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Is it Smart to be Climate-Smart?

The Efficiency of Climate-Smart Agriculture in Tanzania

by

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Abstract

Does it pay to adopt Climate-Smart Practices? Despite the general understanding that CSA practices or innovative land management methods increase farmers’ food security, the key to the current debate within the literature is to understand the extent to which CSA practices explain differences in farmers’ productivity and resilience to climatic shocks. To fill this gap, this study examines the variation in crop yields among Tanzanian farmers across three CSA practices: intercropping, inorganic fertilization, and improved seeding. By using panel data collected by the National Bureau of Statistics in Tanzania (NBS) between 2008-2011, a plot-level analysis concluded that intercropping and inorganic fertilization are positively associated with increased productivity (kg/acre), increasing crop yields by 59 and 54 percent respectively. Climatic shocks, while reducing productivity across all plots, were less damaging in plots where intercropping and inorganic fertilization occurred.

Keywords: Climatic shocks, Climate-Smart Agriculture, Crop Productivity, Tanzania

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1 Introduction

One of the greatest challenges of our time is meeting the needs of the increasing global population projected to reach 9.8 billion by 2050 (UN, 2017). Regardless of societal development, countries will face a tremendous task in facing the demand of their population without further compromising the ability of future generations to do the same (WCED, 1987). One major concern relating to this is the provision of an adequate food supply. It needs to increase by 56 percent, or else, one-third of the global population will suffer from malnutrition by 2050 (UN, 2020). Simultaneously, the agricultural sector, which stands as the primary source of the global food supply, is highly affected by global warming and is estimated to lose 30 percent of its productivity over the 21st century (IPCC, 2001). Unpredictable weather patterns, both in terms of precipitation and temperature, have exceptional effects on sustainable livelihoods and agricultural production due to prolonged droughts, floods, soil erosion, and vegetation degradation leading to a rapid spread of pests and diseases. Hence, increasing the level of sufficient food supply by 2050 without further depleting precious resources of soil and water will be a task that might occupy us for generations to come (Below, Artner, Siebert & Sieber, 2010; Dell, Jones & Olken, 2012; Smil, 2016; IPCC, 2018; Nyasimi, Amwata, Hove, Kinyangi & Wamukoya, 2014; Rogelj, Meinshausen, & Knutti, 2012).

To highlight these issues and construct pathways towards sustainable land management, scholars have stressed the climatic effect on agricultural output from several angles (Adams, Rosenzweig, Peart, McCarl, Glyer, Curry, James, Jones, Kenneth, Boote & Hartwell, 1990; Mendelsohn, Dinar & Sanghi, 2001; Schlenker & Roberts, 2006; Deschenes & Greenstone, 2007) whereas Climate-Smart Agriculture (CSA) is a recurring topic within the literature (Sova, Grosjean, Baedeker, Nguyen, Wallner, Nowak, Corner-Dolloff, Girvetz, Laderach & Lizarazo, 2018; FAO, 2019; CIAT &World Bank, 2017; Komarek, Thurlow, Koo & De Pinto, 2019; Abdulai, 2016; Arslan, McCarthy, Lipper, Asfaw, Cattaneo & Kokwe, 2012; Cholo, Fleskens, Sietz, & Peerlings, 2019; Samberg, Gerber, Ramankutty, Herreo & West, 2016; Thornton, Rosenstock, Förch, Lamanna, Bell, Henderson & Herreo, 2018; Engel & Muller, 2016). The term CSA was introduced in 2009 by the Food and Agriculture Organization (FAO, 2009) and is defined as "agriculture that sustainably increases productivity, enhances resilience[1] (adaptation), reduces/removes GHGs (mitigation) where possible, and enhances achievement of national food security and development goals" (FAO, 2013, p.2).

Through this definition, the principal goal of CSA is identified as development and food security (FAO 2013; Lipper, Thornton, Champel & Torquebiau, 2014); while adaptation, mitigation, and productivity are established as three interlinked pillars (the "triple win") necessary for reaching this goal (FAO 2013; World Bank, 2011). The latter pillar, *productivity,* is often mentioned as a central approach in facing global hunger since it seeks sustainable intensification of the food supply while also reducing greenhouse gas emissions per production unit. In general, productivity within CSA is measured to understand the level of performance. Regardless of economic unit or entity, such as agricultural holdings, it is defined as "the ratio of outputs (O) to inputs (X), expressed either in volumes or, when possible, in physical quantities (kg, tons, etc.)'' (FAO, 2018b, p.2). Factors of production or intermediate inputs are the resources needed to produce given output. In this case, they usually refer to labor inputs (factors of production), agrochemicals, seeds, or fertilizers (intermediate inputs). An increase in the values of this ratio is, however, associated with

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[1] "Resilience" is within agriculture usually defined as the process of "equipping farmers to absorb and recover from shocks and stresses to their agricultural production and livelihoods" (Farming First, 2014)

improved performance (FAO, 2018b). It is within this context that this study is set to investigate if CSA practices explain productivity differences.

