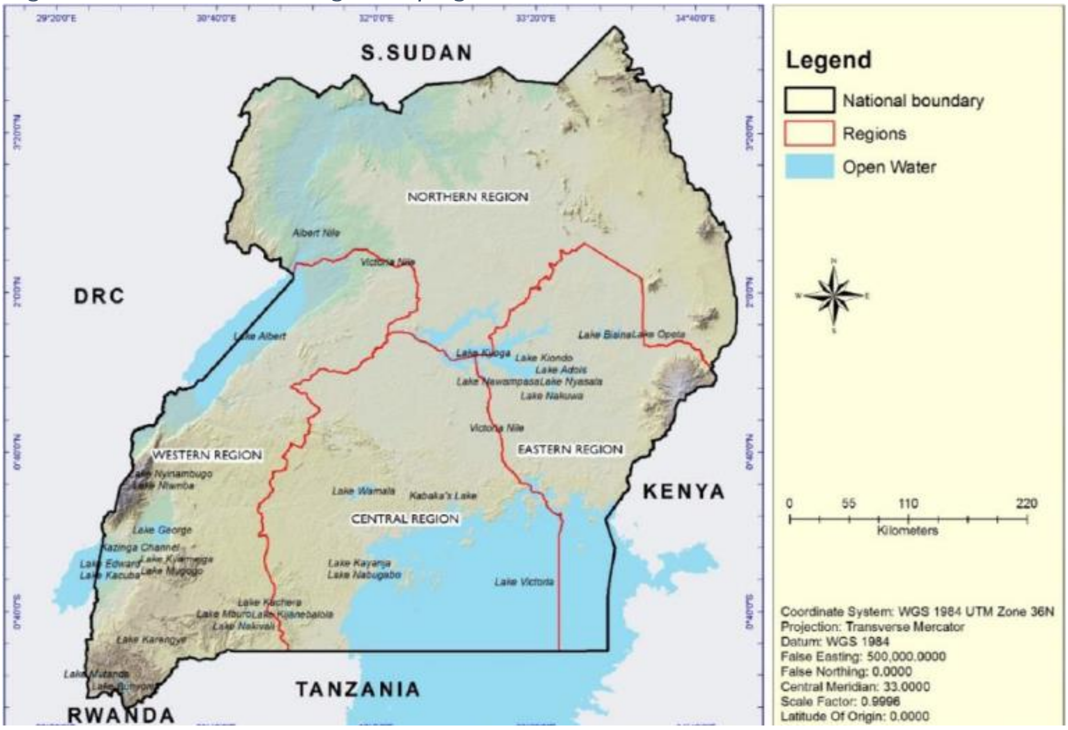
Uganda is a land-locked East African country of about 241,500 square km, sharing borders with the Democratic Republic of the Congo, Kenya, Rwanda, the Sudan and Tanzania (Figure 1). Its geography is characterized by a sizable availability of natural resources, a relatively fertile soil as well as rich biodiversity and vegetation. Further, the country is rich in water resources, with approximately 18 percent of its surface area being composed of water bodies or swamps. Lake Victoria, which is located on Uganda's southeastern border, is the largest lake of the African continent (UNDP, 2020). The country is divided into the Northern, Eastern, Western and Central region (Figure 2) and counts 116 districts (Bernard et al., 2018).

Figure 1: Location of Uganda

Source: Google Maps.

Uganda’s annual population growth rate is among the highest on a global level, amounting to 3 percent. The high fertility rate can be mainly explained by socio-cultural factors such as early marriage, the unmet need for family planning, low educational levels, high poverty, low contraceptive use and the general low status of women within the Ugandan society (Government of Uganda, 2020b; UNFPA, 2017). The country’s population is expected to grow from 35 million to 100 million by 2050. Simultaneously, the annual urban growth rate is 5.2 percent and the population living in urban areas which is currently about 6.4 million is expected to reach 22 million by 2040 (World Bank, 2020a). The map in Appendix A.1 shows the population distribution in 2018, with most people being located in the south and southeastern regions.

Figure 2: Administrative Regions of Uganda

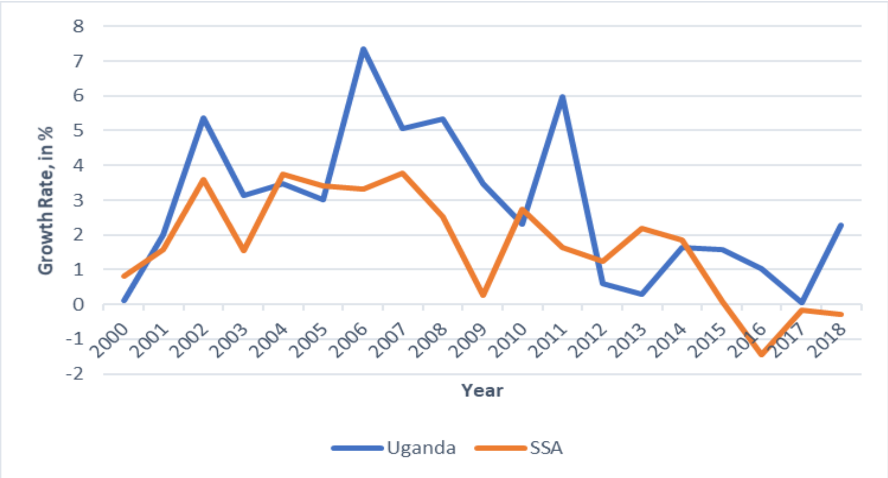


Source: Bernard (2018).

Despite the country’s goal to reach the lower middle-income status until 2020, it is still classified as low income economy according to the World Bank classification. After recording relatively high GDP per capita growth rates between 2002 and 2011 and generally significantly higher growth than the Sub-Saharan African average, growth slowed down (Figure 3). Reasons for this slowdown were sluggish productivity growth, different shocks such as adverse weather conditions, conflicts in South Sudan, private sector credit constraints and poor execution of public projects (World Bank, 2020c). However, as can be seen in Figure 3, per capita income growth rates started to increase again in 2017. In 2019, the Ugandan economy experienced strong economic growth of 6.5 percent. This growth has been mainly driven by increasing domestic consumption as well as private and public investments, improving the country’s business environment. Net foreign direct investment (FDI) inflows, targeting primarily the oil and gas, manufacturing and hospitality sectors, reached a level of 5.1 percent of GDP in 2019 as compared to 3 percent of GDP in 2018. Higher levels of public spending especially favored manufacturing, construction and real estate sectors. In 2019, the economy's exports, mainly encompassing primary products, could not keep up with the rapid growth of investment-related imports, resulting in a widening trade deficit (AFDB, 2020; World Bank 2020c). Despite the recent favorable growth progress however, wages remain on low levels by international standards (Van Waeyenberge and Bargawi, 2018).

Regarding the economy's structure, Figure 4 shows that Uganda's services sector accounts for the highest share of value added as percentage of GDP, indicating the country's transition to a service economy. However, the economy faces severe challenges, such as low productivity levels and low job creation. In general, productivity between sectors differs significantly, with the industrial sector reporting productivity levels that are eight times higher than in agriculture or services. Nevertheless, the industrial sector is not able to absorb the large number of young people reaching working age every year (AFDB, 2020). The young age structure (Figure 5) poses major challenges for the economy. Whereas 700,000 young people are ready to enter the labor market per year, only 75,000 jobs are created. As a consequence, more than 70 percent of Ugandans are employed in the agricultural sector (Figure 6), often on a subsistence basis. The country's expected growing population will additionally exacerbate this situation (World Bank, 2020a).

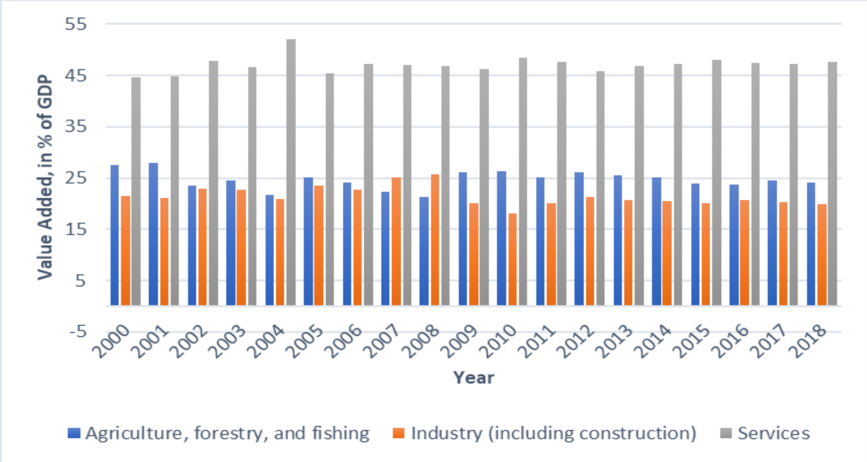
Figure 3: GDP per capita Growth, Uganda in comparison to Sub-Saharan Africa, 2000-2018



Source: Based on data from World Bank (2020b).

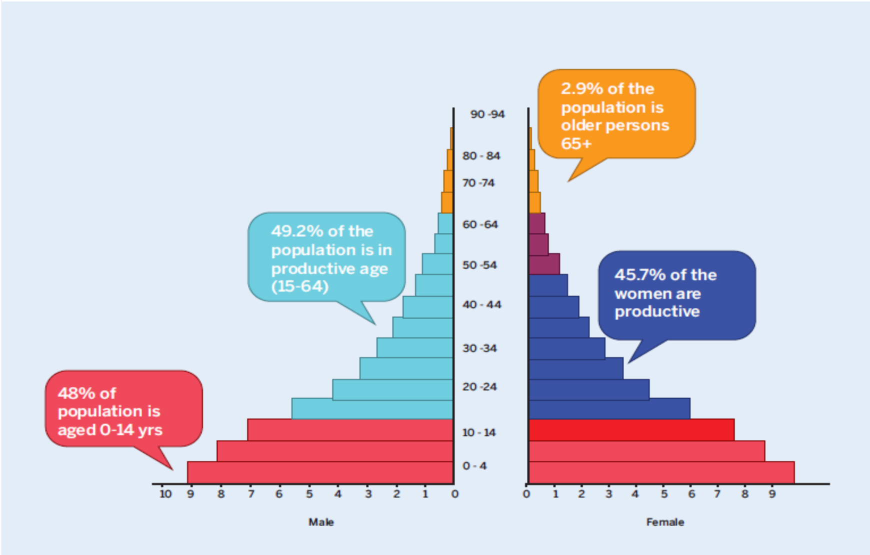
The government's strategy to stimulate growth and make it more inclusive is to support industrial development since this sector is rather underdeveloped (accounting for around 18 percent of GDP) but highly important to absorb an increasing number of low-skilled labor. These efforts might explain the sector's high contribution to GDP growth in 2019 (Appendix A.2).

Figure 4: Value Added per Sector, Uganda, 2000-2018



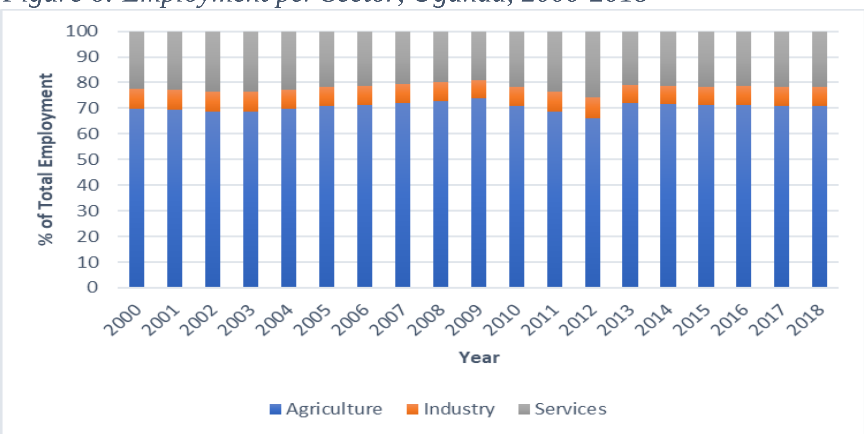
Source: Based on data from World Bank (2020b).

Figure 5: Demographic Structure of Uganda's Population



Source: UNFPA (2017).

Figure 6: Employment per Sector, Uganda, 2000-2018



Source: Based on data from World Bank (2020b).

Even though agriculture contributed only marginally to the recent high growth rates (Appendix A.2), the sector is of major relevance for the broader economy, livelihoods and poverty reduction. Firstly, primary and processed agricultural goods account for about 45 percent of the country's exports. As already outlined, the sector further employs more than 70 percent of the workforce and is hence important for household income growth and consumption, being simultaneously key to stimulate growth of other sectors. Additionally, the living standards of Ugandans dependent on agriculture are highly related to the performance of the mainly rainfed agricultural sector and therefore vulnerable to external or climatological shocks. Declining agricultural commodity prices or absent rainfall affect crop income growth negatively, having severe consequences for poverty reduction. The increasing risk imposed by climate change is also a major constraint to productivity growth. People facing those risks are less likely to invest in inputs critical to make production processes more efficient. Channels proved to be effective for risk mitigation are investments in irrigation systems, the modernization of agricultural production and practices as well as improved social protection programs (World Bank, 2020c).

Improving the agricultural sector's productivity and resilience seems even more important when looking beyond economic growth developments. The high growth rates between 1990 and 2010 allowed the country to reduce poverty levels substantially. However, along with sluggish growth rates poverty levels increased again from 19.7 to 21.4 percent between 2012 and 2016, implying that 10 million people were living below the national poverty line (AFDB, 2020; IMF, 2020; World Bank, 2020a). Moreover, growth seems to be less inclusive since its impact on poverty reduction has declined as compared to the period 2000 to 2009 (World Bank, 2020c). Additionally, the Human Development Index of 0.528 in 2018 (rank 159 out of 189 countries; low human development level) confirms Uganda's poor performance in terms of economic development, by reflecting not only its low incomes levels, but also the poor quality of the country's education and health system (UNDP, 2019). Undernutrition is a severe problem, affecting one-third of all children aged five years and below (World Bank, 2020a).

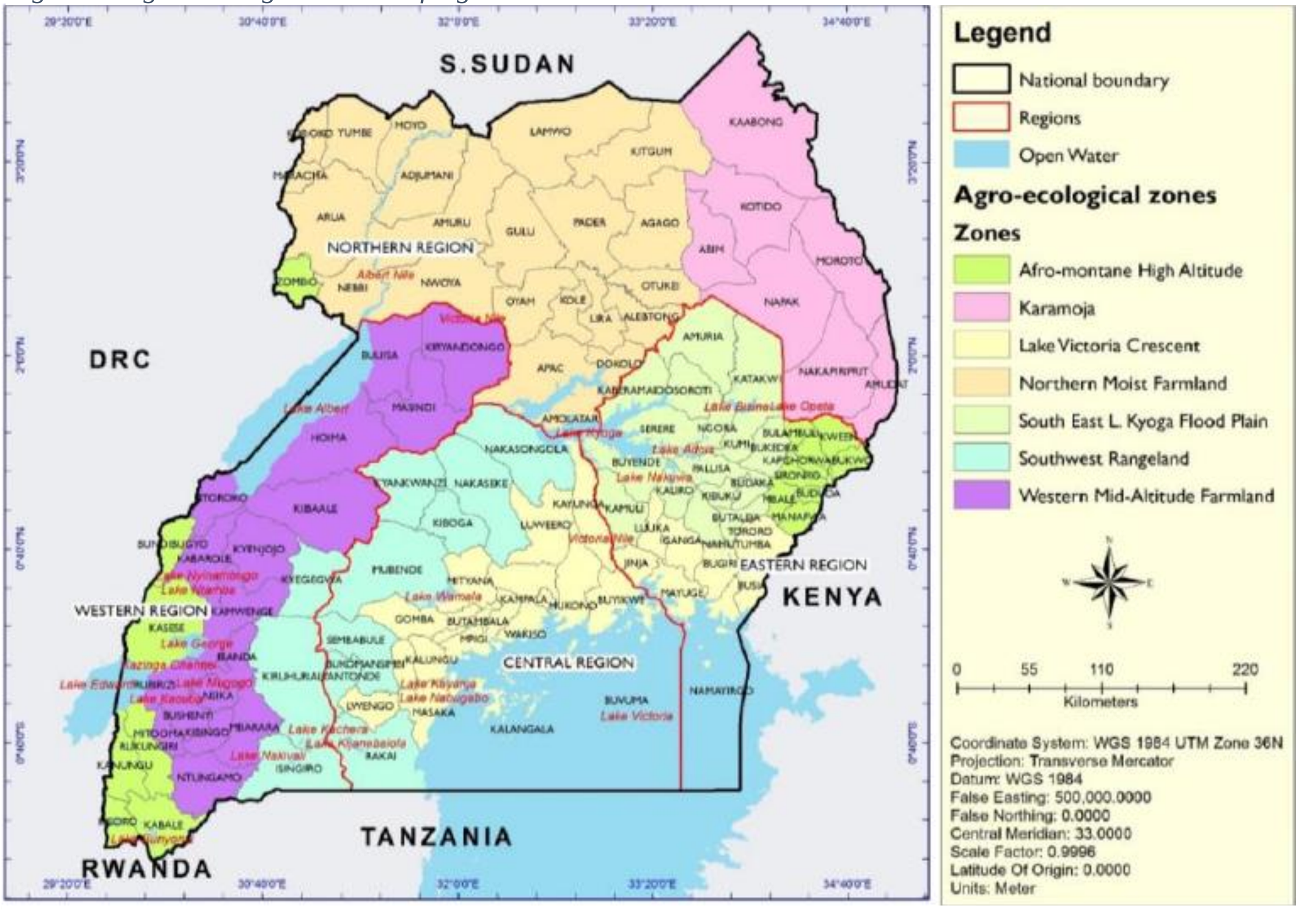
The agricultural sector consequently seems to play a key role, being closely linked to poverty reduction, food security for a growing population and future inclusive growth paths of the country. A sustainable development strategy should not only include increasing investments in education and health, but also focus on economywide productivity improvements. Considering the overall significance of agriculture and its potential to boost structural transformation, finding solutions to make this sector more productive and resilient to adverse climatological events should become a priority.

2.2 Geographical and Agricultural Characteristics

Uganda is located within a relatively humid equatorial climate zone. The country's topography, prevailing winds and water bodies, however, are responsible for large differences in rainfall patterns across regions (Babel and Turyatunga, 2015). The average annual precipitation rate is between 800 and 1500 mm. The rainfall is dividing the south, eastern, central and northern regions into two seasons (March to May and September to November), whereas the northeastern region is only characterized by one season (April to October) (Onyutha, 2016). The temperature is relatively stable across seasons, varying mainly with altitude. Variations in the sea surface temperatures of the tropical Pacific, Indian and Atlantic Oceans have a strong influence on the magnitude and timing of annual rainfall in Uganda (Bernard et al., 2013).

A common approach to classify regions of a country according to soil, landform and climatic characteristics are so called agro-ecological zones. The elements used in the definition of these zones further include climatic and edaphic requirements of crops and different management systems under which the crops are grown (FAO, 1996). One way to categorize Uganda's regions is presented in Figure 7, dividing the country into the seven AEZs of Western Mid-Altitude Farmlands, Lake Victoria Crescent, Karamoja, South Kyoga Flood Plains, Afro-Montane, Northern Moist Farmland and Southwest Rangelands. Another classification that I will use for the empirical analysis was introduced by the International Food Policy Research Institute and divides Uganda into a tropic-warm/humid, tropic-cool/humid, tropic-warm/subhumid and tropic-cool/subhumid zone (Appendix A.3).

Figure 7: Agro-Ecological Zones of Uganda



Source: Bernard (2018).

Generally, the Ugandan agricultural sector produces 17 major food crops, encompassing cereals (maize, millet, sorghum, rice), root crops (cassava, sweet potatoes, Irish potatoes), pulses (beans, cow peas, field peas, pigeon peas), oil crops (groundnuts, soya beans, sim sim) and plantain bananas (for food, beer, sweet types). In 2012, the total land area planted for food crops was about 5,700,000 ha. Maize, potatoes, cassava, and bananas are the crops with the highest production quantities. The main cash crops are coffee, tea, cotton and tobacco. Out of these, coffee presents a principal source of foreign exchange for the country, being the leading export commodity in terms of value (Government of Uganda, 2018). Table 1 summarizes the distribution of the main crops grown across AEZs.

As mentioned in the previous section, agricultural goods account for almost half of the country's exports. However, the degree of commercialization of agriculture is generally low and most of the production is consequently locally consumed. This is also reflected by the fact that food crops account for about 12 percent of GDP whereas exported cash crops only account for 1.7 percent. The cash crops, however, constitute a large share of the export revenues (Van Waeyenberge and Bargawi, 2018). The fact that local consumption is high as compared to exports is confirming that agricultural output is of major relevance for food security and for securing income levels of Ugandan farmers. Having the long-term goal of sustained economic growth in mind and the necessity of structural transformation, the agricultural sector has obviously to become more competitive and better integrated into the world economy. This again, can only be reached if farmers can increase their productivity levels.

Table 1: Agro-Ecological Zones and Key Crops Grown

Agro-ecological landscapes	Part of Uganda	Rainfall distribution	Farming systems	Cash and food crops grown
Afro-montane	Eastern	Bi-modal high rainfall (>1,200mm/year)	Banana-coffee systems	Coffee, Banana, Cassava , Sweet potatoes, Irish potatoes, Maize, Sorghum, Finger millet, Rice
Karamoja	North eastern	Uni-modal low rainfall (400-700mm/ year)	Agro-pastoral system	Finger millet, Pearl millet, Maize, Sorghum, Irish potatoes, Beans, Cowpeas, Ground nuts, Cassava, Sweet potatoes
Lake Victoria Crescent	Central	Bimodal high rainfall (>1,200mm/ year)	Banana – coffee system	Banana, coffee
Northern moist	Northern	Uni-modal low to high rainfall (1000-1,200 mm/year)	Mixed cropping system	Cereal, cassava, cotton, legumes
South East L.Kyoga floodplain	Eastern	Bimodal high rainfall >1,200mm/ year	Mixed cropping systems	Finger millet, banana, maize
Southwest rangeland	South west	Bimodal low to medium rainfall (900-1,200 mm/year)	Banana-coffee system	Bananas, coffee, cereal, sweet potatoes
Western Mid-altitude	Mid-western	Bimodal average rainfall of 1,270mm/ year with high variability	Banana-coffee system	Maize, beans, irish potatoes, sorghum, sweet potatoes

Source: Bernard (2018).

The country's agricultural sector is generally rather fragmented, being mainly dominated by small-scale farmers combining subsistence farming with cash crop and livestock farming. Regarding land ownership, the majority owns land individually, but in the northern parts pastoralists land areas are owned communally. The sector is gradually modernized, but this process is happening at a rather slow pace, with large parts of cultivation still being done by hand or cattle driven ox ploughs. Commercial cash crop farms including tea, palms, rice and sugarcane plantations are mainly found in the Central, South and Southwest of Uganda. Coffee and bananas are usually produced on small-scale plantations, expect for some areas of the Southwest where bananas are grown on a larger scale to supply urban centers of the country (Government of Uganda, 2020a).

2.3 Uganda and Climate Change

Climate change can be considered a global threat, however, countries are not equally exposed to its risks and adverse consequences. Uganda is among the most affected countries, ranking 155 out of 181 countries in the ND-GAIN index (2017)[1] measuring climate vulnerability. It is the 14th most vulnerable and 48th least prepared country, implying that it is not able yet to cope with the negative implications climate change brings along (ND-GAIN, 2020).

Regarding current trends in changing climatic conditions, data suggests no clear pattern of changes in annual rainfall in Uganda. However, there has been a decrease in precipitation in the northern districts of Gulu, Kitgum and Kotido as well as in Kasese in the West. Temperatures have increased significantly, rising at a rate of 0.52°C per decade over the past 30 years. In the period 1960 to 2003, the yearly average number of hot days experienced an increase of about 20 percent and the average number of hot nights an increase of over 37 percent (Ministry of Foreign Affairs of the Netherlands, 2018).

Projections which analyze the future climate developments in Uganda indicate that most parts of the country will face a substantial decrease in precipitation (-5 to -30mm per month) and a much wetter December-January-February season, a combination that will lead to drier conditions for the rest of the year or a less favorable rainfall distribution over the year (the wet season will extend from September-October-November towards December-January-February). Simultaneously, temperatures are expected to increase even further, particularly in the March-April-May and June-July-August seasons. Moreover, the country's water bodies will be adversely affected. For instance, a drop of total rainfall over Lake Victoria in combination with rising temperatures will impact the water level. Extreme weather events are further likely to occur more frequently in the future in large parts of Uganda. Projections conclude that especially the southern and north-eastern regions will experience more and excessive heats and rains, whereas the southwestern and north-western parts seem to face the lowest risk (Government of Uganda, 2015).

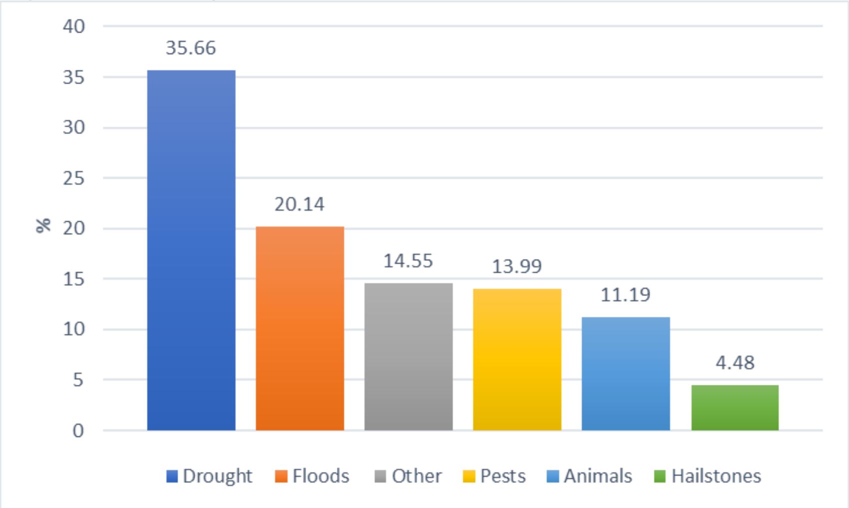
Economic growth is one key element for a government being able to provide effective adaptation measures to climate change since it usually implies lower poverty levels, a higher capacity to build sustainable infrastructure and a larger tax revenue base for the government. However, climate change also has a negative impact on growth (Government of Uganda, 2015). According to Dell et al. (2012), a one degree increase in temperature results in a decrease of 1.8% in GDP growth for Sub-Saharan African countries. The negative link between climate change and agricultural productivity seems to be one core channel through which this adverse effect on growth can be explained, especially when thinking of Uganda's high dependency on rainfed agriculture.

[1] The ND-GAIN index measures a country's vulnerability to climate change and other global challenges in combination with readiness to improve resilience.

For the case of Uganda, implications of climate change have been identified as integral components of the overall constraints to agricultural productivity. Rising temperatures and extreme weather events lead to reduced yields and a loss in livestock. Crops and post-harvest activities are further affected by increasing precipitation during dry seasons. A general decrease in the predictability of rainfall intensity and a potentially false onset of the rainy season makes crop failure more likely (Ministry of Foreign Affairs of the Netherlands, 2018). The largest impact is expected for the food crops cassava, potato and sweet potato whose yields could decline by 40 percent by 2050. Likewise agricultural exports are a major concern since export cash crops of coffee, tea and cotton will be hit strongly by climate change. Yield losses for coffee alone could amount to 50-75 percent by 2050 due to reduced yields and a loss of areas where coffee can be cultivated (Government of Uganda, 2015).

More specifically, Hisali and Kasirye (2008) for example find that around 34 percent of crop damage in Uganda is due to climate induced phenomena such as rainfall shortage, crop diseases and insect damage. This trend is confirmed when having a first look at the data used for this research (Figure 8), indicating that pre-harvest losses among Ugandan farmers are mainly caused by droughts, floods, pests and animals. Other research finds that 70-97 percent of households will be adversely affected by changing climatic conditions in Uganda. The southwest will be most affected due to smaller farm sizes and limited livelihood alternatives (Bagamba et al., 2012). Secondary effects derive from the fact that the agricultural sector remains of great importance for Uganda's economy, especially in terms of employment, as outlined in the previous sections. Improving the resilience of households depending on the agricultural sector seems therefore crucial.

Figure 8: Reason for Pre-Harvest Loss in 2011, in %



Source: Based on data from UBOS (2020), (UNPS, Wave 2011).

3 Literature and Theory Section

Possible adaptation strategies to climate change in agriculture are diverse and it is crucial to discuss their effectiveness in the light of climate change. This section seeks to give an overview of different adaptation strategies and to justify why the approach of climate-smart agriculture is particularly relevant in this context. Afterwards, I briefly summarize what literature has generally found in terms of productivity implications for the CSA practices to be analyzed, while also highlighting the contribution of my research to the literature.

3.1 Adaptation Strategies to Climate Change

The combination of the adverse impacts of climate change and the weak adaptive capacity of African households implies that sustainable adaptation strategies have to come to the fore in policy analysis and debate.

According to the Government of Uganda (2015), there are six general adaptation possibilities in agriculture. The first one is to expand extension services and provide rural farmers with systems conveying timely climatic information. Further, more diversified agricultural activities and improved post-harvest storage methods can help compensating for the climate-related yield losses, improve food security and incomes. Specific insurance schemes and improved access to low-interest credits is important to insure farmers against crop damage and livestock loss. Another strategy is to make rangeland management more integrated and sustainable or to improve the water storage possibilities for households or villages in areas particularly affected by droughts. Lastly, promoting the application of climate-smart agriculture practices is considered crucial to increase resilience to the impacts of climate change.

Looking more specifically at possible solutions on the micro-level, Hisali et al. (2011) identify 5 different broad adaptation strategies of households to climate change in Uganda: 1) borrowing from formal and informal sources; 2) increasing wage employment, working as self-employed, increasing agriculture labor supply, migration to work elsewhere and withdrawing children from school and sending them to work; 3) reducing consumption; 4) running down assets and savings including mortgaging assets, selling assets and utilizing savings; and 5) technology based adaptation strategies such as changes in crop choices and improving technology (CSA).

The only option out of the ones identified by Hisali et al. (2011) that improves the resilience of Ugandan smallholders in a sustainable way and which bears potential to increase productivity levels is the one of climate-smart agricultural practices, while the others can rather be considered to be short-term solutions. Since the agricultural sector employs the major part of the population, it is crucial for household income growth and consumption, being in turn critical to stimulate growth in other industries. As already pointed out, structural change from an economy dominated by subsistence agriculture to an economy based on commercial agriculture and manufacturing has not really materialized in Uganda yet. However, the persistent high population growth rate combined with challenges such as posed by climate change imply that structural transformation is an urgent matter. The main reason behind slow structural change and the lack of productive employment creation is the failure to expand the productive capacity in sectors that are able to absorb the rapidly growing population entering the labor force. Additionally, absent structural transformation can be explained by the failure to accelerate agricultural upgrading and is likewise associated with the failure to increase manufacturing value added shares in GDP (Van Waeyenberge and Bargawi, 2018). In brief, considering the structure of Uganda's economy and future challenges, the option of climate-smart agricultural practices is of particularly high relevance since agricultural productivity is crucial for sustained economic growth, bearing potential to stimulate structural transformation, and also in terms of food security on a national level.

Climate-Smart Agriculture is generally defined as an approach that puts emphasis on the farmer, fisher and/or herder. The overall goal is to sustainably increase agricultural productivity and improve the incomes and livelihoods of farmers. Different CSA practices are seeking to support farmers to adapt to changing climatic conditions and simultaneously contribute to reduced GHG emissions (FAO, 2018). The concept of CSA is certainly not a "one-size-fits-all" approach that can be universally applied but, in contrast, should be adapted to local contexts (CCAFS and UNFAO, 2014). Practices with CSA potential include: minimum soil disturbance, crop rotation, legume intercropping, the use of inorganic fertilizers and improved seeds, (inter alia) agro-forestry, improved livestock/grazing management and joint crop-livestock systems (FAO, 2014; Arslan et al., 2015). All of these practices theoretically have the potential to increase productivity, incomes and resilience and/or to reduce GHG emissions stemming from agriculture.

For the case of Uganda, there are already several projects in place to support the implementation of CSA practices, such as for example a $130 million project for the period 2016-2020 under the Northern Uganda Social Action Fund, supported by the World Bank (World Bank, 2019).

3.2 Productivity Implications of Climate-Smart Agriculture

The general productivity benefits from the use of inorganic fertilizers and improved seeds varieties have been widely discussed in the literature dealing with green revolution technologies. The adoption of improved seeds has been proved to increase agricultural production in many regions and to be an effective instrument for reducing rural poverty (De Janvry and Sadoulet, 2002; World Bank, 2005). Likewise, inorganic fertilizer is considered important to increase yields in Sub-Saharan African countries (Larson and Frisvold, 1996; Evenson, 2003). Practices such as minimum tillage, legume intercropping and crop rotation are also called *conservation agriculture* (CA), potentially having positive environmental and yield effects. Findings from different meta-studies generally agree on the yield improving potential of these practices, however, it still remains an open question under which exact circumstances this is the case. Lal (2009), for example, concludes that mulching and no-till practices improve soil conditions, yields in some cases and profits since lower inputs are required. Pretty et al. (2006) looks at 286 country case studies from developing countries and reveals that the introduction of CA in the context of 'best practice' sustainable agriculture interventions for smallholders led to an average yield improvement of about 100 percent. Another meta-analysis comprising 217 case studies by Branca et al. (2011) finds that practices such as cover crops, crop rotations and improved varieties have increased cereal yields on average by 116 percent. In addition, reduced tillage and crop residue management are estimated to increase yields by 106 percent, while agroforestry techniques are associated with a 69 percent increase. The beneficial impact of tillage management and agroforestry seems to be particularly strong in dry regions. However, it should be highlighted that the studies by Pretty et al. (2006) and Branca et al. (2011) are mainly based on examples where the use of CSA practices was actively promoted and therefore not implemented spontaneously by farmers not being part of these intervention projects.

If the impact of CSA practices is positive in the end is context-dependent and can thus not be generalized. Arslan et al. (2015) for example examine the case of Zambia and find that minimum soil disturbance and crop rotation have no significant impact on agricultural productivity, but that legume intercropping significantly increases yields and reduces the probability of low yields even under climatic stress. They further find that the average positive impacts of inorganic fertilizer and improved seeds use are significantly conditioned by climatic variables. Timely access to fertilizer emerges as one of the most robust determinants of yields and their resilience. For the case of Uganda, there barely exists literature which assesses the productivity implications of climate-smart agriculture practices. One study by Bagamba et al. (2012) investigates possible adaptation strategies to increase the resilience and sustainability of agricultural systems in three regions of Uganda and find that there will be no positive gains from encroaching on swamps. They conclude that improving productivity of important crops in addition to adoption of grade cattle will probably be a better adaptation strategy for climate change. A study by Pender et al. (2004), investigating general strategies to increase agricultural productivity in Uganda, further emphasizes that the effectiveness of specific measures is location-specific and might thus differ across regions or AEZs. My research seeks to contribute to the debate by providing unseen evidence on the effectiveness of a set of practices with CSA potential, including intercropping, inorganic fertilizer application and improved seeds use. Most importantly, the use of CSA is not assessed in the context of specific interventions which are most likely subject to self-selection biases and therefore not necessarily meaningful, but my research is about the spontaneous adoption of these practices among Ugandan smallholders. Additionally, I provide evidence on how the impact of these practices changes along with variables measuring climatic stress or shocks and I evaluate the effectiveness on more disaggregated levels.

4 Data and Methodology

4.1 Data and Sample Construction

This research is based on data from the Uganda National Panel Surveys (UNPS) that are conducted as part of the *Living Standards Measurement Study - Integrated Surveys on Agriculture* (LSMS-ISA) household survey project. The idea behind this initiative is to improve existing agricultural data, often being subject to inconsistent investment, institutional and sectoral isolation as well as methodological weakness. The LSMS-ISA team collaborates with national statistical offices in the Sub-Saharan African region, by supporting multiple rounds of a nationally representative panel survey, based on a multi-topic approach which aims at improving the understanding of the links between agriculture, socioeconomic status, and non-farm income activities. For the case of Uganda, the UNPS are conducted by the Division for

Socioeconomic Surveys of the Uganda Bureau of Statistics (UBOS). The LSMS-ISA team provides technical assistance to the design of the project and also supports the data analysis (World Bank, 2020d).

The UNPS encompasses household-level panel data from six survey waves: 2005-2006, 2009-2010, 2010-2011, 2011-2012, 2013-2014 and 2015-2016. For this research, the years 2009, 2010 and 2011 will be used. Per year, two survey rounds are conducted since Uganda has two growing seasons: January-June and July-December. The UNPS sample covers approximately 3,200 households and is representative at the national, urban/rural and main regional levels (North, East, West and Central regions). The initial sample was visited for two consecutive years (2009/10 and 2010/11). In the subsequent survey rounds, parts of the sample were replaced by new households from the updated sample frames of the 2012 Population and Housing Census (World Bank, 2020e).

Data across all waves can be linked through the unique household identifier. Due to observed attrition at the household- and individual-levels, and the inclusion of new enumeration areas, households, and individuals to the UNPS sample, matching data across all waves at the household- and individual-levels is certainly not perfect.

Generally, the UNPS contains a broad range of indicators on socio-economic, agricultural and climatological conditions. According to the selection of included variables, the number of observations can vary between the analyzed models.

The figures provided in Appendix B show how the households of the sample are distributed among regions and AEZs (two definitions used). One can see that the four regions are covered relatively equally by the sample. In terms of AEZs (definition 1), most households are located in the tropic-warm/humid or tropic-cool/humid areas. Looking at the second definition of AEZs, the distribution is rather fragmented, with the major part being found in the Lake Victoria Crescent and Northern Moist Farmland zones.

4.2 Econometric Model

The modelling is divided into three parts. In this way, the different hypotheses can be examined stepwise.

H1: CSA practices increase agricultural productivity.

Firstly, I analyze which factors are generally determining agricultural productivity, thereby testing if increased productivity is due to climate-smart agricultural practices or rather due to "lucky" conditions.