1.1 Research Problem

While it is clear that CSA is environmentally beneficial, it is limited by its requirement for a wide range of capacity and institutional coordination. Even though CSA practices are context-specific and have to be implemented with concern to local conditions, local farmers are still often left out of the agenda (Arslan et al. 2012; Rioux et al. 2017). Therefore, it is essential to examine the topic with greater depth. This will enable us to understand its potential in making farmers more resilient to climate change and help them maintain stable food production in the future. CSA has been widely introduced in Sub-Saharan Africa (SSA), a heavily affected region due to its reliance on rain-fed agriculture, low adaptive capacity, and unstable socio-economic and political systems. This weak capacity refers mainly to absorbing innovations established on the market to foster farmers' use of sustainable agricultural methods seeking to increase productivity (CIAT &World Bank., 2017). Although some SSA countries have seen steady development over the past years with a growing agricultural sector, countries still face challenges with the provision of basic needs - an issue that has come to classify SSA as the poorest region in the world (Schoch & Lakner, 2020; UN, 2020).

Within the literature, Tanzania is often mentioned as an SSA country that recently has faced steady economic growth, as evidenced by its rise in educational attainment and distribution of wealth relative to other SSA countries. Yet, Tanzania sees stagnation within the agricultural sector, a challenge that will hinder it from intensifying agricultural supply to meet global demand while leaving the classification of being a low middle-income country (Rioux et al. 2017). Agriculture is the key driver to development, contributing to 95 percent of domestic food production and employing 59 percent of the active population. Still, the agricultural sector sees a decrease of 25 percent in agricultural output every year, and over 30 percent of the population lives under the poverty line, meaning that the country has one of the lowest Human Development Indices (HDI) in the world (FAO, IFAD, & WFP, 2015). Scholars argue that Tanzania, despite its recent progress, is stuck in a negative loop due to an agricultural yield gap caused by low agricultural productivity, poor access to inputs, unsustainable production methods, over-reliance on rainfall, and poor capacity to deal with weather shock (Rioux et al. 2017). Its geographical location, with varying physiography and both tropical and subtropical climatic zones, has caused issues with rising sea levels, changes in rainfall patterns, and inland droughts (FAO, IFAD, & WFP, 2015; CIAT & World Bank, 2017).

To tackle future challenges and improve agricultural productivity, the Tanzanian government has implemented policies and CSA programs to support innovative technologies and sustainable agricultural methods (TaCCIRe, 2012). Although actions have been taken, the CSA guidelines are still under development while investments fail to support technologies and agricultural practices for local farmers. Limited knowledge among extension officers supporting CSA technologies leads to inadequate capacity to scale up CSA at ward and village levels (Rioux et al. 2017). Moreover, due to the variation in Tanzania's climate, CSA methods are context-dependent and cannot be generalized. Each method needs to be treated concerning its contextual capacity and capture challenges faced by farmers from a local perspective. By examining Tanzania, a country that has seen rapid growth relative to its neighboring countries, this case study provides policymakers within the SSA region with valuable tools on how to target efficient agricultural methods at an earlier stage of development. Targeting efficient policies prevents the issue with productivity yield gaps, supports sustainable development, and increases our understanding of the farmers-perspective.

1.2 Aim, Scope and Research Question

This study investigates whether CSA practices increase agricultural productivity when Tanzanian farmers are exposed to extreme weather and climatic shocks such as droughts and floods[2]. Using micro-level data collected from 7 204 Tanzanian households between 2008-2011, this research seeks to quantify the weather effect by focusing on the magnitude of the crop yield when the farmers implemented a set of CSA practices. When controlling for CSA practices, the analysis focuses on the ones recommended by the FAO (Rioux et al. 2017) as important practices for the Tanzanian context; *inorganic fertilizer, improved seeding,* and *intercropping*. Furthermore, crops that will be covered in the analysis are; *maize, beans, cassava, paddy, sunflower, sorghum, and banana*.

To capture site-specific variation in climate, this research seeks to control for six regions, four main climatological agro-ecological zones (AEZ) and ten landscape-specific AEZ accounting for terrain roughness and altitude. The six regions covered are; *central, northeast, east, southeast, west, and northwest* Tanzania. The main climatological AEZ are *tropic-cool/subhumid, tropic-warm/subhumid, tropic-cool/humid,* and *tropic-warm/humid* climate. Finally, the ten landscape-specific AEZ are clustered as *semi-arid lands/mid-altitude plateaus, semi-arid lands/high-altitude plateaus, arid lands/mountains* and *coastal areas/lowlands/alluvial plains*[3]. Even though the effect of CSA practices may have a positive impact on the crop yield, it is important to remember that CSA is context-dependent and cannot be generalized. However, by estimating its impact quantitatively and whether it differs when controlling for climatic shock, this study has crucial implications for targeted CSA policies in Tanzania. Therefore, the following research question seeks to be investigated:

Can differences in agricultural productivity be explained by CSA practices, particularly when testing for the impact of climatic shocks?

A step-wise analysis was implemented to investigate this research question, using three hypotheses covering both the general and the context-specific climatic variation within the country. Hypothesis 1 (H1) controls for the general impact of CSA on crop yield output, while hypothesis 2 (H2) adds the weather effect to test farmers' resilience. Hypothesis 3 (H3) controls for the climatic variation across regions (H3A), agro-ecological zones (H3B), and crops (H3C) and seeks to give a more detailed understanding of the local impact of CSA.

H1: Agricultural productivity increases when CSA practices are implemented
H2: Farmers utilizing CSA practices are more resilient to climatic shocks
H3: The effect of the given CSA practices varies across:
  A: Regions
  B: Agro-ecological zones (AEZ)
  C: Crops

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[2] The term "extreme weather" represents short-term changes in local atmospheric conditions above average (e.g. sudden droughts, floods, rainfall season changes, increase in precipitation). In contrary, the term "climate change" is used to define long-term changes in global trends (NASA, 2021). A definition of terms used will be discussed further in section 2.3

[3] The geographical division will be described in depth under section 2.2.

1.3 Contribution

Scholars have analyzed crop productivity from several angles, although most studies use case studies to evaluate CSA practices (Branca et al. 2011; Pretty et al. 2006). Using data where farmers did not participate in a certain CSA evaluation, captures the individual choice of the farmers and the resilience in the methods applied when unpredictable weather changes affected the plot. Analyzing data where farmers did not participate in a certain CSA evaluation, highlights the implementation issue faced by the individual. Additionally, while the literature has mainly used data collected at a household level (Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998; Arslan et al. 2015; Mugabe, 2015), this study use a new level of granularity by examining the plot level.

1.4 Limitations

This study inevitably faces limitations that have to be taken into account. The variables in the analysis have been chosen after availability, meaning that they are certainly not perfect to understand the context in detail. Moreover, several factors affect productivity levels and which is not included in this thesis. The issue of unobservable factors is something that influences estimations of the population parameter and can cause problems with endogeneity. To address this, several robustness tests were applied and fixed effect reduced time-invariant factors, which lead to unbiased estimates. Since this data was not based on a natural experiment, applying propensity score matching created an "experiment-like" situation. It provides the study with tools on how to face issues such as reverse causality and self-selection bias. Moreover, due to many missing observations in the data, the estimated results have to be approached carefully. By comparing the results to maps, weather projections, and geographical variations, findings in this thesis were possible to support through previous literature. To fill the gap of potential unobservable factors influencing productivity levels in Tanzania, further research should, however, include more factors into the analysis. As soon as improved microlevel data is available.

1.5 Outline of the Thesis

The thesis is divided into seven chapters. In chapter 2, an overview of the conceptual framework is given by providing insights about the case of Tanzania in terms of agriculture characteristics, climate change, and CSA implementations. In chapter 3, the relevant literature on agriculture strategies is discussed with a particular focus on CSA and its potential in increasing food security, income, collaborative partnerships, and productivity. In chapter 4, the data used in this study is analyzed and significant limitations addressed. In chapter 5, the empirical strategy is outlined by discussing variables included, estimation methods, and robustness checks performed. In chapter 6, the empirical results are presented concerning each stated hypothesis. In chapter 7, the empirical results are analyzed in connection to the literature. In chapter 8, the concluding remarks of this study are presented and suggestions for further studies are made.

2 Contextual Framework

This part aims to give the reader a background of the context and why the research topic is relevant to examine. It is crucial to understand the role of agriculture on both livelihoods and how climate change expects to impact prevailing climatological conditions and agricultural output. To begin with, an overview of the agricultural sector will be provided. Next, an outline of agricultural characteristics across regions, AEZ and crops. Finally, a thorough description of climate change in Tanzania will be given, followed by a presentation on operationalizing CSA, from theory into practice.