The baseline (reduced form) specification is the following:

$$(1)\ Y_{cpait} = \alpha + \beta_1 CSA_{cpait} + \beta_2 ECON_{it} + \beta_3 SOCIO_{it} + \beta_4 PROD_{pait} + \beta_5 INFRA_{it} + \beta_6 CLIMA_{it} + \varepsilon_{cpait}$$

where Y_{cpait} denotes agricultural productivity proxied by the yield of crop c (kg/acre) on plot p of parcel a owned by household i at time t. CSA_{cpait} is a vector of different climate-smart agricultural practices (dummies indicating crops/plots that have been cultivated with the corresponding practice at time t: Intercropping, Inorganic fertilizer, Improved seeds). $ECON_{it}$ is a vector of economic factors (Commercial agriculture, Off-farm income, Assets, Land size), $SOCIO_{it}$ encompasses socioeconomic variables (Age head, Number of adults, Labor availability, Education – less than primary/junior/secondary/degree, Certificate, Tenure insecurity, Training, Female head), $PROD_{it}$ production-specific (Organic fertilizer, Pesticides/herbicides, Irrigated) and $INFRA_{it}$ infrastructure factors (Electricity access, Distance road, Distance market center). Lastly, $CLIMA_{it}$ a vector of climatic and agro-ecological variables (Shock, Erosion, Good soil quality, Poor soil quality, Moderate nutrient constraint, Average temperature, Rainfall, False onset rainy season, Rainfall pattern change). In order to confirm the first hypothesis of climate-smart agricultural practices having a positive impact on agricultural productivity, the coefficients of the CSA indicators have to be positive and significant.

GLS: Random Effects and Correlated Random Effects Model

My research is based on a panel model analysis, using the generalized least squares (GLS) estimator. Several tests are executed in order to test for the validity of the basic assumptions of GLS. One essential aspect to consider is the assumption of normality which presumes that the errors, and hence the dependent variable y, are normally distributed. Tests for the fulfillment of this assumption show that the log transformation of the variables agricultural productivity, non-agricultural income, assets and land size should be used. Furthermore, GLS assumes no collinearity which means that the values of each explanatory variable should not be exact linear functions of the other explanatory variables in order to obtain reliable estimates (Hill et al., 2018). The correlation matrix provided in the Appendix C.1 shows that the correlation degree of all used explanatory variables is on acceptable levels. Further, I use cluster-robust standard errors in order to avoid problems of serial correlation and heteroskedasticity.

Panel models generally provide two modelling options which control for time-invariant heterogeneity: fixed or random effects methods. Whereas fixed effects (FE) models allow the unobservables to be correlated with the right-hand side, the random effects (RE) models treat these parameters as a random variable uncorrelated with the right-hand side, whose probability distribution can be derived from data (Wooldridge, 2010). Since FE models do not facilitate the inclusion of time-invariant variables which are relevant in this context, this model is not the best option to choose. Instead, I estimate a RE model in a first step. However, since the Hausman test rejects the unrelatedness assumption of RE and therefore suggests that a FE estimation would actually be more appropriate, I apply a Chamberlain-like correction to the RE model in order to estimate a correlated random effects (CRE) model. This solution is a common approach to get FE estimates for the time-variant variables included in the model and simultaneously include time-invariant factors (Mundlak, 1978; Wooldridge, 2010; Schnuck, 2013). The CRE model allows and right-hand side variables to be correlated (Chamberlain, 1980) and its estimation is based on the inclusion of all time averages of the time-variant factors as explanatory variables (Wooldridge, 2009).

Propensity Score Matching

In order to check the robustness of the results from the first model and to establish a more causal relationship, however, I use the method of propensity score matching (PSM) in a second step. This method seems useful since randomization is impossible and no convincing natural experiments can be found for this case. The key idea is for each treated individual to find an untreated counterpart that has the same propensity score but that remains untreated. Any difference in the outcomes of treated and untreated individuals are then attributed to the treatment. The "treatment" in this case would be the use of the respective CSA practice. The parameter of interest is then the 'average treatment effect on the treated' (ATET) (Caliendo and Kopeinig, 2005).

PSM is based on several assumptions. The conditional independence assumption implies that the selection is exclusively including observable factors and that all variables having an impact on the treatment assignment and potential outcomes are observed. Further, the assumption of common support or overlap condition requires that individuals with the same observed covariate value X have a positive likelihood of becoming both treated and non-treated (Heckman et al., 1999).

When applying the method of PSM for binary treatment variables, the first fundamental decision to take is concerning the inclusion of covariates. The selection should be based on two criteria. Firstly, only variables that simultaneously influence the participation decision (CSA practices) and the outcome variable (agricultural productivity) should be included. Secondly, it is required that only variables that are unaffected by the participation are included (Caliendo and Kopeinig, 2005). Taking these criteria into consideration, my selection of covariates for the PSM includes the variables land size, the distance to the capital of the district, commercial agriculture as income strategy, a certificate indicator (tenure security), the length a household was hit by a shock and education.

Before the matching, the pre-treatment observable characteristics should be different by group (see Appendix C.2 for proof). After the matching, however, there should not be considerable differences anymore between the treatment and control groups. Thus, the matching process should balance the distribution of the relevant variables in both the control and treatment group (balancing condition) (Caliendo and Kopeinig, 2005). To justify the matching and to show that the balancing condition is fulfilled, the results from the t-test are provided in Appendix C.3-C.5). The graphs in Appendix C.6 additionally prove that the overlap assumption is satisfied as well.

Besides the right choice of covariates, an appropriate matching algorithm has to be found. Algorithms generally determine how the estimated propensity scores are used to create treatment and control groups. Considering the high number of observations, I decide for the nearest neighbor (NN) matching estimator for which the individual from the comparison group is chosen as matching partner for a treated individual that is closest in terms of propensity score. I further chose the 'with replacement' option that allows an untreated individual being used more than once as a match, thereby increasing the average quality of matching and decreasing the bias (Smith and Todd, 2005).

H2: CSA practices increase agricultural productivity, especially when exposed to climatic shocks.

CSA practices are expected to have a positive effect on yields especially when facing rainfall or temperature stress. In order to test whether the impact of the CSA practices is conditional on climatic conditions, I use interaction terms between different CSA practices and selected climatic variables in the CRE model. More specifically, I look at interactions between the CSA indicators and indicators for a false onset of the rainy season, a rainfall pattern change and a climate shock (flood/drought). The general specification to test this hypothesis is the following:

$$(2)\ Y_{cpait} = \alpha + \beta_1\left[CSA_{cpait} \cdot CLIMA_{it}\right] + \beta_2 CSA_{cpait} + \beta_3 ECON_{it} + \beta_4 SOCIO_{it} + \beta_5 PROD_{pait} + \beta_6 INFRA_{it} + \beta_7 CLIMA_{it} + \varepsilon_{cpait}$$

If these interactions are positive and significant, the hypothesis would be confirmed since the effect of CSA practices on agricultural productivity would be greater under climatic stress.

H3: The effect of CSA practices might differ across regions, AEZs and crops.

In a third step, specification (1) is further used to examine hypothesis 3, testing if the estimation results differ across Ugandan regions, agro-ecological zones (two definitions used) and the most important crops grown.

4.3 Variables

The selection of variables for the model meant to examine the adaptation implications of CSA practices in Uganda was inspired by related scientific papers referred to in the theory sections (chapter 2 & 3) and in the following discussion. An overview of all variables can be found in Appendix D.

Dependent variable: agricultural productivity [Y_{cpait}]

The dependent variable of agricultural productivity is measured by yields in kg per acre, thereby using a common approach of proxying this factor (Fermont and Benson, 2011). Following the argumentation by Reynolds et al. (2015), I use the weight of a crop harvested divided by the plot area planted to take into account that farmers might lose crop area between planting and harvest. Additionally, my measure is adapted when farmers use intercropped cultivation systems, combining several crop cultivations on a single plot.

Key explanatory variables: CSA practices [CSA_{cpait}]

The most relevant explanatory variables for the purpose of my research are the CSA practices. Restricted by data availability, my research looks exclusively at three different CSA practices, more precisely the use of improved seeds, inorganic fertilizer application and intercropped cultivation systems.

For the empirical analysis of this research, other factors apart from the main variables of interest potentially affecting agricultural productivity have to be taken into consideration. I choose a diverse set of variables covering economic, socioeconomic, production, infrastructure as well as agro-ecological and climatological factors.

Economic factors [$ECON_{it}$]

Agricultural productivity is certainly affected by the economic background of a household. One important factor is off-farm income. Especially when access to credit is limited, households involved in non-farm activities may more likely be able to use inputs that require investments such as fertilizer or hired labor (Reardon et al., 1994; Clay et al., 1998). Moreover, households with better off-farm opportunities may be able to sell their crops at better prices since they are usually more liquid and have advantages in terms of risk management. Thus, they do not have to sell right at harvest for example (Nkonya et al., 2004). However, considering potential opportunity costs of labor, households that are also engaged in non-agricultural activities may be less prone to invest labor in crop production or land management practices (Scherr and Hazell, 1994). In order to control for this factor, non-agricultural income is included in the analysis. Additionally, the general wealth of a households plays an important role. Farmers who own more physical assets, better equipment, more land or livestock might have greater possibilities to do agricultural investments, either by liquidating assets or better access to credit (Nkonya et al., 2004). To account for these factors, the total value of assets owned and the land size are included. Further, an indicator for commercial agriculture accounts for the income strategy of a household.

Socioeconomic factors [$SOCIO_{it}$]

Next to economic factors, there are several socioeconomic variables potentially having an impact on agricultural productivity levels. One relevant aspect to be considered is human capital which is measured by education levels and the age of the household head. Better education is expected to translate into more efficient decision-making since farmers can make better use of available information, have a better understanding of problems and greater ability to solve them (Asadullah and Rahman, 2009). Well-educated farmers usually also have better access to required knowledge and are more likely to invest in new technologies, being more capable of assessing if an innovation is promising or not (Nelson and Phelps, 1966). Other positive byproducts of human capital are increasing opportunities for salaried off-farm employment and better access to credit, facilitating the purchase of physical capital and inputs. However, since education might also increase the opportunity costs of labor and capital, more educated households could also be less prone to make input or labor-intensive land investments (Barrett et al., 2001; Deininger and Okidi, 2001; Feder et al., 1985; Nkonya et al., 2004).

Labor availability is another relevant factor for agricultural productivity of households. Greater labor endowment per unit of land usually implies that labor is used more intensively in agricultural production. Moreover, greater labor availability might also encourage households facing land constraints to engage in non-farm activities (Feder et al., 1985). This aspect is measured by the number of adults per household and total labor in person days per unit of land.

Another factor potentially influencing agricultural productivity is tenure security. In case of insecurity of tenure, households may have less incentives to invest in their land (Feder et al., 1988). However, the link might be different if a household can increase tenure security by investing in the land (Otsuka and Place, 2001). To control for this factor, I include indicators for households that have a certificate for their land and households facing concerns regarding tenure insecurity in the analysis.

The provision of information and technical assistance is likely to be an important determinant of the adoption of improved agricultural practices and therefore productivity since agricultural technologies are usually knowledge-intensive (Barrett et al., 2002; Swinkels and Franzel, 1997). Households that receive extension services might hence be more productive. Depending on the emphasis of specific programs, however, productivity and income may also be unaffected or even negatively affected in the short run if programs are focusing on labor-intensive practices which are not necessarily increasing production (opportunity costs of labor) (Nkonya et al., 2004). To account for this factor, an indicator for households that participated in an agriculture-related training is included.

A last factor accounted for is gender measured as indicator for female-headed households. According to Ragasa et al. (2013), there are for example considerable differences regarding the access to extension services which is lower for women as compared to men. Additionally, the access to education often differs significantly.

Production-specific factors [$PROD_{pait}$]

Next to the CSA practices, other production-specific factors potentially affecting productivity levels should be taken into account. Following Arslan et al. (2015), the application of organic fertilizer, pesticides or herbicides is included. Investment in irrigation infrastructure is further very likely to increase agricultural productivity as it might increase the investment and crop production options (higher value crops), increase yields, improve quality and stabilize market supplies by mitigating the risk of drought or climatological variability and reducing the dependency on rainy seasons in general (Hanjra et al., 2009; Nkonya et al., 2004).

Infrastructure [$INFRA_{it}$]

Agricultural productivity is further determined by the transport infrastructure. Better road networks improve the connectivity with key market centers and simultaneously translate into lower input (e.g. fertilizer), market output and transaction costs for producers and consumers, by reducing travel times and the frequency of transport damage. Consequently, improved access to markets and roads is likely resulting in increased use of agricultural inputs and capital intensity by rising profitability and availability and also leads to greater consumer demand

(Llanto, 2012; GTZ, 2005). Households that are better connected to market centers have usually also better opportunities for off-farm activities, either related to the agricultural sector or in other areas due to higher demand as well as in urban industries (Barrett et al., 2001; Reardon, 1997). To account for these factors, I include the distance to the market center and roads.

Similarly, access to electricity is considered to be an important tool for increasing productivity and competitiveness of farmers, for example by increasing possibilities of storage, refrigeration or irrigation (Andersen and Shimokawa, 2007; Knox et al., 2013). To proxy for this factor, the number of hours a household has access to power is included in the regressions.

Agro-ecological and climatological factors [$CLIMA_{it}$]

As already discussed in chapter 2, agro-ecological and climatological conditions are affecting agricultural productivity in a significant way. In order to control for soil characteristics, I include indicators for soil quality and for nutrient constraints. Climatological factors taken into account encompass growing season rainfall, the average temperature of the wettest quarter as well as indicators for a false onset of the rainy season and rainfall pattern change. In addition, two further variables are an indicator for erosion problems and shocks proxied by the total number of months a household was hit by shocks.

4.4 Descriptive Statistics

Descriptive statistics of all the used variables are provided in Table 2. Agricultural productivity (log transformed) is ranging between -4.60 and 18.24 kg/acre and has a mean value of 6.23. The boxplots in Appendix E.1 additionally show that there is little variation across years and seasons when it comes to productivity levels. However, when looking at differences between regions, one can see that the Central/Kampala and Western regions are slightly more productive. The boxplots illustrating productivity by AEZ (definition 1) indicate little differences. However, across AEZ based on the second definition, Karamoja is significantly less productive than the other zones, while farms in the Western Mid-Altitude Farmland are on average the most productive.

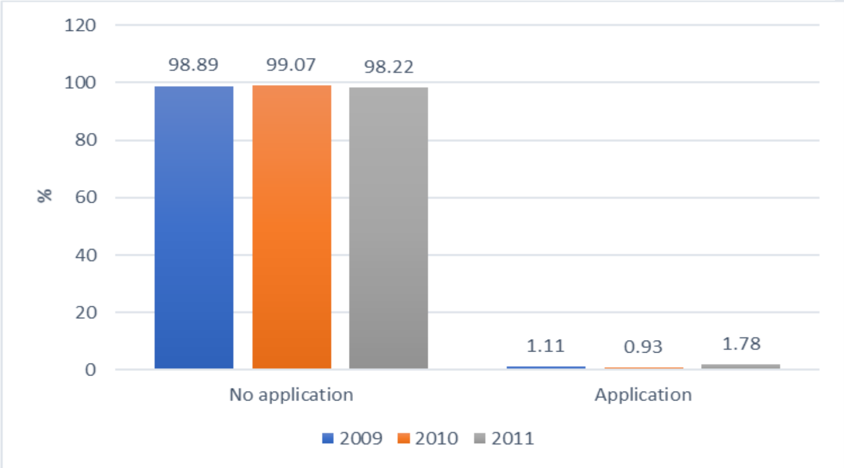
Regarding the use of CSA practices, the application of inorganic fertilizer seems not to be very common among Ugandan farmers yet. As can be seen in Figure 9, only 1.11 percent of all plots were manured with inorganic fertilizer in 2009. After a slight decrease in 2010, the application increased to 1.78 percent in 2011. In contrast, intercropped systems are already relatively common and increasingly used, accounting for 54.44 percent in 2009 and 56.02 percent in 2011 (Figure 10). The use of improved seeds is generally low and a downwards trend is observed, decreasing from 19.18 percent in 2009 to 9.86 percent in 2011 (Figure 11). Another striking fact is that the seed type choice seems to be partly dependent on the used cropping system. As can be seen in Appendix E.2, farmers who are using a pure stand system are more likely to purchase improved seeds.

Table 2: Descriptive Statistics

VARIABLES	(1) N	(2) mean	(3) sd	(4) min	(5) max
Agricultural productivity (log)	49,378	6.234	1.497	-4.605	18.24
Intercropping	64,794	0.547	0.498	0	1
Inorganic fertilizer	64,298	0.0133	0.115	0	1
Improved seeds	21,629	0.136	0.342	0	1
Commercial agriculture	62,003	0.0230	0.150	0	1
Off-farm income (log)	42,336	13.02	1.574	1.099	19.58
Assets (log)	61,924	15.49	1.564	8.294	21.89
Land size (log)	64,248	0.334	1.132	-4.605	5.704
Age head	62,060	48.30	14.83	20	100
Number of adults	62,728	3.507	2.017	0	20
Labor availability	63,026	118.6	481.1	0	83,567
Education - less than primary	50,521	0.0101	0.100	0	1
Education - junior	50,521	0.232	0.422	0	1
Education - secondary	50,521	0.0671	0.250	0	1
Education - degree	50,521	0.0101	0.0999	0	1
Certificate	53,295	0.227	0.419	0	1
Tenure insecurity	53,174	0.119	0.324	0	1
Training	64,640	0.222	0.416	0	1
Female head	62,566	0.255	0.436	0	1
Organic fertilizer	64,216	0.0630	0.243	0	1
Pesticides/herbicides	64,089	0.0464	0.210	0	1
Irrigated	64,375	0.0184	0.135	0	1
Electricity access	62,206	0.668	3.611	0	24
Distance road	62,482	8.452	7.321	0	40.48
Distance market center	62,482	33.27	18.37	0.498	116.2
Distance district capital	62,482	22.37	17.43	0.278	203.3
Shock	62,176	2.492	3.894	0	54
Climate shock (flood or drought)	62,191	0.414	0.493	0	1
Erosion	64,296	0.200	0.400	0	1
Good soil quality	64,381	0.626	0.484	0	1
Poor soil quality	64,381	0.0515	0.221	0	1
Moderate nutrient constraint	62,482	0.618	0.486	0	1
Average temperature	62,482	215.2	15.91	148	252
Rainfall	56,039	421.7	115.6	165	834
False onset rainy season	56,039	0.364	0.481	0	1
Rainfall pattern change	62,478	0.449	0.497	0	1

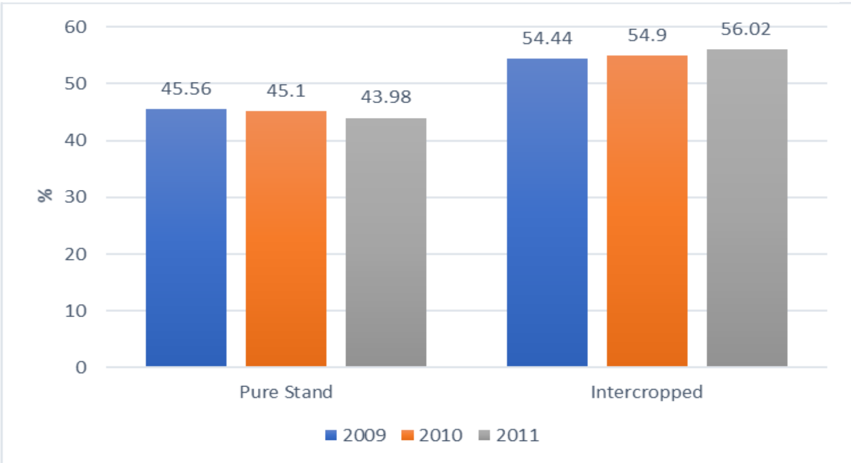
Source: Based on data from UBOS (2020).