2.1 The Tanzanian Economy: The Role of Agriculture

Tanzania is located at the East African Coast and shares borders with Burundi, Rwanda, and DRC to the west; Uganda and Kenya to the north; Malawi and Zambia to the southwest and Mozambique to the south, while the Indian Ocean lies in the east (see Figure 1). Its geography is characterized by open woodlands, closed mountain forests, scrub and bushlands, wetlands, and coastal forests. Moreover, two-thirds of the land area is dominated by ancient plateau with highlands stretching up to 5 000 meters. This highland flanks Lake Tanganyika in the west and continues across the northeast borders (see Figure 1 and Figure 3 for elevation details)[4]. Approximately 44 million hectares of land (46 percent) have the potential for crop production, but due to soil infertility, degradation, erosion, and proneness to drought, large areas are unsuitable for production (URT, 2015; UN, 2019; CIAT & World Bank, 2017; Mitawa & Marandu, 1995). Land-holding is mainly characterized by small-scale farming, accounting for 91 percent of total land-holding, with average farm sizes of around 0.2-2 hectares. Small-scale farmers usually combine subsistence farming with livestock, fishery, and crop production. Among these, about 20 percent are women. In contrast to men who make 150 Tanzanian shillings (TZS) per month (corresponding 65 US dollars), women only make an average monthly earning of 92 TZS or 40 US dollar per month (CIAT & World Bank, 2017; Mitawa & Marandu, 1995).

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[4] A detailed map of elevation, human population density, and habitat suitability in Tanzania can be found in Appendix C.1

Figure 1. Geographical characteristics of Tanzania
Source: Google Earth (2021)
Note: Lake Tanganyika is located in the west by Kigoma.

When analyzing Tanzania's recent decade of sustained economic growth, it is clear that the country reached a milestone in July 2020 when it formally received the status of a low middle-income country instead of a low-income country (World Bank, 2021). Overall, the agricultural sector accounts for 32 percent of GDP, one of the highest in Africa when comparing Tanzania to other countries (see Figure 2). Due to its rich natural endowments, agriculture has long been the backbone of its growth, with a local manufacturing industry specializing in processing agricultural products, both for exports and domestic food security. Every year, around 1,146 million US dollars' worth of agricultural goods are exported (CIAT & World Bank, 2017) and the main cash crops (tobacco, tea, coffee, sisal cashew nuts, and pyrethrum) account for a large share of these export revenues (Oxford Business Group, n.d; CIAT & World Bank, 2017; World Bank, 2016). Most industries within the country, whether in terms of producing farm tools, fertilizers, or processing agricultural products, are linked to the agricultural sector. However, the level of commercialization is still generally low, and most goods are consequently consumed locally.

One explanation for this is the dominance of small-scale farming and its low output nature relative to the high volume demand from the global market. Despite that the sector has seen a shift towards modernization, a significant part of the production is still executed using cattle-driven ox plows or by hand, and this, in turn, leads to the slow growth in total output (World Bank, 2016; FAO 2016).

Economic growth has seen a significant slowdown over the recent years, with a GDP growth rate falling from 5.8 to 2 percent after 2018 (World Bank, 2021). This number is mainly attributed to the growing yield gap within the agricultural sector as a direct effect of adverse weather conditions, poor implementation of public projects, private sector constraints, and sluggish productivity growth. By looking at the value-added per worker within the agricultural sector in Tanzania, the country sees a value of 564, which is much lower than an average value of 1184 in SSA (CIAT & World Bank, 2017). This has led to a stagnant growth of 4.4 percent over the past years, despite the Comprehensive Africa Agriculture Development Programme (CAADP) targeting a growth rate of 6 percent (URT, 2013). Hence, the necessity of having a long-term plan of sustained growth is essential for a structural transformation. This can only be reached if farmers can increase their productivity and increase the competitiveness of the sector on the global market (Leyaro & Morrissey, 2013; Rioux et al. 2017). The explanation behind the current stagnation in agricultural productivity will be explained in more detail in the next section.