Figure 9: Inorganic Fertilizer Application by Ugandan Farmers (2009, 2010, 2011), in %



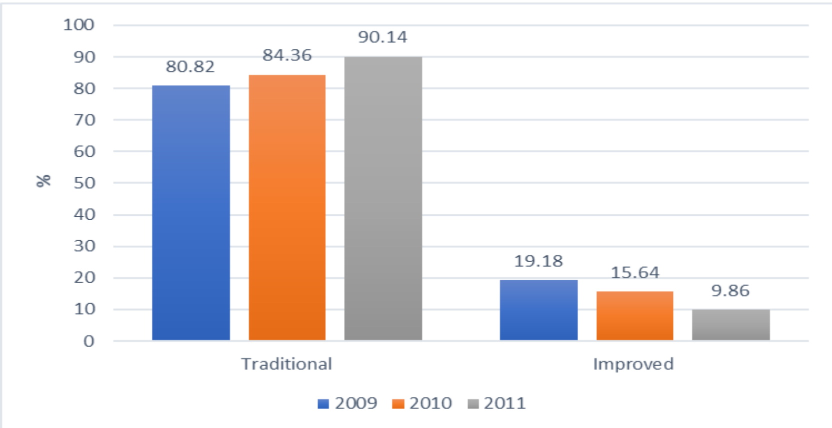
Source: Based on data from UBOS (2020).

Figure 10: Cropping System used by Ugandan Farmers (2009, 2010, 2011), in %



Source: Based on data from UBOS (2020).

Figure 11: Type of Seeds used by Ugandan Farmers (2009, 2010, 2011), in %

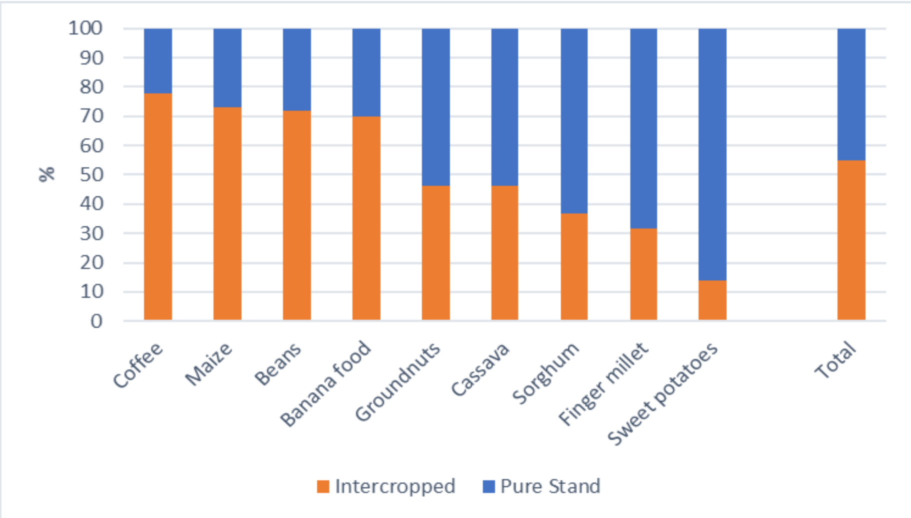


Source: Based on data from UBOS (2020).

However, the use of these CSA practices also differs between crop types. A general overview of all crops cultivated by Ugandan farmers can be found in Appendix E.3. The main crops cultivated by farmers in the sample are cassava, beans, maize and banana food (Appendix E.4). Figure 12 reveals that there are considerable differences regarding the cropping system used for different crop types. Whereas an intercropped system is used for coffee in 77.65 percent of all cases, it is only used for 13.7 percent of all sweet potato cultivations. Similarly, the type of seed used differs across crop types. Improved seeds are especially used for cassava, maize, banana food and coffee plantations (Figure 13).

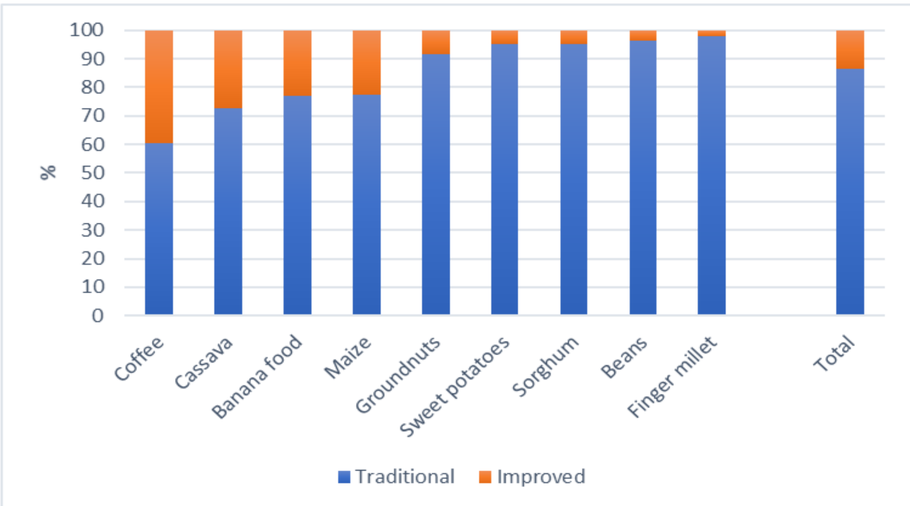
As already mentioned, Uganda's agricultural sector is mainly dominated by small-scale farmers combining subsistence farming with cash crop farming. This explains also why 61.65 percent of the farmers out of the sample are indicating that their principal income source is subsistence farming, while it is commercial agriculture for only 2.3 percent.

Figure 12: Cropping System used by Crop Type, in %



Source: Based on data from UBOS (2020).

Figure 13: Seed Type used by Crop Type, in %



Source: Based on data from UBOS (2020).

5 Empirical Results

This chapter presents the main empirical findings of the analysis. It is structured by following each of the three hypotheses. After describing the regression results, I draw specific conclusions in terms of my established hypotheses and discuss the findings in the light of future policy interventions and research limitations. Lastly, I also suggest topics which seem to bear potential for future research.

5.1 General Determinants of Agricultural Productivity

- H1: CSA practices increase agricultural productivity. -

In a first step, I analyze if CSA is generally effective, thus increasing agricultural productivity of Ugandan smallholders. The main regression results are presented in Table 3. The first two columns show the estimation results for the random effects and correlated random effects model when agricultural productivity as measured by crop yields in kg/acre is regressed on the CSA indicators of intercropping and inorganic fertilizer and all explanatory variables. In columns (3) and (4) the regressions additionally include the indicator for improved seeds. This is done since the inclusion of the improved seeds indicator leads to the loss of a substantial number of observations.[2]

Regarding the CSA indicators, key to test H1, the regression results show a significant effect of the practice of intercropping, increasing yields when compared to a pure stand system substantially. The coefficient means that crop yields increase by 47.6 percent when an intercropped system is used. In contrast, the coefficient for the application of inorganic fertilizer and the use of improved seeds over traditional seeds is only positive and significant for the RE model specifications in columns (1) and (3). The considerable differences observed between the estimation results in combination with the higher fit of the CRE model generally prove the importance of fixed effects estimates for time-variant factors in order to account for unobserved heterogeneity. This is also why only the estimation results of the CRE model (columns (2) and (4)) are further analyzed.

Looking at the impact of economic factors, the results show that off-farm income is of major relevance for increased crop yields, thereby suggesting that households involved in non-agricultural activities have probably more resources to make crucial investments and have general advantages in terms of selling and risk management as indicated by the literature. Moreover, the impact of land size is negative and significant in all specifications. Smaller areas of land by a household are probably easier to manage and cheaper to maintain which could also indirectly affect the investments made by a household. Interestingly, the fact that the income strategy of a household is commercial agriculture does not imply higher productivity levels, at least the effect is not found to be significant.

[2] Information about seed type only available for households that purchased seeds.

Table 3: Determinants of Agricultural Productivity

	(1) RE	(2) CRE	(3) RE	(4) CRE
CSA practices				
Intercropping	0.298***	0.476***	0.283***	0.478***
Inorganic fertilizer	0.194**	0.141	0.343***	0.119
Improved seeds			0.438***	0.134
Economic factors				
Commercial agriculture	0.123	-0.013	0.094	0.069
Off-farm income	0.031***	0.028***	0.037***	0.034**
Assets	0.071***	0.014	0.061***	-0.018
Land size	-0.192***	-0.191***	-0.107***	-0.106***
Socioeconomic factors				
Age head	-0.001	-0.003	-0.001	-0.003
Number of adults	0.023***	0.081***	0.013	0.121***
Labor availability	0.001**	0.001***	0.001***	0.001***
Education - less than primary	-0.600***	-0.588***	-0.902***	-0.879***
Education - junior	0.098***	0.095***	0.020	0.023
Education - secondary	-0.213***	-0.235***	-0.164*	-0.168*
Education - degree	0.128	0.103	0.526***	0.505***
Certificate	0.063**	-0.100	0.179***	0.073
Tenure insecurity	0.012	-0.062	0.146**	0.050
Training	0.097***	0.074	0.105***	0.160
Female head	-0.094***	-0.093***	-0.096**	-0.097**
Production-specific factors				
Organic fertilizer	0.212***	0.022	-0.017	0.238*
Pesticides/herbicides	0.064	0.016	0.313***	0.102
Irrigated	0.118	0.042	0.093	-0.003
Infrastructure				
Electricity access	-0.002	-0.023***	-0.005	-0.042**
Distance road	0.002	0.077**	0.002	0.010
Distance market center	0.002***	0.002***	0.002**	0.003**
Agro-ecological and climatological factors				
Shock	-0.005	0.006	0.001	0.015
Erosion	-0.105***	0.014	-0.123***	0.084
Good soil quality	0.167***	0.165***	0.147***	0.136***
Poor soil quality	0.065	0.057	-0.098	-0.104
Moderate nutrient constraint	0.032	0.025	0.005	0.006
Average temperature	-0.011***	-0.011***	-0.010***	-0.010***
Rainfall	0.000	0.000	0.001***	0.001***
False onset rainy season	0.027	0.017	0.057	0.107
Rainfall pattern change	-0.076***	-0.027	-0.055	0.026
Constant	6.690***	6.571***	5.502***	5.448***
Observations	18,291	18,291	5,547	5,547
R^2 between/(overall)	0.0869/ (0.1050)	0.0918/ (0.1151)	0.1183/ (0.1218)	0.1234/ (0.1287)

*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.
Note: Complete table with robust standard errors provided in Appendix F. Dependent variable: agricultural productivity measured by crop yields in kg/acre. For detailed explanation regarding the construction of all other variables please consult Appendix D.

Among socioeconomic variables, the number of adults per household and labor availability are positively related to productivity levels. An interesting observation is how the impact of education differs according to the respective level. The negative impact when the educational background of the household head is less than primary school and the positive effect of having completed the junior level (between primary and secondary) clearly suggests that basic education is of major relevance for agricultural productivity. However, the results simultaneously show a negative link between completed secondary education level and crop yields. The findings consequently indicate that basic education is crucial, possibly since it provides farmers with some general understanding of problems and of the potential of agricultural innovations. On the other hand, the estimations confirm the fact that more educated households are facing higher opportunity costs of labor and capital, therefore having less incentives to invest in their land. Another relevant socioeconomic factor is the gender aspect. Households that are female-headed clearly have a disadvantage according to the estimation results. This can possibly be explained by the fact that women have less access to relevant information and education.

Regarding other potential relevant production-specific variables, only the application of organic fertilizer seems to be positively linked to crop yields.

In terms of variables capturing infrastructural conditions, the factors of access to electricity and market centers have a significant impact, but surprisingly the opposite effect of what one would expect. A possible explanation for these finding is that a high share of the households in the sample are subsistence farmers and better infrastructure might rather encourage them to start involving in off-farm activities than rising their production levels.

Agro-ecological factors influencing crop yields in a positive and significant manner are a good soil quality and precipitation levels. The effect of the average temperature is negative and significant, indicating that anticipated rising temperatures will affect productivity levels considerably.

To sum up and taking the magnitude of the effects into consideration, the most important variables determining agricultural productivity is the CSA practice of intercropping, the economic factors of income from non-agricultural activities and land size, the educational background and soil quality. Other production-specific factors and infrastructure, in contrast, seem to be less relevant.

Estimating the effects of agricultural practices on agricultural productivity is automatically subject to various endogeneity problems since adoption behaviour cannot be considered random and farmers adopting a given technology are likely to have unobserved characteristics that are correlated with their productivity level (Mundlak, 2001). This implies that there is a standard self-selection problem, potentially biasing the estimation results. An instrumental variables approach is usually used to address this issue. However, finding appropriate IVs in this context is complicated. This is particularly due to difficulties to meet the exclusion restriction requiring that the instrumental variable Z has no direct influence on the outcome variable Y. Potential IVs such as soil quality for instance, however, will always affect Y through the explanatory variable X but simultaneously have a direct effect on the outcome. Panel data (fixed or random effects) models control for unobserved time invariant household variables, thereby solving this endogeneity problem inasmuch as the selection into adoption is due to household characteristics that do not change over time. Selection usually arises due to the impossibility to observe farmer ability or openness to innovation (Arslan et al., 2015). However, these factors can be expected to change only marginally over short periods of time. This is why a RE/CRE model seems reasonable to apply.

However, taking the potential of endogeneity into consideration, I check the robustness of the results for the key variables of interest from the first model by using the method of propensity score matching in a second step and am thereby able to establish a more causal relationship. This approach facilitates the comparison of treated and untreated individuals and therefore the calculation of the average treatment effect on the treated. The "treatment" is the use of the respective CSA practice (intercropping vs pure stand; application of inorganic fertilizer or not; use of improved seeds vs traditional seeds). I apply the PSM method for the first season of the year 2009 only. Having the relatively short time period in mind, it seems justified to state that the results are nevertheless comparable to the estimations from the CRE model.[3]

The results of the PSM compared to the baseline results from the previous CRE model estimation are presented in Table 4. One can see that the positive link between an intercropped system and crop yields is strongly confirmed. The average treatment effect on the treated of intercropping is 0.315 and highly significant. This means that the use of an intercropped cultivation system increases productivity levels on average by 31.5 percent. The estimation for the use of inorganic fertilizer received from the CRE model also seems to be robust since the results from the PSM confirm the insignificance of this factor. An interesting result, however, is the positive and significant impact of the use of improved seeds which contradicts the findings from the CRE model. According to the PSM, the average treatment effect on the treated of these kind of seeds as opposed to traditional seeds is 0.555, implying that improved seeds use increases crop yields on average by 55.5 percent. The difference of the estimation results of the two models for this factor indicates that the effect might be dependent on other factors or not be the same for the country's different regions, AEZs or crop types grown. Potential reasons for this differing result are further analyzed in the next two sections.

Table 4: Effectiveness of CSA Practices – Robustness Check (Propensity Score Matching)

	(1) Intercropping (Intercropped vs Pure Stand)	(2) Inorganic Fertilizer (Yes vs No)	(3) Improved Seeds (Improved vs Traditional Seeds)
ATET	0.315***	0.095	0.555***
	(0.066)	(0.231)	(0.125)
CRE baseline results	0.478***	0.119	0.134
	(0.081)	(0.236)	(0.127)
Observations (PSM)	5,461	6,589	1,541

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.
Note: ATET = Average Treatment Effect on the Treated.

[3] For explanation about the construction of treatment and control group please consult section 4.2.

5.2 The Impact of Climatological Factors

- H2: CSA practices increase agricultural productivity, especially when exposed to climatic shocks. -

CSA practices are expected to increase yields especially when exposed to climatological stress. This implies that the fact that individual effects as examined in the previous section are insignificant does not necessarily mean that the use of specific practices is ineffective in face of changing climatic conditions or extreme weather events which Ugandan farmers have to deal with more and more frequently.

In this section, I look at three potential conditioning factors by including interactions between the respective CSA practice and indicators measuring climatological shocks. The first one is the false onset of the rainy season, constructed as indicator. A value of 1 means that there is a considerable time difference between the start of the rainy season in the respective season and the usual start of the rainy season. I measure this by looking if the difference between the average onset of the rainy season and the onset in the specific season is higher than the mean difference (by AEZ) or lower than the mean difference. The same logic applies to the indicator of rainfall pattern change, capturing the difference between the average total rainfall and total rainfall of the respective year. The third indicator is measuring if a household was hit by a climate shock, more specifically a drought or a flood.

When model specifications include interaction terms, the coefficients cannot be interpreted directly as the relationship between the covariates and the outcome is determined by several coefficients. In order to interpret the interaction terms accurately, I look at marginal effects by making use of the margins command in Stata. Marginal effects reflect the rate at which the dependent variable changes at a specific point in the covariate space, holding all explanatory variable values constant. In case of an GLS estimation, marginal effects therefore present the marginal contribution of a covariate x to the outcome. In general, there are different ways to examine marginal effects. In the context of my research, the marginal effects are derived as average values (AMEs), calculating the marginal effects at every observed value of the covariate and averaging across the corresponding effect estimates. AMEs contain a lot of information about the impact that a covariate has on the outcome and are therefore particularly useful (Leeper, 2017).

The estimation results (based on CRE model) can be found in Table 5. Additionally, Figure 14 presents the interaction effects for intercropping and the use of improved seeds in a graphical way. In general, I find significant effects for the practices of intercropping and the use of improved seeds, while inorganic fertilizer application does not prove to have a significant impact when interacted with climatological factors neither. Concerning the practice of intercropping, the AME on crop yields is higher if a household is exposed to a shock of a false onset of the rainy season. Whereas the use of intercropping increases yields on average by 41.5 percent without having experienced a shifted rainy season start, the effect amounts to 60 percent when this is the case. If the amount of total annual precipitation diverges significantly from the normal levels, the effect is positive but slightly higher when there is no severe rainfall pattern shock. In face of a climate shock (drought or flood), the effect of intercropping on productivity is not higher than without, but the AME is still positive, amounting to 45.2 percent. Similar trends are observed for the use of improved seeds. The AME of improved seeds use on the linear prediction is also higher when a household is exposed to a false onset of the rainy season, increasing yields on average by 43.5 percent as compared to 35.5 percent without the shock. For the shock of a rainfall pattern change, however, there is only a significant effect found if the indicator takes a value of 0, implying that improved seeds are only positively linked to yields when the amount of precipitation varies to a certain extent. Regarding the exposure to a climate shock, the AME of improved seeds is only significant when a household is hit by a shock (indicator = 1), increasing yields by 33.2 percent in this case. Thus, even though I do not find a general impact in section 5.1, improved seeds are actually efficient conditional on climatic stress.