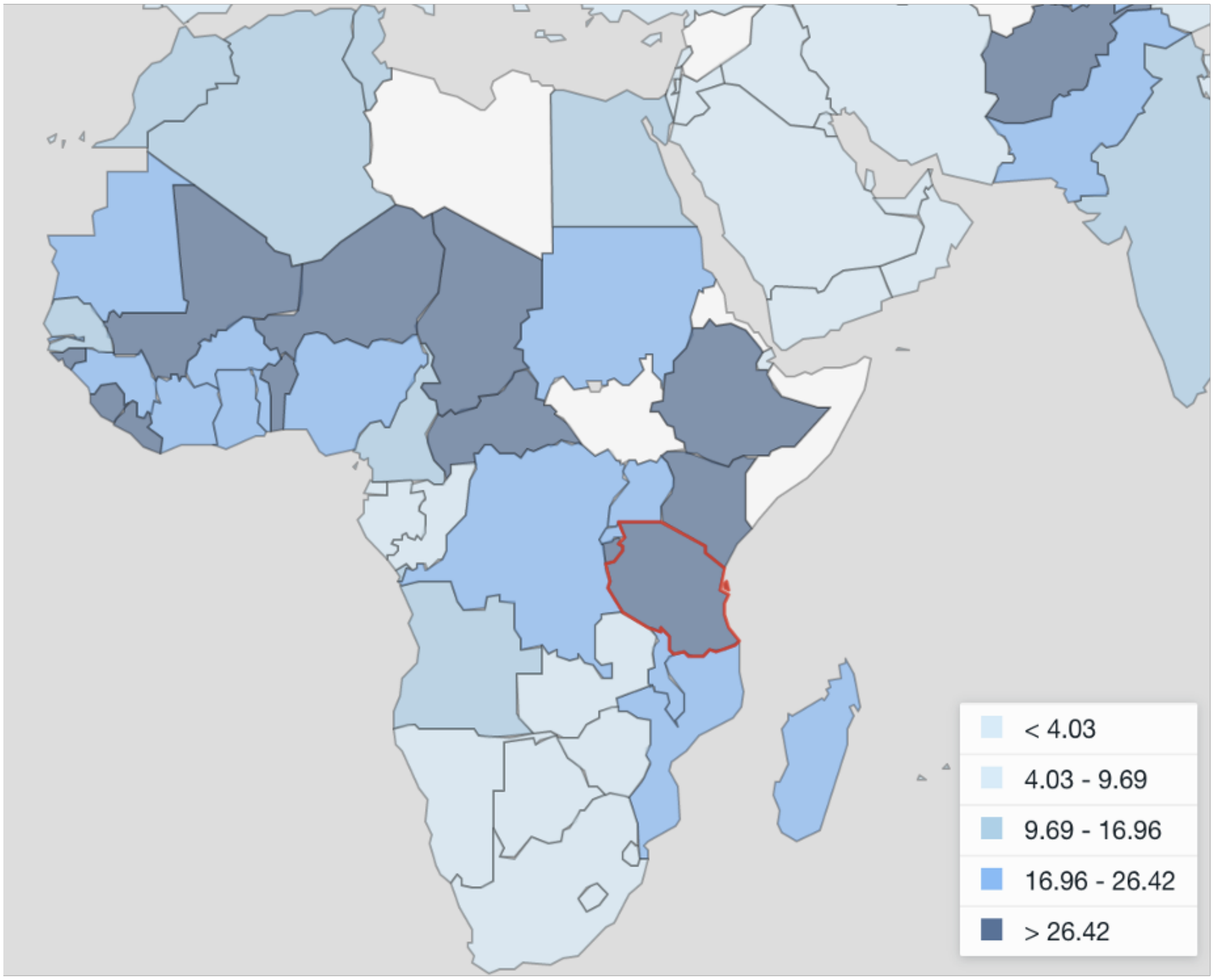

Figure 2. Agriculture value added (% of GDP) in Tanzania
Source: Based on data from World Bank (2020)

2.2 Agricultural characteristics

Tanzania is divided into 64 AEZ based on soil water holding capacity, rainfall patterns, altitude, physiographic features, and growing season. The element of the zones further includes edaphic and climate requirements of how crops are grown and under which circumstances the crop management should be executed to achieve desirable output (FAO 1996; De Pauw 1984). Edaphic refers to the different characteristics of the soil conditions and drainage texture rather than only accounting for the climatic or physiographic factors (Ulery & Goss, 2013). The complexity of the 64 zones are visually provided in Appendix C.2, however, to get a general overview of this map, this study has clustered the AEZs under five main categories (Figure 3), which are often used within empirical studies; *tropic-cool/subhumid, tropic-warm/subhumid, tropic-cool/humid, and tropic-warm/humid* (Yengoh & Ardö, 2020; Arslan et al. 2015; De Pauw 1984). In Figure 3 (next page), a *humid* climate often describes a climate characterized by cold to mild winters while the summers tend to be very hot. Something that makes a *humid* climate more affected by droughts or soil erosion. The *subhumid* climate, on the other hand, is similar to the *humid* climate but is often a term used to describe prairie or grassland areas with less fluctuating temperatures (AMS, 2012).

To operationalize these five categories in Tanzania, the country is often divided according to ten zones which account for altitude and terrain roughness (see Figure 4). These factors directly impact the edaphic conditions of the soil and therefore explain the climate within the 64 AEZs. The primary landscape-specific AEZ within the country is central arid plains, southern highlands, northern highlands, and eastern coastal plains. These zones are characterized by extreme rainfall variability and dry lands, which compromise productivity through land degradation. This, in turn, makes farmers' livelihoods vulnerable to agricultural and weather-related weather changes (FAO, 2019).

Despite farmers being located geographically close to each other, they face different climate conditions since weather changes are site-specific. Looking at Figure 3 and Figure 4, the eastern regions around Mtwara, Dar es Salaam and Tanga are characterized by tropic-warm/humid/subhumid climate due to their coastal location and alluvial plains[5]. Moreover, tropic-cool/humid/subhumid climate appears rather in the western regions around Arusha, Manyara, Kilimanjaro and by the borders to Rwanda and Burundi (see Figure 1 for geographical understanding). In these areas, the lands are arid with mid-and high-altitudes, as seen in the left map in Figure 3 and Figure 4.

Major cultivated food crops are rice (paddy), maize, cassava, banana, bean, sorghum, sunflower. Nevertheless, according to an evaluation by CIAT and World Bank (2017) these seven crops are generating a lower output compared to the average of Eastern Africa. Maize, which accounts for 24 percent of the land harvested in Tanzania, has an output of 1307 kg/ha on average, compared to Eastern Africa with an average of 1717 kg/ha. By putting it differently, this means that Tanzania produces approximately 34 percent less per hectare of land despite that maize is the major food crop cultivated and essential for national food security. This yield gap also accounts for rice/paddy, which generates an output that is approximately 32 percent below the average of Eastern Africa, however, this crop only accounts for 7 percent of the total harvested area. Additionally, cassava, sunflower, and banana, represent 3-6 percent of harvested land with an output 20 percent lower than the average of Eastern Africa. This leaves only beans and sorghum with crop yields that produce more per kg/ha than the average of Eastern Africa, namely, 19 and 13 percent above average, respectively (CIAT & World Bank, 2017).

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[5] An alluvial plain is a flat landform created by rivers and deposition of sediment of which alluvial soil is formed over a long time period (Flores, 2014).

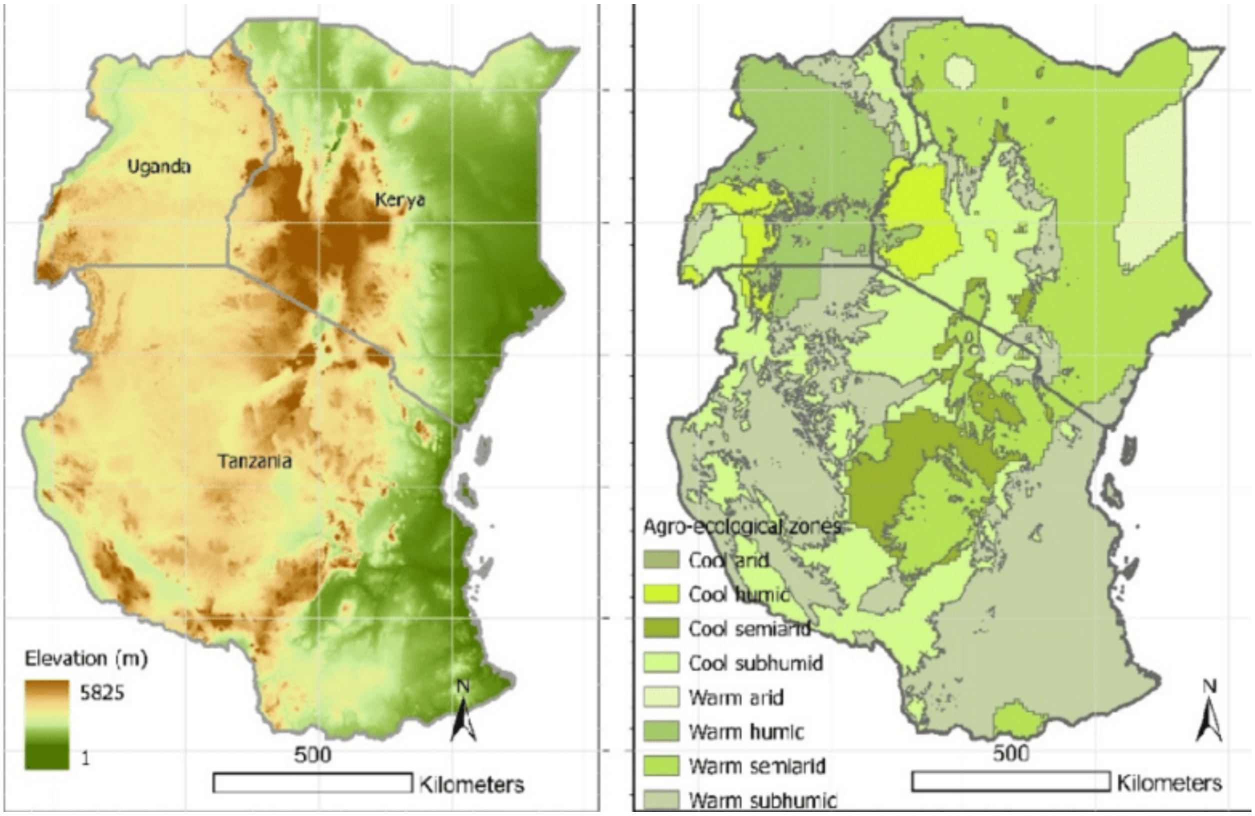

Figure 3. Agroecological zones (AEZ) and elevation details of Tanzania
Source: Ardö and Yengoh (2020)