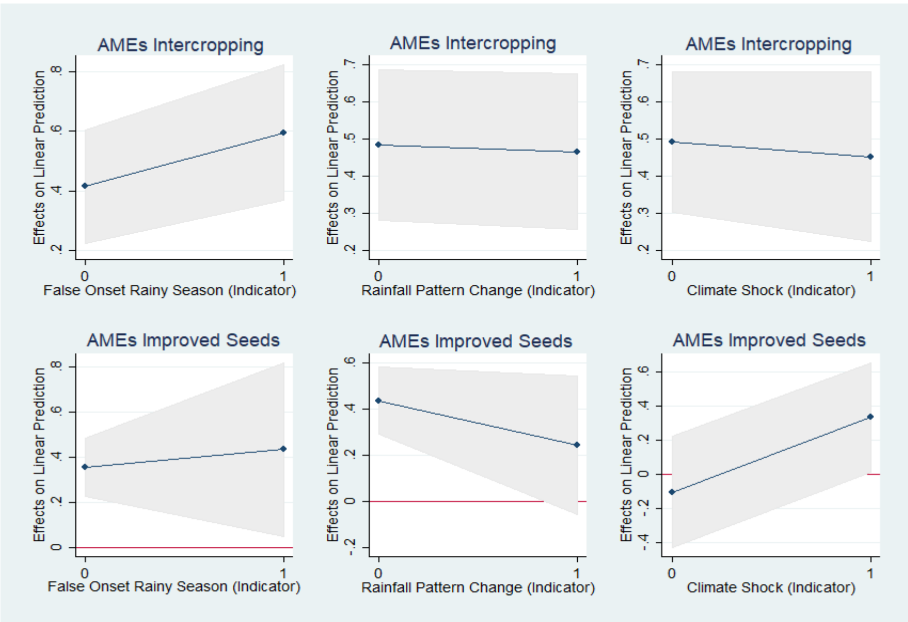
Table 5: Effectiveness of CSA Practices conditional on Climatological Factors – AMEs

	(1) False onset interactions	(2) Rainfall pattern change interactions	(3) Climate shock interactions
Intercropping			
Without shock	0.415***	0.484***	0.492***
With shock	0.6***	0.465***	0.452***
Inorganic fertilizer			
Without shock	-0.048	0.083	0.313
With shock	0.794	-0.025	-0.206
Improved seeds			
Without shock	0.355***	0.434***	-0.106
With shock	0.435**	0.243	0.332**
Observations	5,547	5,547	5,547

*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.

Figure 14: Average Marginal Effects of Intercropping and Improved Seeds



Source: Based on data from UBOS (2020). Author's own estimation results.
Note: With 95% Confidence Intervals.

5.3 Differences across Regions, Agro-ecological Zones and Crop Types

- H3: The effect of CSA practices might differ across regions, AEZs and crops. -

Uganda is characterized by heterogenous agro-ecological regions and farmers are growing a broad selection of different crops. A fact that certainly should be taken into consideration is that the impact of CSA might consequently differ, thus the general effects found in section 5.1 might not apply to every zone or crop type. In a third step, I therefore examine if the estimation results differ across Ugandan regions, agro-ecological zones (two definitions used) and the most important crops grown. The estimations in this section are generally based on the CRE model and done firstly with the indicator for improved seeds and additionally without it (larger sample size).

Firstly, I look if there are significant differences on the regional level. The results as presented in Table 6 confirm the general findings regarding the effectiveness of the CSA practices, hence there are no substantial differences between the four regions.

Table 6: Determinants of Agricultural Productivity by Region

	(1) Central	(2) Eastern	(3) Northern	(4) Western
A: with improved seeds				
Intercropping	0.545***	0.431***	0.611***	0.253
	(0.155)	(0.162)	(0.168)	(0.160)
Inorganic fertilizer	-0.206	0.421	1.475	1.068**
	(0.293)	(0.417)	(1.754)	(0.539)
Improved seeds	-0.075	0.074	0.243	0.517
	(0.257)	(0.190)	(0.278)	(0.318)
Observations	1,264	1,659	1,364	1,260
R^2	0.1641	0.1868	0.1712	0.1382
B: without improved seeds				
Intercropping	0.447***	0.427***	0.479***	0.554***
	(0.075)	(0.092)	(0.139)	(0.082)
Inorganic fertilizer	0.060	0.378	-0.085	-0.341
	(0.157)	(0.235)	(0.932)	(0.496)
Observations	5,727	4,903	2,418	5,243
R^2	0.0964	0.0991	0.1195	0.1590

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.
Note: Reduced form table (only variables of main interest displayed). Dependent variable: agricultural productivity measured by crop yields in kg/acre. For detailed explanation regarding the construction of all other variables please consult Appendix D.

When looking at potential differences between the AEZs dividing the country into four broader areas (tropic-warm/subhumid; tropic-warm/humid; tropic-cool/subhumid; tropic-cool/humid) one can observe some differences (Table 7). The coefficient for the practice of intercropping is positive and significant for all AEZs, except for the tropic-warm/subhumid zone. However, the magnitude of the effect clearly differs, increasing yields in the tropic-cool/humid zone by 68% but only 38.3% in the tropic-warm/humid zone. For inorganic fertilizer application, there is a highly significant effect found for the tropic-cool/subhumid area (Table 7, Part A). However, since this effect is no confirmed by the regression results in Part B of Table 7 which has a higher model fit, this result should be taken carefully. For the use of improved seeds there is no significant effect found in any of the four AEZs.

Table 7: Determinants of Agricultural Productivity by AEZ

	(1) Tropic-warm/subhumid	(2) Tropic-warm/humid	(3) Tropic-cool/subhumid	(4) Tropic-cool/humid
A: with improved seeds				
Intercropping	0.240	0.383***	0.527***	0.680***
	(0.577)	(0.124)	(0.191)	(0.124)
Inorganic fertilizer		0.363	1.466***	-0.032
		(0.461)	(0.144)	(0.288)
Improved seeds	-0.227	0.088	0.348	0.174
	(0.714)	(0.168)	(0.262)	(0.225)
Observations	188	3,081	645	1,633
R^2 between/(overall)	0.2858/	0.1411/	0.2024/	0.1899/
	(0.2992)	(0.1410)	(0.2047)	(0.2015)
B: without improved seeds				
Intercropping	1.028***	0.343***	0.561***	0.523***
	(0.290)	(0.071)	(0.084)	(0.074)
Inorganic fertilizer		-0.085	-0.657	0.293*
		(0.219)	(0.590)	(0.158)
Observations	648	8,656	3,105	5,882
R^2 between/(overall)	0.2453/	0.1071/	0.2216/	0.0853/
	(0.2900)	(0.1114)	(0.2340)	(0.0941)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.
Note: Reduced form table (only variables of main interest displayed). Dependent variable: agricultural productivity measured by crop yields in kg/acre. For detailed explanation regarding the construction of all other variables please consult Appendix D.

However, more differences are observed when looking at the more disaggregated definition of AEZs. Table 8 illustrates the differences between the zones Afro-Montane High Altitude, Lake Victoria Crescent, Northern Moist Farmland, South East L. Kyoga Flood Plain, Southwest Rangeland and Western Mid-Altitude Farmland. Karamoja has to be left out since the observations for this zone are insufficient. The results for the practice of intercropping differ when the specification in Part A and B of Table 8 are compared. However, since the estimation leaving the indicator for improved seeds out is based on a substantially higher number of observations, it seems reasonable to assume that the findings of Part B are more reliable. They show that intercropping has no significant effect in the Southwest Rangeland and Western Mid-Altitude Farmland zones, but is increasing yields with 68.7, 53.4 and 54.1 percent in the Afro-Montane, Lake Victoria and South East L. Kyoga Flood Plain areas significantly. The use of inorganic fertilizer has a positive and highly significant effect on productivity in the zones of Afro-Montane (66.5 percent) and Southwest Rangeland (84.5 percent), whereas its impact is negative in the Western Mid-Altitude Farmland. Further, using improved seeds varieties has a very high positive (171.4 percent) and significant effect on yields in the Western Mid-Altitude Farmland. This finding matches the results from section 5.2 since this agro-ecological zone is generally characterized by high variability in precipitation and improved seeds most likely help making farmers more resilient against this. An interesting observation is that improved seeds seem to have a disadvantage over traditional seeds in the Afro-Montane, Lake Victoria and South East L. Kyoga zones. It remains an open question how this can be explained. One possible reason which will be further examined in the next step is that improved varieties might not be an efficient option for every crop type.

Table 8: Determinants of Agricultural Productivity by AEZ

	(1) Afro-Montane High Altitude	(2) Lake Victoria Crescent	(3) Northern Moist Farmland	(4) South East L. Kyoga Flood Plain	(5) Southwest Rangeland	(6) Western Mid-Altitude Farmland
A: with improved seeds						
Intercropping	0.653	0.089	0.494*	0.597	0.375	1.130
	(0.438)	(0.306)	(0.276)	(0.514)	(0.475)	(0.800)
Inorganic fertilizer	1.503**	0.000	3.421	-3.518	4.386***	
	(0.675)	(0.838)	(2.713)	(2.935)	(1.646)	
Improved seeds	-0.841*	-0.651*	0.099	-2.103**	0.387	1.714***
	(0.459)	(0.335)	(0.413)	(1.018)	(0.881)	(0.624)
Observations	225	398	668	207	125	168
R^2 between/(overall)	0.4330/ (0.4102)	0.3099/ (0.3084)	0.1888/ (0.1858)	0.4701/ (0.4556)	0.5137/ (0.5052)	0.4600/ (0.4653)
B: without improved seeds						
Intercropping	0.687***	0.534***	0.137	0.541**	0.195	0.288
	(0.159)	(0.163)	(0.159)	(0.257)	(0.183)	(0.187)
Inorganic fertilizer	0.665*	-0.022	0.466	0.478	0.845*	-1.871***
	(0.366)	(0.321)	(1.472)	(1.310)	(0.464)	(0.579)
Observations	1,014	2,083	1,468	818	851	1,161
R^2 between/(overall)	0.2886/ (0.3078)	0.1151/ (0.1121)	0.1290/ (0.1238)	0.1770/ (0.1698)	0.2506/ (0.2505)	0.1686/ (0.1580)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.
Note: Reduced form table (only variables of main interest displayed). Dependent variable: agricultural productivity measured by crop yields in kg/acre. For detailed explanation regarding the construction of all other variables please consult Appendix D.

Differences between crop types are analyzed for the crops accounting for the highest share of cultivated crops, namely cassava, beans, maize, banana food, sweet potatoes, coffee, groundnuts, sorghum and finger millet (Table 9). The positive and significant effect of intercropping is proved for all crops, except for cassava and finger millet. In terms of magnitude, the use of an intercropped system is especially beneficial for beans and sorghum, increasing yields by 70.4 and 65.2 percent respectively. Inorganic fertilizer use seems to have a positive and robust impact for finger millet, increasing productivity by 135 percent. Improved seeds, in contrast, do not have the expected positive effect compared to traditional seeds for finger millet. However, the coefficient for improved seeds use is positive and significant for groundnuts and sorghum. In this context, also the considerable magnitude of the effect should be emphasized. While improved seeds use increases groundnuts yields by 105 percent, it increases sorghum yields by 167 percent. These findings might provide a plausible explanation for the negative impact of improved seeds found for the Afro-Montane, Lake Victoria and South

East L. Kyoga zones where finger millet is mainly cultivated and the positive impact for the Western Mid-Altitude Farmland zone which accounts for major parts of sorghum cultivations.

Table 9: Determinants of Agricultural Productivity by Crop Type

	(1) Cassava	(2) Beans	(3) Maize	(4) Banana food	(5) Sweet potatoes	(6) Coffee	(7) Groundnuts	(8) Sorghum	(9) Finger millet
A: with improved seeds									
Intercropping	-0.697	0.680***	0.491***	0.159	0.446	-1.165	0.609*	0.786***	-0.183
	(1.161)	(0.099)	(0.127)	(0.764)	(0.532)	(0.904)	(0.319)	(0.230)	(0.576)
Inorganic fertilizer	7.653	0.215	-0.032	-5.22***		2.018**	-0.450		1.361***
	(12.067)	(0.345)	(0.316)	(0.592)		(0.857)	(2.033)		(0.469)
Improved seeds	-1.793	0.252	0.105	0.078	-0.134	-1.659	1.047*	1.672***	-1.105*
	(1.098)	(0.286)	(0.155)	(0.420)	(0.749)	(1.352)	(0.618)	(0.313)	(0.630)
Observations	168	1,779	1,444	83	216	58	536	250	221
R^2 between/(overall)	0.3182/	0.1767/	0.1960/	0.1636/	0.4120/	0.0416/	0.2441/	0.2334/	0.2934/
	(0.3354)	(0.1950)	(0.1854)	(0.1615)	(0.4172)	(0.0666)	(0.2712)	(0.2730)	(0.3073)
B: without improved seeds									
Intercropping	0.139	0.704***	0.555***	0.489***	0.627***	0.509***	0.401*	0.652**	0.034
	(0.147)	(0.081)	(0.102)	(0.082)	(0.189)	(0.194)	(0.224)	(0.273)	(0.302)
Inorganic fertilizer	0.704	0.259	0.238	-0.278	0.568	0.196	0.786	-0.070	1.355***
	(0.571)	(0.292)	(0.363)	(0.202)	(0.484)	(0.252)	(0.811)	(0.345)	(0.281)
Observations	1,707	2,941	2,777	3,004	1,714	1,324	933	485	483
R^2 between/(overall)	0.1584/	0.1858/	0.1658/	0.2445/	0.1404/	0.1352/	0.1771/	0.1975/	0.2081/
	(0.1510)	(0.1922)	(0.1640)	(0.2569)	(0.1469)	(0.1439)	(0.1966)	(0.2065)	(0.2342)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.
Note: Reduced form table (only variables of main interest displayed). Dependent variable: agricultural productivity measured by crop yields in kg/acre. For detailed explanation regarding the construction of all other variables please consult Appendix D.

5.4 Discussion of the Results

The empirical analysis provides some evidence for the three hypotheses initially established.

H1: CSA practices increase agricultural productivity.

The findings show that the use of an intercropped system is generally one of the most relevant determinants of agricultural productivity, increasing crop yields by around 48 percent. Likewise, the use of improved seeds has a positive significant average treatment effect of about 56 percent. Although this general effect is not confirmed by the CRE model, the further analysis shows that there is an impact conditional on climatological factors and that differences exist between agro-ecological zones and crop types. Inorganic fertilizer application, in contrast, has no general significant effect on productivity levels.

H2: CSA practices increase agricultural productivity, especially when exposed to climatic shocks.

The general statement that the effect of CSA is conditional on climatic factors is confirmed by the results, at least for the practices of intercropping and improved seeds use. These two practices are particularly increasing yields when a household is exposed to a false onset of the rainy season, raising the effect by 18 and 8 percent respectively. Another important observation is that these practices are proved to increase yields even when a household is hit by a extreme weather shock, such as a drought or a flood, increasing yields still by 45 and 33 percent respectively. However, the positive effect of improved varieties is also conditioned by the extent of rainfall variability. If precipitation level variation reaches abnormal levels, the effect of improved seeds use becomes insignificant.

H3: The effect of CSA practices might differ across regions, AEZs and crops.

The previous results indicate that there are considerable differences for the more disaggregated levels of analysis. Inorganic fertilizer, for example, proves to be efficient only in very specific contexts. The impact of the different CSA indicators differs across AEZs, implying that agro-ecological conditions such as soil characteristics, climate and topography seem to play a crucial role for the potential of CSA to increase agricultural productivity. Similarly, the effectiveness of CSA should not be generalized among crop types. Intercropping is especially raising productivity for beans and sorghum, increasing yields by 70.4 and 65.2 percent respectively. Inorganic fertilizer use has a beneficial effect for finger millet yields, raising productivity by 135 percent. Improved seeds prove to be efficient for groundnuts and sorghum, increasing yields by 105 percent and 167 percent respectively. The differences observed on the AEZ level are therefore most likely also related to the type of crops grown in the specific zones.

5.4.1 Policy Implications

The results clearly indicate that CSA practices are a powerful tool to increase or maintain productivity levels of Ugandan farmers and making them more resilient to the adverse consequences of climate change. At the same time, they highlight the importance of adapting the adoption of these practices to specific countries, agro-ecological conditions and crop types.

The observed trend of an increasing use of intercropped cultivation system by farmers in Uganda can be evaluated as positive, while the declining trend of improved seeds use seems not necessarily be justified. The findings from my empirical analysis suggest that the decision of which CSA practices should be invested in should be adapted to the crop types cultivated and site-specific conditions. The practice of intercropping is found to be especially beneficial for beans and sorghum cultivations. However, particularly for sorghum the system of intercropping is not common yet and should be promoted. Likewise, intercropping can increase productivity substantially for coffee crops and although this practice is already relatively common among coffee farmers there is still room to exploit its full potential, especially considering the fact that coffee is an important export product. Further, the use of improved seeds bears high potential for the crops of groundnuts and sorghum and should be supported. However, it should also be considered that the effectiveness of improved seeds is sensitive to abnormally high rainfall level variability. Inorganic fertilizer application is only found to have an positive impact for finger millet. Additionally, the analysis on the AEZ level shows that its efficiency seems to be highly dependent on conditions such as soil characteristics, topography and climate since the impact differs significantly across agro-ecological areas.

Having these implications in mind, policy makers should think about solutions on how to best promote the targeted, crop- and site-specific adoption of CSA and generally focus on investing in agricultural programs which provide the necessary training to farmers and help them making the most efficient decisions based on farm-specific characteristics. Simultaneously, it has to be identified how to guarantee wide and equal access to CSA practices. In the end, farmers often do not have the required knowledge regarding the benefits or are not willing or able to take potentially risky investments. The fact that the effectiveness depends on the specific circumstances makes these decisions even more complex. Consequently, it would be crucial to identify the reasons behind farmers deciding to take specific investments or not and which factors are holding them back. If the implementation of CSA practices is for example dependent on economic factors, it should come to the fore of the debate how to make these practices more accessible. Most likely, a combination of different measures would be necessary. Thus, policy makers should extend the training possibilities for farmers and simultaneously increase the availability and access to credits. One idea would be to make the granting of credits dependent on the participation in special trainings or the assessment of a farmers' situation by trained extension workers in order to ensure the efficient use of resources.

Based on my findings, agricultural policies currently in process of being developed such as the National Agricultural Extension Strategy (NAES), the National Fertilizer Policy of Uganda or the National Seed Policy (Mugagga et al., 2018) can be considered to be important steps for improving food security and initiating agricultural transformation. However, these policy measures should generally be designed in a more flexible manner and delegate the execution to sub-national levels, while also involving a network of different actors such as research and educational institutions. Besides, more emphasis should be put on conservation agriculture practices such as intercropping.

5.4.2 Limitations

It should be stressed that my research faces some limitations. In general, data availability is limited and the selection of variables is based on the best available options which not necessarily implies that the used indicators are perfect or that there are no other factors potentially influencing agricultural productivity. For the purpose of creating better research opportunities, it would thus be important to improve the scope and quality of available agricultural data on the micro-level.

As already mentioned before, it should further be considered that this research encounters an endogeneity issue. In order to get clear and unbiased estimates, it would be necessary to disentangle the effect that certain unobservables such as openness to innovation might have on adoption behaviour and the implications these effects have on agricultural productivity. The correlated random effects model including fixed effects estimates can partly account for this problem since it controls for unobserved factors that are time-invariant. Likewise the method of propensity score matching creates experiment-like conditions and therefore presents a strong approach to face the standard self-selection bias and reverse causality issues. However, since the propensity score is exclusively defined in terms of the observed covariates, it would still be more accurate to analyze the question using an instrumental variable approach in order to rule out any hidden bias.