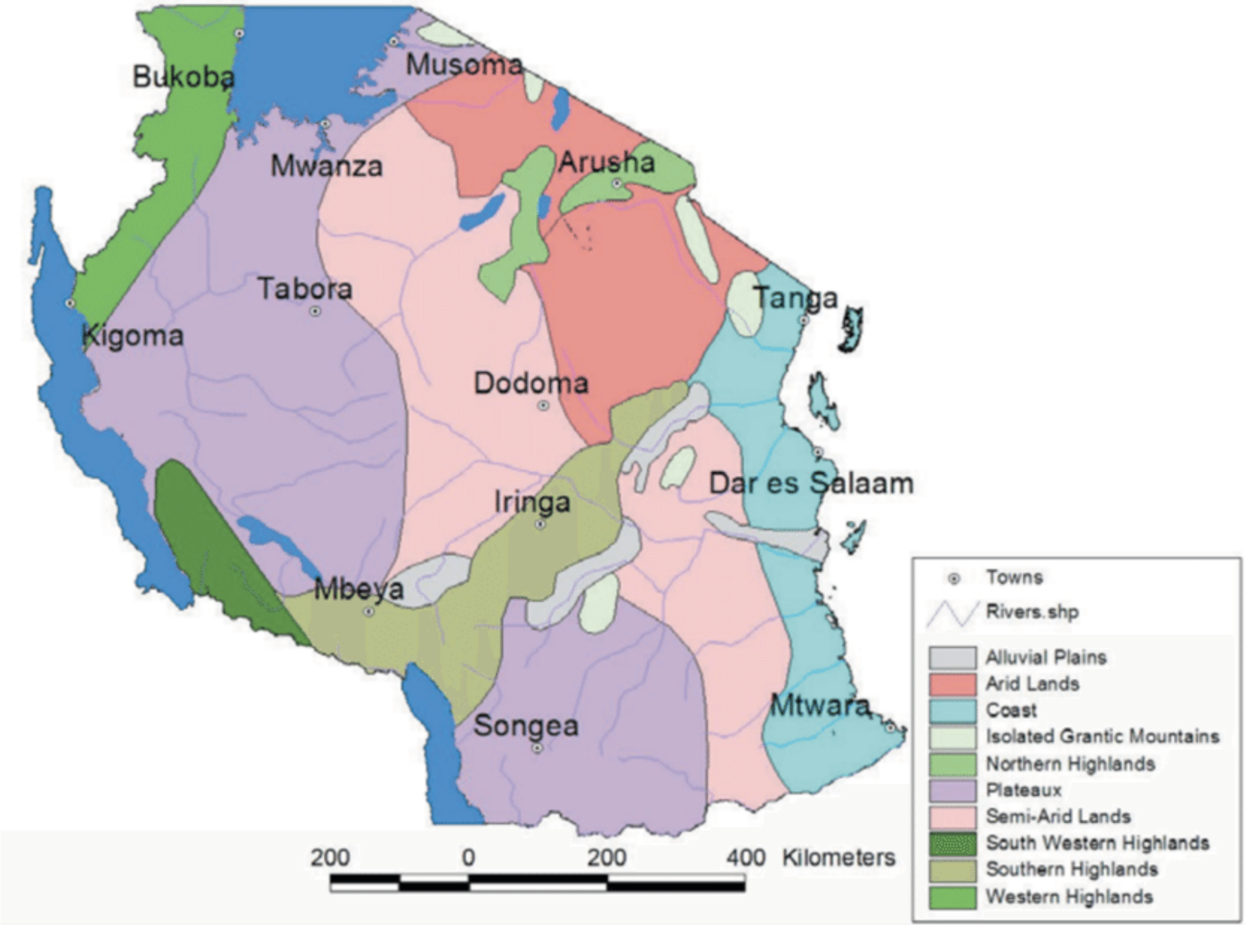

Figure 4. Agroecological zones (AEZ) accounting for the Tanzanian landscape
Source: Adapted from Malozo (2014)

The production systems of these seven crops are distributed across the whole country. Table 1 on the next page summarizes the main food crops grown within each region. By looking at the crop distribution, it is clear that the main food crop grown, namely maize, is produced in several areas despite that climate and soil are unstable (URT, 2009). This is due to maize not being as sensitive to physiographic and climatic conditions as bananas which are mainly grown in coastal areas where the altitude is lower and the average temperature is higher. Still, maize, including the other six crops grown, requires stable precipitation throughout the year (Rioux et al. 2017). As well as outlining the main crops grown, Table 1 summarizes major AEZ, rainfall distribution, and an average temperature within each region of analysis. Details about the respective sensitivity to climate change will be explained in greater detail in the next section.