Generally, there is still a lot of scope to continue doing research on this topic. As soon as more data is available, several open questions should be addressed in order to make the adoption of CSA practices even more efficient. Firstly, it would be good to look at additional agricultural practices with climate-smart potential such as for example crop rotation and improved livestock or crop residue management. It would also be important to check if efficiency can be improved by specific combinations of different CSA measures or if the timing is not of major relevance as well. For instance, the impact of inorganic fertilizer might not be effective per se according to my estimation results but there might be other factors determining its efficiency. The empirical research by Arslan et al. (2015) for example suggests that it is the timely access to inorganic fertilizer that matters the most. Taking the country's context and thus the importance of agricultural exports into account, future research should also particularly focus on how the production of cash crops such as coffee can be improved. Another relevant question that requires further research is the implications that specific CSA practices might have for land degradation or more generally if there might be negative consequences creating a trade-off between the goal of making farmers resilient against the threat of climate change and the long-term goal of decreasing the speed of climate change. Rockström et al. (2009) for example emphasize that large parts of agricultural land in Sub-Saharan Africa are already subject to land degradation. This phenomenon might be reinforced when practices such as inorganic fertilizer application are used in the wrong manner or combined inadequately (Muchena et al., 2005).

6 Conclusions

The aim of my thesis has been to improve the understanding of the general effectiveness of agricultural practices with climate-smart potential in Uganda. Considering the increasing impact of climate change, the dependency of large part of the population on rainfed agriculture, the overall role of the agricultural sector for the economy and demographic developments, the topic is of major relevance.

Structural change is an urgent matter considering the various challenges the country is facing. Promising trends are observed for adding value and creating jobs in the agri-food sector, increasing demand for higher-value foods and improving vertical integration of smallholders into agricultural value chains (World Bank, 2018). In order to stimulate structural transformation, however, Ugandan farmers which are currently mainly working on a subsistence basis have to engage more in agricultural commercialization. Making this transition will only be possible if smallholders succeed in rising their productivity levels, despite the adverse impact of climate change. This is why studying the productivity implications of solutions with the potential to increase yields under climatic stress, more precisely climate-smart agriculture, is crucial.

Studies evaluating the impact of CSA in the Ugandan country-specific context are rare or only assessing the effectiveness in the context of specific programs promoting the use of CSA which might suffer from serious selection biases and are consequently not necessarily representative or conclusive. My research was therefore meant to fill a relevant gap by examining the question if Ugandan smallholders “randomly” adopting these CSA measures are experiencing productivity benefits and whether the effect changes along with climatic factors.

To examine my research question, I applied a correlated random effects model and a propensity score matching method. After looking at the main hypothesis by analyzing the impact of the selected CSA practices of intercropping, inorganic fertilizer application and improved seeds use on crop yields, I also examine if the effect is conditional on climatological conditions and different between regions, agro-ecological zones and crop types. The results of the empirical analysis suggest that the CSA practices of intercropping and improved seeds use are associated with higher agricultural productivity levels, increasing yields by around 48 to 56 percent according to the sample, whereas inorganic fertilizer application does not have a general significant effect. The impact of an intercropped cultivation system is particularly strong or at least still positive when farmers are exposed to critical weather stress, while the positive effect of improved varieties is conditioned by climatic variables. Further, I find substantial differences in terms of effectiveness of CSA between agro-ecological zones of Uganda and crop types.

My findings generally imply that investing in CSA is an effective tool to make Ugandan farmers more productive and resilient in the face of climate change, thereby improving food security for a growing population and stimulating agricultural transformation critical for structural change and sustained economic growth. However, my analysis on more disaggregated levels provides evidence on substantial differences, suggesting that the effectiveness is highly dependent on soil characteristics, topography, climate and crop types. This implies that policy makers should not only focus on the promotion of CSA per se, but find context-specific solutions. In brief, policy makers should make sure that farmers have access to CSA practices and to required information regarding the respective potential. However, these initiatives have to be targeted, otherwise they will be resource-inefficient since the practices can even have adverse effects in some contexts. Lastly, dynamics regarding changing climatic conditions or farmer specific needs have to be taken into account.

Obviously, having the dimension of the consequences of climate change in mind, the adoption of CSA can only be one part of the puzzle. Other measures have to be taken to complement CSA tools, such as providing better water systems, improved harvest storage possibilities or improved access to systems conveying timely climatic information for farmers. Additionally, the previous discussion has made clear that there are still a lot of open questions in terms of effectiveness of CSA worth doing research on. In the light of the increasing adverse impact of climate change, it would be important to investigate these as soon as better or more detailed agricultural data is available.

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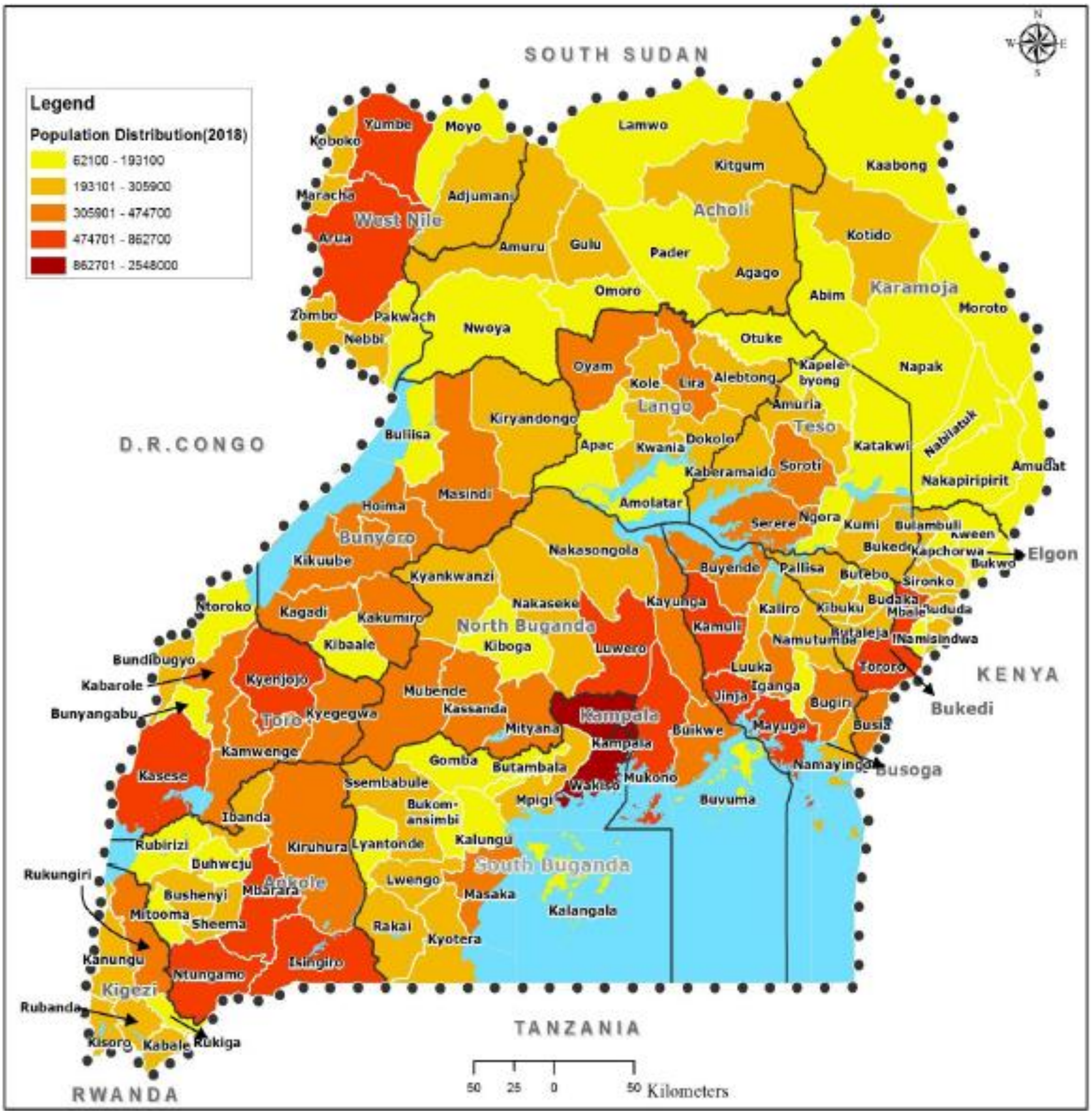
8 Appendix

Appendix A.1: Population Distribution in Uganda, 2018



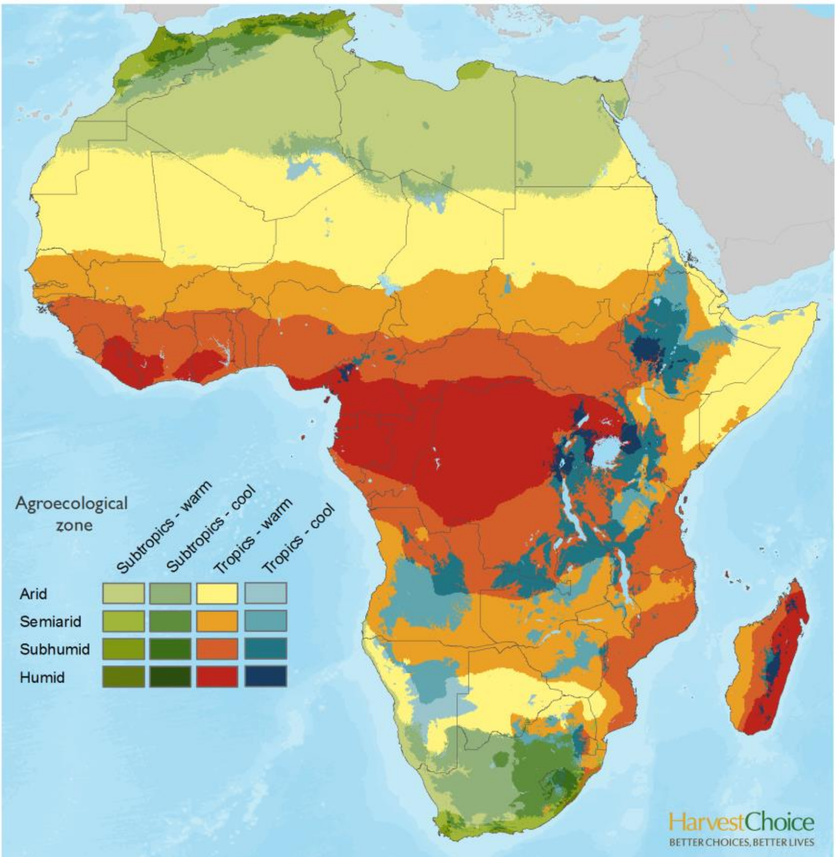
Source: UBOS (2018).

Appendix A.2: Real GDP (percent change y/y unless indicated, selected sub-sectors), Uganda, 2019

	Growth rate	% share of GDP	% contr. to Growth
GDP	**6.5**	**----**	**----**
AGRICULTURE, FORESTRY & FISHING	**5.0**	**24.2**	**1.2**
Cash crops	7.7	2.4	0.19
Food crops	2.6	13.0	0.35
Livestock	7.3	3.3	0.24
Forestry	2.4	3.7	0.09
Fishing	24.3	1.8	0.37
INDUSTRY	**10.8**	**29.5**	**3.1**
Mining & quarrying	37.4	2.1	0.62
Manufacturing	7.1	16.5	1.16
Construction	16.5	7.1	1.07
SERVICES	**4.9**	**46.2**	**2.3**
Trade & Repairs	4.1	9.6	0.40
Transportation & Storage	3.0	3.6	0.11
Accommodation & Food Services	3.0	3.1	0.10
Information & Communication	-0.6	1.8	-0.01
Financial & Insurance	8.8	2.8	0.24
Real Estate Activities	10.2	7.0	0.69
Public Administration	1.0	2.5	0.03
Education	4.5	4.5	0.21
Health & Social Work	2.1	3.4	0.07

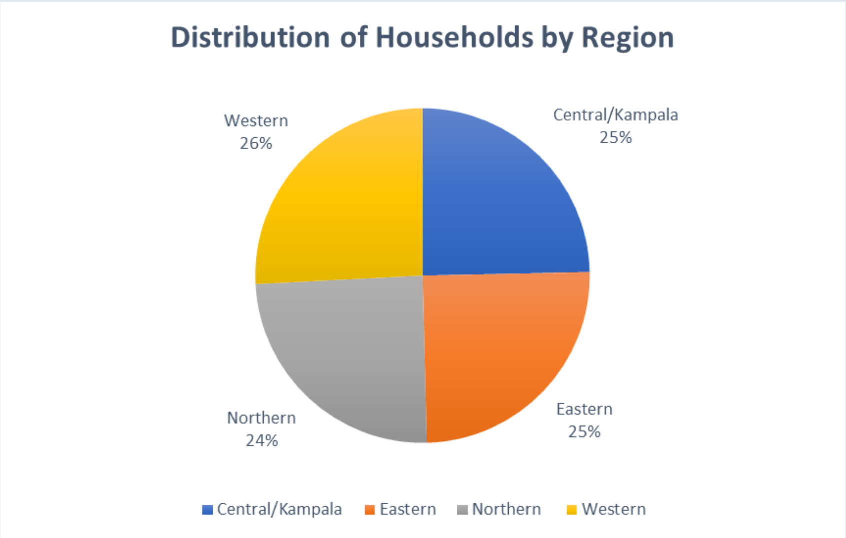
Source: World Bank (2020c).

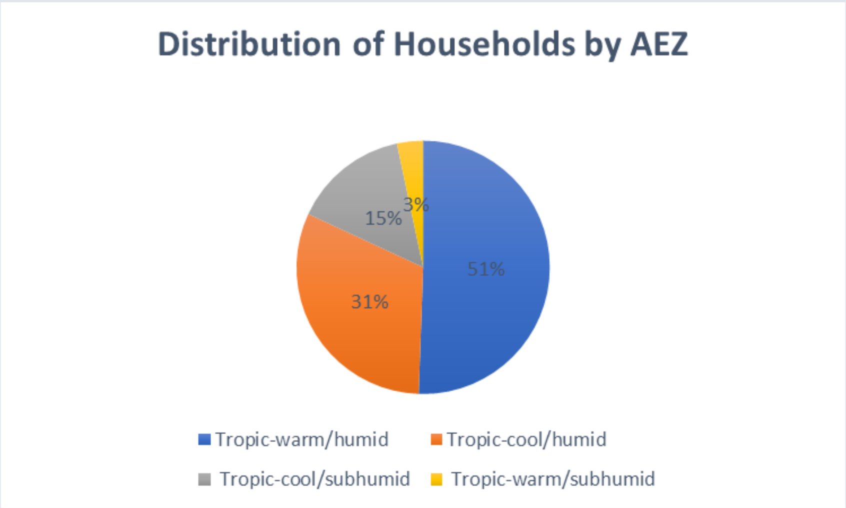
Appendix A.3: Agro-ecological Zones of Africa

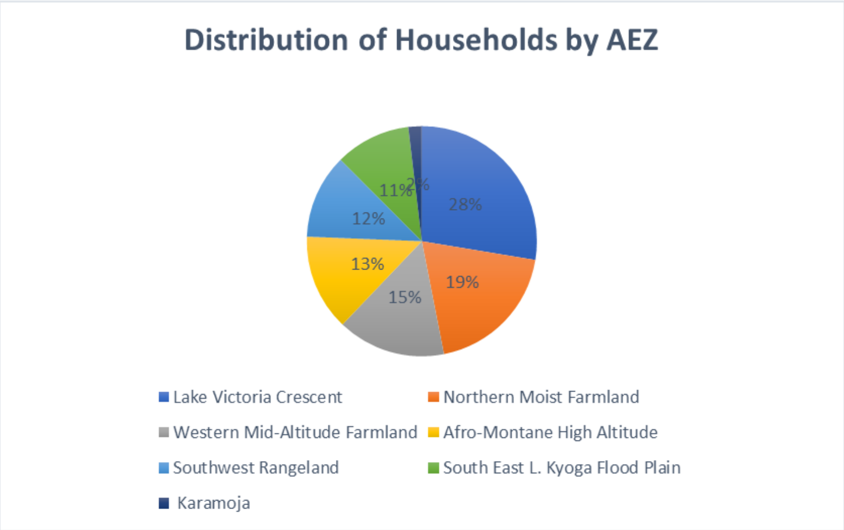


Source: Sebastian (2009).

Appendix B: Distribution of Households by Group, in %







Source: Based on data from UBOS (2020).

Appendix C.1: Correlation Matrix

Variable	Intercropping	Inorg. fertilizer	Impr. Seeds	Comm. agric.	Off-farm income	Assets	Land size	Age head	Nr. adults	Labor avail.	Education - less pr.	Education - jun.	Education - sec.	Education - degr.	Certificate	Tenure insec.	Training	Female head	Org. fertilizer	Pest./herb.	Irrigated	Elec. access	Dist. road	Dist. center	Dist. headq.	Shock	Clim. shock	Erosion	Good soil qual.	Poor soil qual.	Mod. nutr. constr.	Avg. temp.	Rainfall	False onset r.s.	Rainf. pat. change
Intercropping	1.0000	-0.0129	-0.0791	-0.0523	0.0027	-0.0446	-0.0957	-0.0235	-0.0409	-0.0146	0.0121	0.0217	-0.0110	-0.0002	0.1004	0.0335	-0.0278	0.0315	0.0705	-0.0317	-0.0188	0.0211	-0.0221	0.0269	0.0145	-0.0049	0.0026	-0.0340	-0.0272	0.0167	0.0340	-0.0035	0.0063	-0.0731	-0.0006
Inorganic fertilizer	-0.0129	1.0000	0.1737	0.1123	0.0362	0.0352	0.0079	-0.0216	0.0164	0.0029	-0.0155	0.0295	0.0269	0.0322	0.0409	0.0347	0.0594	-0.0352	0.0851	0.2307	-0.0096	0.0526	0.0014	0.0083	0.0050	-0.0082	0.0114	-0.0190	0.0208	-0.0024	0.0172	-0.0690	-0.0133	-0.0530	0.0078
Improved Seeds	-0.0791	0.1737	1.0000	0.0601	0.0524	0.0432	0.0192	-0.0145	0.0138	-0.0083	-0.0297	0.0876	0.0653	0.0240	0.0377	0.0257	0.0933	-0.0693	0.0711	0.1813	-0.0102	0.0386	0.0374	-0.0014	-0.0384	0.0574	0.0479	0.0126	0.0015	0.0163	0.0210	0.0537	-0.0041	0.0308	0.0159
Commercial agriculture	-0.0523	0.1123	0.0601	1.0000	0.0910	0.1628	0.1120	0.0520	0.0917	-0.0194	-0.0157	0.0741	-0.0058	0.0164	0.0555	0.0011	0.0646	-0.0502	0.0119	0.0601	0.0071	0.0308	0.0253	-0.0408	0.0070	0.0575	0.0568	0.0547	0.0655	-0.0306	0.0442	-0.0144	-0.0204	0.0142	0.0263
Off-farm income	0.0027	0.0362	0.0524	0.0910	1.0000	0.4549	0.1194	0.0471	0.2859	-0.0174	-0.0633	0.2899	0.2315	0.1348	0.1670	-0.0062	0.1171	-0.0578	0.0655	0.0767	-0.0305	0.2888	-0.1126	-0.0427	-0.0654	-0.0398	-0.0389	-0.0363	0.0576	-0.0166	-0.0259	-0.0020	0.0086	-0.0647	-0.0015
Assets	-0.0446	0.0352	0.0432	0.1628	0.4549	1.0000	0.3247	0.2281	0.4633	-0.0577	-0.1111	0.2857	0.2253	0.1538	0.1532	-0.0588	0.2040	-0.1498	0.0970	0.0840	-0.0267	0.2610	-0.0762	-0.1486	-0.0787	0.0212	-0.0483	-0.0223	0.0689	-0.0539	0.0154	-0.0374	-0.0181	-0.1020	-0.0156
Land size	-0.0957	0.0079	0.0192	0.1120	0.1194	0.3247	1.0000	0.1677	0.2205	-0.1262	-0.0080	0.0740	0.0522	0.0113	0.0559	0.0304	0.0938	-0.1485	0.0093	0.0865	-0.0034	0.0609	0.0679	0.0908	0.1024	0.0741	0.1255	-0.0033	0.1374	-0.0162	0.0351	0.2420	0.0114	-0.0041	-0.0320
Age head	-0.0235	-0.0216	-0.0145	0.0520	0.0471	0.2281	0.1677	1.0000	0.3385	-0.0281	-0.0094	-0.0285	0.0337	0.0463	0.1231	-0.0068	0.0791	0.0251	0.0157	0.0088	0.0392	0.0635	0.0088	-0.0841	-0.0579	0.0303	0.0257	0.0024	0.0284	-0.0372	0.0177	0.0234	0.0117	-0.1026	-0.0594
Number adults	-0.0409	0.0164	0.0138	0.0917	0.2859	0.4633	0.2205	0.3385	1.0000	0.0060	-0.0315	0.1422	0.1619	0.0815	0.1043	-0.0473	0.1555	-0.0974	0.0555	0.0485	-0.0045	0.2395	-0.0078	-0.0733	-0.0541	0.0467	0.0028	-0.0037	0.0262	-0.0147	0.0055	-0.0125	-0.0252	-0.1295	-0.0419
Labor availability	-0.0146	0.0029	-0.0083	-0.0194	-0.0174	-0.0577	-0.1262	-0.0281	0.0060	1.0000	-0.0148	-0.0151	-0.0137	-0.0165	0.0443	-0.0080	-0.0535	-0.0047	-0.0054	-0.0023	-0.0047	0.0003	-0.0209	-0.0480	-0.0249	-0.0043	-0.0251	0.0338	0.0097	0.0211	-0.0376	-0.1052	-0.0660	0.0336	-0.0080
Education - less than primary	0.0121	-0.0155	-0.0297	-0.0157	-0.0633	-0.1111	-0.0080	-0.0094	-0.0315	-0.0148	1.0000	-0.0521	-0.0262	-0.0115	-0.0481	-0.0122	-0.0509	0.1174	-0.0212	-0.0129	-0.0101	-0.0203	-0.0246	0.1087	-0.0397	0.0108	0.0377	0.0024	-0.0089	-0.0030	-0.0654	-0.0492	-0.0789	0.0345	0.0053
Education - junior	0.0217	0.0295	0.0876	0.0741	0.2899	0.2857	0.0740	-0.0285	0.1422	-0.0151	-0.0521	1.0000	0.5031	0.2208	0.1047	0.0187	0.1405	-0.1429	0.0836	0.0461	-0.0349	0.2009	-0.0817	-0.0704	-0.0880	-0.0043	-0.0200	-0.0167	0.0236	-0.0482	0.0338	0.0389	0.0026	-0.0288	-0.0411
Education - secondary	-0.0110	0.0269	0.0653	-0.0058	0.2315	0.2253	0.0522	0.0337	0.1619	-0.0137	-0.0262	0.5031	1.0000	0.4389	0.0613	0.0274	0.0967	-0.0580	0.1096	0.0537	-0.0201	0.1934	-0.1284	-0.0486	-0.0796	0.0046	-0.0012	-0.0124	0.0217	-0.0099	-0.0263	0.0376	0.0021	0.0133	-0.0531
Education - degree	-0.0002	0.0322	0.0240	0.0164	0.1348	0.1538	0.0113	0.0463	0.0815	-0.0165	-0.0115	0.2208	0.4389	1.0000	0.0546	0.0068	0.0887	0.0155	0.0452	0.0136	-0.0135	0.1286	-0.0816	-0.0782	-0.0865	0.0173	-0.0506	-0.0099	-0.0015	-0.0135	0.0117	0.0377	-0.0083	-0.0239	-0.0265
Certificate	0.1004	0.0409	0.0377	0.0555	0.1670	0.1532	0.0559	0.1231	0.1043	0.0443	-0.0481	0.1047	0.0613	0.0546	1.0000	0.1227	0.0208	-0.0278	0.0926	0.0703	0.0308	0.1604	-0.0468	-0.0048	0.0503	0.0056	0.0379	0.0077	0.0510	0.0265	0.0298	-0.0380	-0.0703	-0.1024	-0.0072
Tenure insecurity	0.0335	0.0347	0.0257	0.0011	-0.0062	-0.0588	0.0304	-0.0068	-0.0473	-0.0080	-0.0122	0.0187	0.0274	0.0068	0.1227	1.0000	-0.0262	0.0753	0.0660	0.0376	0.0634	0.0276	0.0303	0.0178	0.0341	0.0748	0.0896	0.0976	-0.0668	0.0719	0.0148	0.0845	-0.0568	0.0105	0.0034
Training	-0.0278	0.0594	0.0933	0.0646	0.1171	0.2040	0.0938	0.0791	0.1555	-0.0535	-0.0509	0.1405	0.0967	0.0887	0.0208	-0.0262	1.0000	-0.0571	0.0486	0.0410	-0.0279	0.0276	0.0250	-0.0695	-0.0563	0.0472	0.0181	-0.0173	0.0212	-0.0319	-0.0095	0.0040	0.0090	-0.0196	0.0064
Female head	0.0315	-0.0352	-0.0693	-0.0502	-0.0578	-0.1498	-0.1485	0.0251	-0.0974	-0.0047	0.1174	-0.1429	-0.0580	0.0155	-0.0278	0.0753	-0.0571	1.0000	-0.0162	-0.0748	-0.0074	-0.0182	-0.0964	-0.0330	-0.0571	-0.0236	-0.0145	0.0218	-0.0448	-0.0043	0.0063	-0.0339	0.0029	0.0169	0.0123
Organic fertilizer	0.0705	0.0851	0.0711	0.0119	0.0655	0.0970	0.0093	0.0157	0.0555	-0.0054	-0.0212	0.0836	0.1096	0.0452	0.0926	0.0660	0.0486	-0.0162	1.0000	0.0929	-0.0056	0.0914	-0.0322	-0.0385	-0.0421	-0.0202	-0.0093	0.0202	-0.0294	0.0044	0.0212	-0.1034	-0.0927	-0.0071	0.0232
Pesticides/herbicides	-0.0317	0.2307	0.1813	0.0601	0.0767	0.0840	0.0865	0.0088	0.0485	-0.0023	-0.0129	0.0461	0.0537	0.0136	0.0703	0.0376	0.0410	-0.0748	0.0929	1.0000	0.0080	0.0558	0.0046	0.0187	0.0182	-0.0021	0.0261	-0.0054	0.0211	0.0011	-0.0027	0.0124	-0.0149	-0.0422	0.0176
Irrigated	-0.0188	-0.0096	-0.0102	0.0071	-0.0305	-0.0267	-0.0034	0.0392	-0.0045	-0.0047	-0.0101	-0.0349	-0.0201	-0.0135	0.0308	0.0634	-0.0279	-0.0074	-0.0056	0.0080	1.0000	-0.0115	0.0422	0.0362	0.0476	0.0022	0.0227	0.0153	0.0311	-0.0156	-0.0125	0.0165	-0.0204	-0.0422	0.0193
Electricity access	0.0211	0.0526	0.0386	0.0308	0.2888	0.2610	0.0609	0.0635	0.2395	0.0003	-0.0203	0.2009	0.1934	0.1286	0.1604	0.0276	0.0276	-0.0182	0.0914	0.0558	-0.0115	1.0000	-0.0502	-0.0403	-0.0558	-0.0093	-0.0351	-0.0093	0.0409	-0.0153	0.0765	-0.0047	-0.0325	-0.0349	-0.0289
Distance road	-0.0221	0.0014	0.0374	0.0253	-0.1126	-0.0762	0.0679	0.0088	-0.0078	-0.0209	-0.0246	-0.0817	-0.1284	-0.0816	-0.0468	0.0303	0.0250	-0.0964	-0.0322	0.0046	0.0422	-0.0502	1.0000	0.2665	0.2989	0.0602	0.0892	0.0040	0.0334	-0.0072	0.0821	0.1676	0.1056	-0.0102	-0.0114
Distance market center	0.0269	0.0083	-0.0014	-0.0408	-0.0427	-0.1486	0.0908	-0.0841	-0.0733	-0.0480	0.1087	-0.0704	-0.0486	-0.0782	-0.0048	0.0178	-0.0695	-0.0330	-0.0385	0.0187	0.0362	-0.0403	0.2665	1.0000	0.2782	0.0517	0.1216	-0.0012	0.0567	0.0211	0.0064	0.1267	-0.0052	0.1069	-0.0858
Distance headquarters	0.0145	0.0050	-0.0384	0.0070	-0.0654	-0.0787	0.1024	-0.0579	-0.0541	-0.0249	-0.0397	-0.0880	-0.0796	-0.0865	0.0503	0.0341	-0.0563	-0.0571	-0.0421	0.0182	0.0476	-0.0558	0.2989	0.2782	1.0000	0.0167	0.0518	-0.0357	-0.0184	0.1029	0.0334	0.0313	0.0117	0.0407	0.0392
Shock	-0.0049	-0.0082	0.0574	0.0575	-0.0398	0.0212	0.0741	0.0303	0.0467	-0.0043	0.0108	-0.0043	0.0046	0.0173	0.0056	0.0748	0.0472	-0.0236	-0.0202	-0.0021	0.0022	-0.0093	0.0602	0.0517	0.0167	1.0000	0.5806	-0.0123	-0.0132	0.0148	0.0362	0.1601	-0.1443	0.0791	0.0244
Climate shock	0.0026	0.0114	0.0479	0.0568	-0.0389	-0.0483	0.1255	0.0257	0.0028	-0.0251	0.0377	-0.0200	-0.0012	-0.0506	0.0379	0.0896	0.0181	-0.0145	-0.0093	0.0261	0.0227	-0.0351	0.0892	0.1216	0.0518	0.5806	1.0000	-0.0063	0.0073	0.0443	0.0196	0.2283	-0.1556	0.0470	0.0235
Erosion	-0.0340	-0.0190	0.0126	0.0547	-0.0363	-0.0223	-0.0033	0.0024	-0.0037	0.0338	0.0024	-0.0167	-0.0124	-0.0099	0.0077	0.0976	-0.0173	0.0218	0.0202	-0.0054	0.0153	-0.0093	0.0040	-0.0012	-0.0357	-0.0123	-0.0063	1.0000	-0.0054	0.0574	-0.0555	-0.1017	-0.0633	0.0095	0.0244
Good soil quality	-0.0272	0.0208	0.0015	0.0655	0.0576	0.0689	0.1374	0.0284	0.0262	0.0097	-0.0089	0.0236	0.0217	-0.0015	0.0510	-0.0668	0.0212	-0.0448	-0.0294	0.0211	0.0311	0.0409	0.0334	0.0567	-0.0184	-0.0132	0.0073	-0.0054	1.0000	-0.2895	-0.0758	0.0050	-0.0058	-0.0288	0.0265
Poor soil quality	0.0167	-0.0024	0.0163	-0.0306	-0.0166	-0.0539	-0.0162	-0.0372	-0.0147	0.0211	-0.0030	-0.0482	-0.0099	-0.0135	0.0265	0.0719	-0.0319	-0.0043	0.0044	0.0011	-0.0156	-0.0153	-0.0072	0.0211	0.1029	0.0148	0.0443	0.0574	-0.2895	1.0000	0.0012	-0.0194	-0.0662	0.0240	-0.0230
Moderate nutrient constraint	0.0340	0.0172	0.0210	0.0442	-0.0259	0.0154	0.0351	0.0177	0.0055	-0.0376	-0.0654	0.0338	-0.0263	0.0117	0.0298	0.0148	-0.0095	0.0063	0.0212	-0.0027	-0.0125	0.0765	0.0821	0.0064	0.0334	0.0362	0.0196	-0.0555	-0.0758	0.0012	1.0000	0.1757	0.0872	-0.0336	-0.1228
Avg. temperature	-0.0035	-0.0690	0.0537	-0.0144	-0.0020	-0.0374	0.2420	0.0234	-0.0125	-0.1052	-0.0492	0.0389	0.0376	0.0377	-0.0380	0.0845	0.0040	-0.0339	-0.1034	0.0124	0.0165	-0.0047	0.1676	0.1267	0.0313	0.1601	0.2283	-0.1017	0.0050	-0.0194	0.1757	1.0000	0.2679	0.0277	-0.1166
Rainfall	0.0063	-0.0133	-0.0041	-0.0204	0.0086	-0.0181	0.0114	0.0117	-0.0252	-0.0660	-0.0789	0.0026	0.0021	-0.0083	-0.0703	-0.0568	0.0090	0.0029	-0.0927	-0.0149	-0.0204	-0.0325	0.1056	-0.0052	0.0117	-0.1443	-0.1556	-0.0633	-0.0058	-0.0662	0.0872	0.2679	1.0000	0.1086	-0.0487
False onset rainy season	-0.0731	-0.0530	0.0308	0.0142	-0.0647	-0.1020	-0.0041	-0.1026	-0.1295	0.0336	0.0345	-0.0288	0.0133	-0.0239	-0.1024	0.0105	-0.0196	0.0169	-0.0071	-0.0422	-0.0422	-0.0349	-0.0102	0.1069	0.0407	0.0791	0.0470	0.0095	-0.0288	0.0240	-0.0336	0.0277	0.1086	1.0000	0.0944
Rainfall pattern change	-0.0006	0.0078	0.0159	0.0263	-0.0015	-0.0156	-0.0320	-0.0594	-0.0419	-0.0080	0.0053	-0.0411	-0.0531	-0.0265	-0.0072	0.0034	0.0064	0.0123	0.0232	0.0176	0.0193	-0.0289	-0.0114	-0.0858	0.0392	0.0244	0.0235	0.0244	0.0265	-0.0230	-0.1228	-0.1166	-0.0487	0.0944	1.0000

Appendix C.2: P-value two-sample t-test for selected covariates

Variables	Cropping System (Intercropping vs Pure Stand)	Inorganic Fertilizer (Yes vs No)	Seed Type (Improved vs Traditional Seeds)
Agricultural productivity	0	0.03	0
Land Size	0	0.408	0
Distance headquarters	0.073	0.044	0
Commercial agriculture	0.098	0.027	0.396
Certificate	0	0.046	0.002
Shock	0	0	0.042
Education - junior	0.008	0	0

Appendix C.3: Balancing Test, Treatment = Cropping system

Variable	Mean Treated	Mean Control	%bias	t-test t	t-test p>|t|	V(T)/V(C)
ln_parcel_size_acres_est	.39477	.41558	-1.7	-0.82	0.413	0.98
earnings_mainsource_commercagri	.03356	.02508	4.5	1.93	0.054	.
certificate_dummy	.23017	.23627	-1.4	-0.55	0.580	.
shock_length_tot	3.3288	3.1556	3.5	1.51	0.132	1.02
dist_admctr	21.468	21.693	-1.3	-0.57	0.567	0.91*
education_head_junior	.2	.21254	-3.1	-1.19	0.234	.

* if variance ratio outside [0.93; 1.07]

Ps R2	LR chi2	p>chi2	MeanBias	MedBias	B	R	%Var
0.001	8.56	0.200	2.6	2.4	7.6	1.08	33

* if B>25%, R outside [0.5; 2]

Appendix C.4: Balancing Test, Treatment = Inorganic fertilizer

Variable	Mean Treated	Mean Control	%bias	t-test t	t-test p>|t|	V(T)/V(C)
certificate_dummy	.27723	.33663	-13.7	-0.91	0.363	.
shock_length_tot	2.0792	1.8812	4.5	0.42	0.673	1.23
dist_admctr	21.014	22.893	-11.3	-0.80	0.423	0.97
earnings_mainsource_commercagri	.0198	.0099	4.2	0.58	0.563	.

* if variance ratio outside [0.67; 1.48]

Ps R2	LR chi2	p>chi2	MeanBias	MedBias	B	R	%Var
0.008	2.18	0.702	8.4	7.9	20.7	0.97	0

* if B>25%, R outside [0.5; 2]

Appendix C.5: Balancing Test, Treatment = Seed type

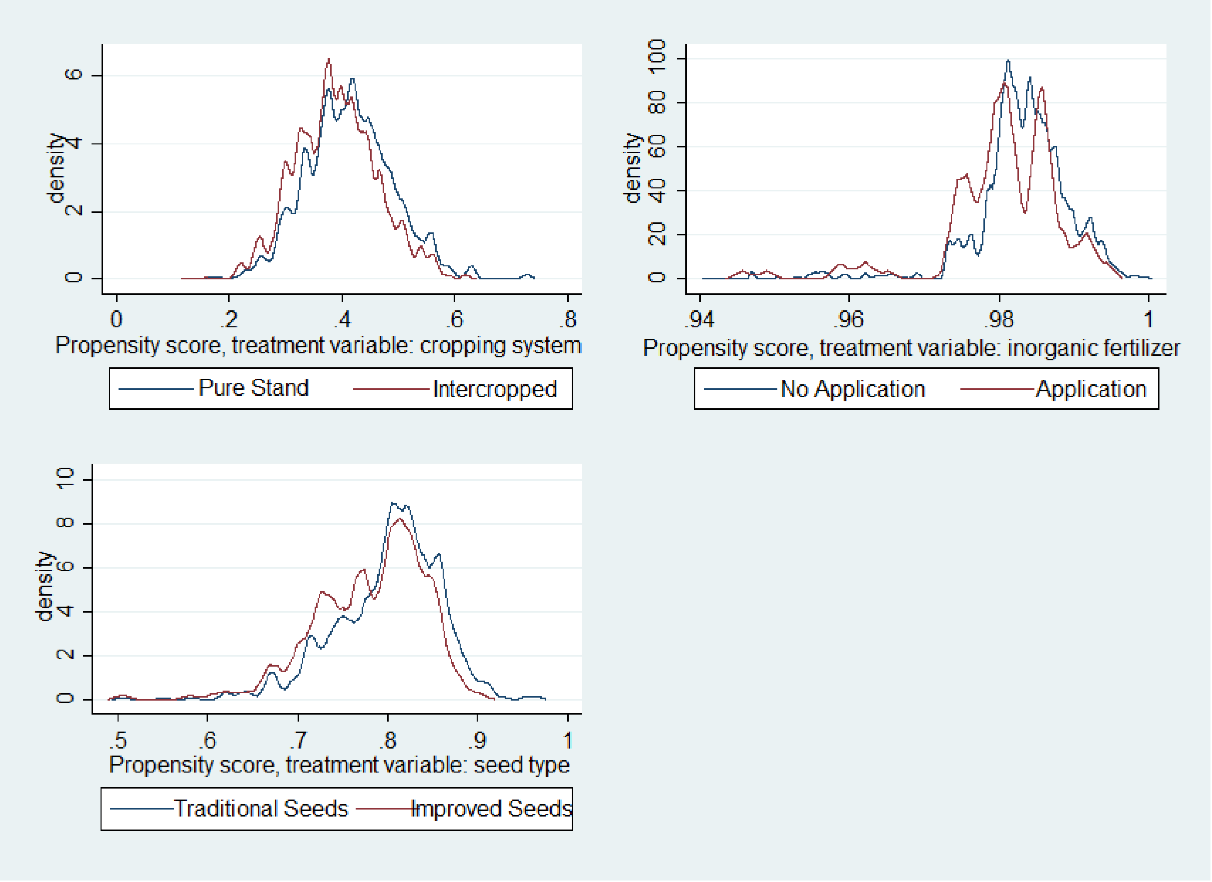
Variable	Mean Treated	Mean Control	%bias	t-test t	t-test p>|t|	V(T)/ V(C)
ln_parcel_size_acres_est	.59334	.61963	-2.2	-0.26	0.794	1.05
certificate_dummy	.19573	.27402	-19.1	-2.19	0.029	.
shock_length_tot	3.1423	3.3167	-3.7	-0.45	0.655	1.12
dist_admctr	20.535	22.392	-11.7	-1.40	0.162	0.85
education_head_junior	.2242	.2242	0.0	0.00	1.000	.

* if variance ratio outside [0.79; 1.26]

Ps R2	LR chi2	p>chi2	MeanBias	MedBias	B	R	%Var
0.008	5.99	0.307	7.4	3.7	20.7	0.86	0

* if B>25%, R outside [0.5; 2]

Appendix C.6: Test of Overlap Assumption



Appendix D: Overview of all Variables

Key dependent variable			
Variable	**Name**	**Description**	**Data Source**
Agricultural productivity	ln_productivity	Yields, in kg/acre (log)	UNPS, Agriculture Survey

Key explanatory variables: CSA practices			
Variable	**Name**	**Description**	**Data Source**
Inorganic fertilizer	inorganic_fertilizer	Indicator variable: use of inorganic fertilizer on the plot 1= yes 0= no	UNPS, Agriculture Survey
Intercropping	cropping_system	Indicator variable: 1=intercropped 0=pure stand	UNPS, Agriculture Survey
Improved seeds	seed_type	Indicator variable: 1=improved seeds 0=traditional seeds	UNPS, Agriculture Survey

Additional explanatory variables: economic factors			
Variable	**Name**	**Description**	**Data Source**
Commercial agriculture	earnings_mainsource_commercagri	Indicator variable: Is the income strategy of this household commercial agriculture? 1 = yes 0 = no	UNPS, Household Survey
Off-farm income	ln_income_nonagri_tot	Household income from non-agricultural activities, in Ugandan Shillings (log)	UNPS, Household Survey
Assets	ln_assets_val_tot	Total estimated value of household assets, in Ugandan Shillings (log)	UNPS, Household Survey
Land size	ln_parcel_size_acres_est	Total size of the agricultural land owned, in acres (log)	UNPS, Agriculture Survey

Additional explanatory variables: socioeconomic factors			
Variable	**Name**	**Description**	**Data Source**
Age head	head_age	Age of household head, in years	UNPS, Household Survey
Number of adults	adults_nr	Number of adults (age >/=15)	UNPS, Household Survey
Labor availability	labor_availability	Labor in person days (family labor and hired labor) per unit of land	UNPS, Agriculture Survey
Education	education_head_lessthanP1 education_head_junior education_head_secondary education_head_degree	Indicator variable: Has the household head completed this education level? 1 = yes 0 = no	UNPS, Household Survey

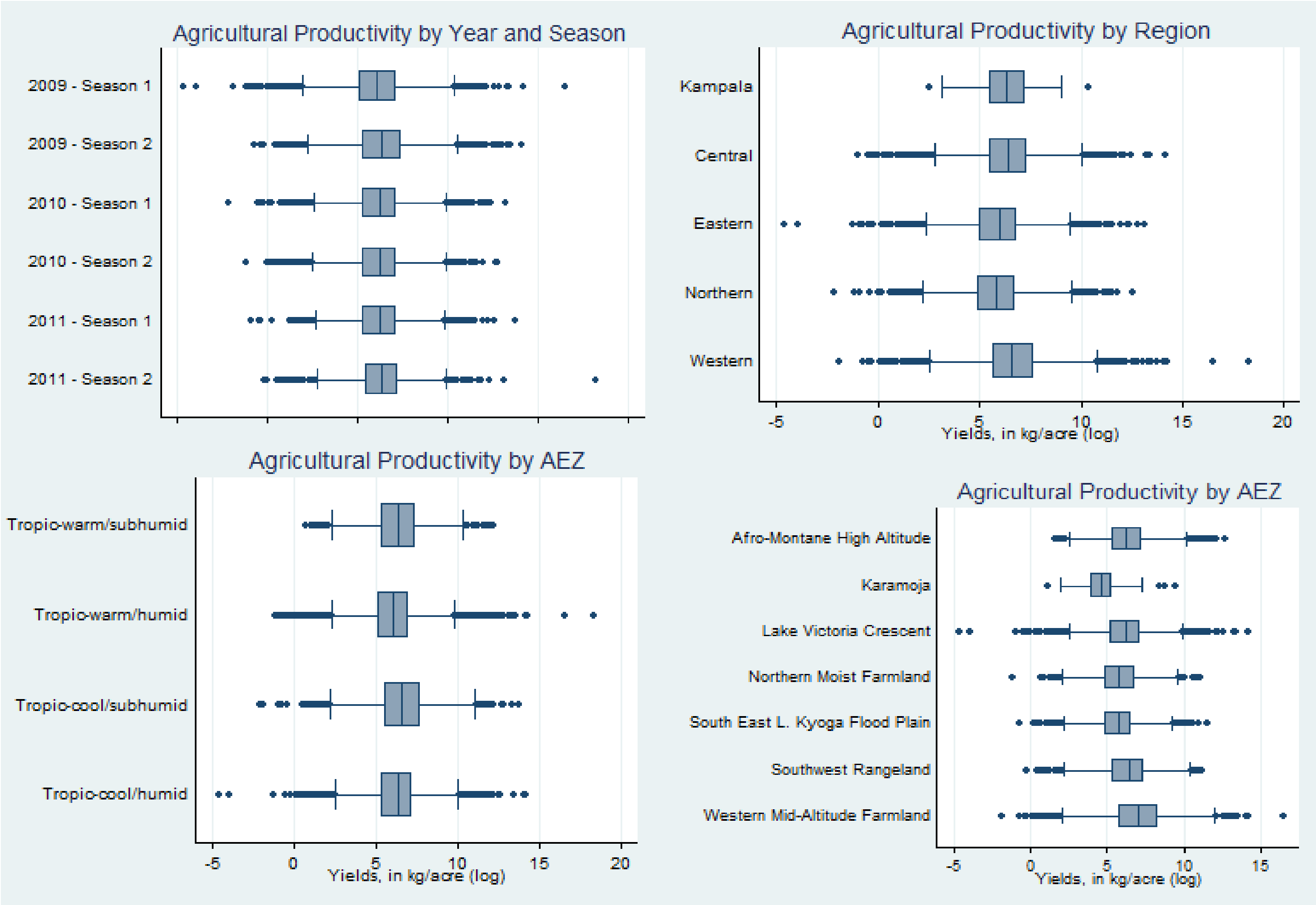
Certificate	certificate_dummy	Indicator variable: Does the household have a tenure certificate for the parcel? 1= yes 0= no	UNPS, Agriculture Survey
Tenure insecurity	parcel_ownership_concerns	Indicator variable: Have you ever been concerned that somebody might dispute your ownership/ use rights on this parcel? 1= yes 0= no	UNPS, Agriculture Survey
Training	training_dummy	Indicator variable: Has any member of your household participated in a training program organized by NAADS in the past 12 months? 1= yes 0= no	UNPS, Agriculture Survey
Female head	head_female	Indicator variable: 1= female headed 0= male headed	UNPS, Household Survey

Additional explanatory variables: production-specific factors			
Variable	**Name**	**Description**	**Data Source**
Organic fertilizer	organic_fertilizer	Indicator variable: organic fertilizer application on the plot 1= yes 0= no	UNPS, Agriculture Survey
Pesticides/herbicides	pesticides_herbicides	Indicator variable: use of pesticides 1= yes 0= no	UNPS, Agriculture Survey
Irrigated	irrigated	Indicator variable: Do you have an irrigation system? 1= yes 0= no	UNPS, Agriculture Survey

Additional explanatory variables: infrastructure			
Variable	**Name**	**Description**	**Data Source**
Electricity access	power_hours	Number of hours per day the household usually has power	UNPS, Household Survey
Distance road	dist_road	Household distance to nearest international or national trunk road (functional class A, B), in km	UNPS, Geospatial Variables
Distance market center	dist_market	Household distance to nearest major market, in km	UNPS, Geospatial Variables
Distance district capital	dist_admctr	Household distance to to the headquarter of the district of residence, according to 2006 district boundaries, in km	UNPS, Geospatial Variables

Additional explanatory variables: agro-ecological and climatological factors			
Variable	**Name**	**Description**	**Data Source**
Shock	shock_length_tot	Number of months the household has been hit by any kind of shock during the past 12 months	UNPS, Household Survey
Drought/Floods	shock_fd	Indicator variable: Has the household been hit by any drought or floods during the past 12 months? 1= yes 0= no	UNPS, Household Survey
Erosion	erosion_dummy	Indicator variable: During the last completed season, were there any problems with erosion in this parcel? 1= yes 0= no	UNPS, Agriculture Survey
Soil quality: Good Poor	soil_qual_good soil_qual_poor	Indicator variables: What soil quality is this parcel? Good? 1= yes 0= no Poor? 1= yes 0= no	UNPS, Agriculture Survey
Moderate nutrient constraint	nutrient_constraint_moderate	Indicator variable: Moderate nutrient availability constraint 1= yes 0= no	UNPS, Geospatial Variables
Average temperature	temperature_avg	Average temperature of the wettest quarter, in °C (multiplied by 10)	UNPS, Geospatial Variables
Rainfall	rainfall	Total rainfall in wettest quarter in first/second growing season, in mm	UNPS, Geospatial Variables
False onset rainy season	falseonset_rainy_dummy	Indicator variable: Difference between average start of wettest quarter and start of wettest quarter in specific season 1=above mean of AEZ 0=below mean of AEZ	UNPS, Geospatial Variables
Rainfall pattern change	rainfall_annual_variation_dummy	Indicator variable: Divergence of annual total rainfall (specific year) from average total rainfall 1=above mean of AEZ 0=below mean of AEZ	UNPS, Geospatial Variables

Appendix E.1: Boxplots Agricultural Productivity



Source: Based on data from UBOS (2020).

Appendix E.2: Type of Seeds used by Cropping System, in %

Type of Seeds	Cropping System: Pure Stand	Cropping System: Intercropped	Total
2009			
Traditional	*78.95*	*82.42*	*80.82*
Improved	*21.05*	*17.58*	*19.18*
2010			
Traditional	*81.43*	*86.9*	*84.36*
Improved	*18.57*	*13.1*	*15.64*
2011			
Traditional	*87.37*	*92.36*	*90.14*
Improved	*12.63*	*7.64*	*9.86*

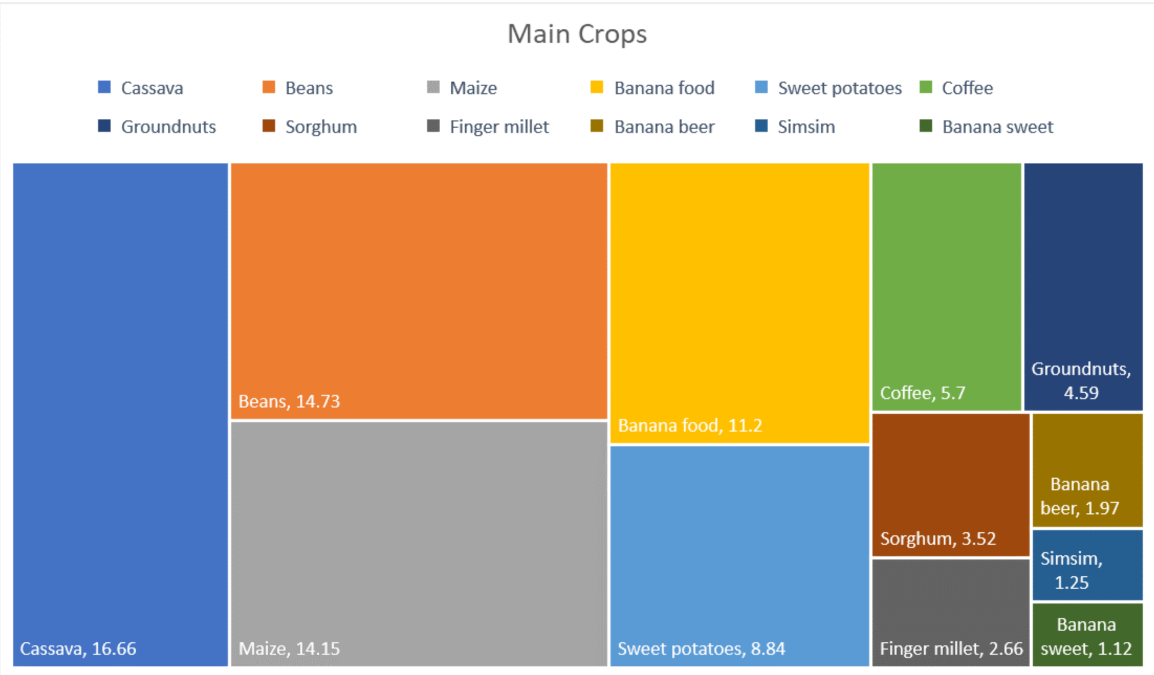
Source: Based on data from UBOS (2020).

Appendix E.3: Overview of Crops Grown by Ugandan Farmers

Ser. no.	Crop name	Crop code	Ser. no.	Crop name	Crop code
1	Wheat	111	31	Oranges	700
2	Barely	112	32	Paw paw	710
3	Rice	120	33	Pineapples	720
4	Maize	130	34	Banana food	741
5	Finger millet	141	35	Banana beer	742
6	Sorghum	150	36	Banana sweet	744
7	Beans	210	37	Mango	750
8	Field peas	221	38	Jackfruit	760
9	Cow peas	222	39	Avocado	770
10	Pigeon peas	223	40	Passion fruit	780
11	Chick peas	224	41	Coffee all	810
12	Groundnuts	310	42	Cocoa	820
13	Soya beans	320	43	Tea	830
14	Sunflower	330	44	Ginger	840
15	Simsim	340	45	Curry	850
16	Cabbage	410	46	Oil palm	860
17	Tomatoes	420	47	Vanilla	870
18	Carrots	430	48	Black wattle	880
19	Onions	440	49	Other	890
20	Pumpkins	450	50	Natural pastures	910
21	Dodo	460	51	Improved pastures	920
22	Eggplants	470	52	Fallow	930
23	Sugarcane	510	53	Bush	940
24	Cotton	520	54	Natural forest trees	950
25	Tobacco	530	55	Plantation trees	960
26	Irish potatoes	610	56	Bamboo	970
27	Sweet potatoes	620	57	Other forest trees	990
28	Cassava	630			
29	Yam	640			
30	Coco yam	650			

Source: UBOS (2020). Extracted from UNPS, Agriculture Surveys Manual.

Appendix E.4: Main Crops Grown, in %



Source: Based on data from UBOS (2020).

Appendix F: Determinants of Agricultural Productivity

	(1) RE	(2) CRE	(3) RE	(4) CRE
CSA practices				
Intercropping	0.298***	0.476***	0.283***	0.478***
	(0.023)	(0.045)	(0.036)	(0.081)
Inorganic fertilizer	0.194**	0.141	0.343***	0.119
	(0.084)	(0.128)	(0.118)	(0.236)
Improved seeds			0.438***	0.134
			(0.055)	(0.127)
Economic factors				
Commercial agriculture	0.123	-0.013	0.094	0.069
	(0.075)	(0.188)	(0.124)	(0.125)
Off-farm income	0.031***	0.028***	0.037***	0.034**
	(0.009)	(0.009)	(0.013)	(0.014)
Assets	0.071***	0.014	0.061***	-0.018
	(0.011)	(0.022)	(0.016)	(0.039)
Land size	-0.192***	-0.191***	-0.107***	-0.106***
	(0.013)	(0.013)	(0.020)	(0.020)
Socioeconomic factors				
Age head	-0.001	-0.003	-0.001	-0.003
	(0.001)	(0.005)	(0.001)	(0.012)
Number of adults	0.023***	0.081***	0.013	0.121***
	(0.006)	(0.023)	(0.009)	(0.037)
Labor availability	0.001**	0.001***	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
Education - less than primary	-0.600***	-0.588***	-0.902***	-0.879***
	(0.137)	(0.138)	(0.197)	(0.200)
Education - junior	0.098***	0.095***	0.020	0.023
	(0.033)	(0.033)	(0.050)	(0.050)
Education - secondary	-0.213***	-0.235***	-0.164*	-0.168*
	(0.058)	(0.058)	(0.088)	(0.089)
Education - degree	0.128	0.103	0.526***	0.505***
	(0.117)	(0.115)	(0.181)	(0.181)
Certificate	0.063**	-0.100	0.179***	0.073
	(0.028)	(0.067)	(0.044)	(0.132)
Tenure insecurity	0.012	-0.062	0.146**	0.050
	(0.038)	(0.064)	(0.058)	(0.098)
Training	0.097***	0.074	0.105***	0.160
	(0.027)	(0.054)	(0.040)	(0.103)
Female head	-0.094***	-0.093***	-0.096**	-0.097**
	(0.030)	(0.030)	(0.046)	(0.046)
Production-specific factors				
Organic fertilizer	0.212***	0.022	-0.017	0.238*
	(0.037)	(0.049)	(0.087)	(0.125)
Pesticides/herbicides	0.064	0.016	0.313***	0.102
	(0.050)	(0.080)	(0.077)	(0.151)
Irrigated	0.118	0.042	0.093	-0.003
	(0.082)	(0.148)	(0.173)	(0.265)
Infrastructure				
Electricity access	-0.002	-0.023***	-0.005	-0.042**
	(0.003)	(0.008)	(0.005)	(0.018)
Distance road	0.002	0.077**	0.002	0.010
	(0.002)	(0.038)	(0.003)	(0.062)
Distance market center	0.002***	0.002***	0.002**	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)

Agro-ecological and climatological factors				
Shock	-0.005	0.006	0.001	0.015
	(0.003)	(0.006)	(0.005)	(0.011)
Erosion	-0.105***	0.014	-0.123***	0.084
	(0.030)	(0.057)	(0.046)	(0.103)
Good soil quality	0.167***	0.165***	0.147***	0.136***
	(0.024)	(0.024)	(0.039)	(0.039)
Poor soil quality	0.065	0.057	-0.098	-0.104
	(0.057)	(0.056)	(0.108)	(0.106)
Moderate nutrient constraint	0.032	0.025	0.005	0.006
	(0.028)	(0.027)	(0.039)	(0.039)
Average temperature	-0.011***	-0.011***	-0.010***	-0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
Rainfall	0.000	0.000	0.001***	0.001***
	(0.000)	(0.000)	(0.000)	(0.000)
False onset rainy season	0.027	0.017	0.057	0.107
	(0.023)	(0.034)	(0.038)	(0.078)
Rainfall pattern change	-0.076***	-0.027	-0.055	0.026
	(0.023)	(0.040)	(0.036)	(0.078)
Constant	6.690***	6.571***	5.502***	5.448***
	(0.271)	(0.290)	(0.404)	(0.436)
Observations	18,291	18,291	5,547	5,547
R^2 between/(overall)	0.0869/	0.0918/	0.1183/	0.1234/
	(0.1050)	(0.1151)	(0.1218)	(0.1287)

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Source: Based on data from UBOS (2020). Author's own estimation results.