Table 1. Agro-ecological zones and main food crops grown in Tanzania

Part of Tanzania	Major agroecological climate	Agroecological landscape and physiography	Rainfall distribution (mm/year)	Average temperature (℃)	Main food crop grown
Central	Tropic-cool/ subhumid Tropic-warm/ humid	Semi-arid lands/Mid altitude plateaus	200-600	22	Rice/Paddy, Sorghum, Sunflower
Northeast	Tropic-cool/ subhumid	Arid-lands/Highlands	400-500	17	Maize, Bean
East	Tropic-warm/ sumhumid	Coastal areas/Semi-Arid Plateaux/Alluvial Plains	400-800	27	Rice/Paddy, Banana
Southeast	Tropic-warm/ subhumid	Semi-Arid Plateau/Semi-Arid highlands	800-1200	18	Maize, Cassava
West	Tropic-warm/ Subhumid Tropic-cool/ subhumid	Southerns Highlands/Southwestern highlands	800-1200	17	Maize, Rice/Paddy, Bean
Northwest	Tropic-cool/ subhumid Tropic-cool/ humid	Plateaux/Western highlands	1200-1700	22	Rice/Paddy

Source: Adapted from World Climate Guide (n.d), Ardö and Yengoh (2020), Malozo (2014) and NBS (2009, 2011) – Construction made by the author
Note: The agroecological zones in the second column are the major AEZ within the specific region. There are zones (e.g. semiarid climate) that are not taken into account in this study.

2.3 Climate Change in Tanzania

Climate change can be seen as a global threat to all societies, and its level of impact varies from country to country. Although the terms “climate change” or “extreme weather” have distinct meanings, they are interchangeably used within the literature. The term ”climate change” refers to the long-term change in the global average seasonal rainfall, humidity, and temperature. In contrast, “extreme weather” represents the short-term changes in local atmospheric conditions (NASA, 2021). Within this definition, the term “climatic shocks” is often used to describe peaks or short-run averages in the minimum or maximum values of temperature (droughts) or precipitation (floods) (FAO, 2019; Rioux et al. 2017). Given that this thesis focuses on a short period (2008-2011) using a local perspective, the principal terms used will be *extreme weather* or *climatic shocks.*

According to the ND-GAIN index[6], Tanzania ranks 148th out of 181 countries and is the 33rd most vulnerable country and the 43rd least prepared for climatic shocks. Within the latter ranking, the sectors highlighted are mainly the agricultural capacity where the change of food crop yields denote the worst scores (ND-GAIN, 2020). Like farmers in other SSA countries, farmers in Tanzania depend on rain-fed agriculture and suffer from unexpected drought, changes in rainfall patterns, and fluctuating rain seasons (Dell, Jones, & Olken, 2012). More specifically, Tanzania has two main rain seasons; the “long rains” that last from March to May, and the “short rains” starting in November and end in December. The short rains are much lighter and less constant than the long rains. However, due to the increasing number of droughts and temperature rising, the short rain period has been largely absent in the past decade, leading to adverse consequences for the rain-dependent agricultural production (Weather & Climate, 2021). As seen in Figure 5 (next page) which was adapted from CIAT and the World Bank (2017), temperature and precipitation are estimated to increase +1.9°C and 4.1 percent in mm over the next decades. From a seasonal perspective, these projections will especially impact the northeastern, western, and northwestern areas. Thus, in a manner that scholars have suggested that it will lead to a loss of $200 million every year and more than 60 kilograms fewer nutrients per hectare over the next decade leaving Tanzania in a food crisis and limited sustainable development (WFP, 2013; CIAT & World Bank, 2017).

As previously stated, the main food crops with low productivity produce less output per hectare than the average of Eastern Africa. With the detrimental impacts caused by fluctuating weather, it will be difficult for Tanzanian farmers to “catch up”. Figure 6 highlights that the farmers included in this study, reported droughts as the main reason for harvest loss between 2008-2011, accounting for more than 50 percent of lost crop yields. Although climatic factors account for the biggest loss, crop thefts and labor shortages are also major contributors to the unsuccessfulness of a harvest.

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[6] The ND-GAIN index (Notre Dame Global Adaptation Initiative) seeks to measure a country’s vulnerability to climate change and its readiness to improve resilience and its capability of immediate response to global challenges.

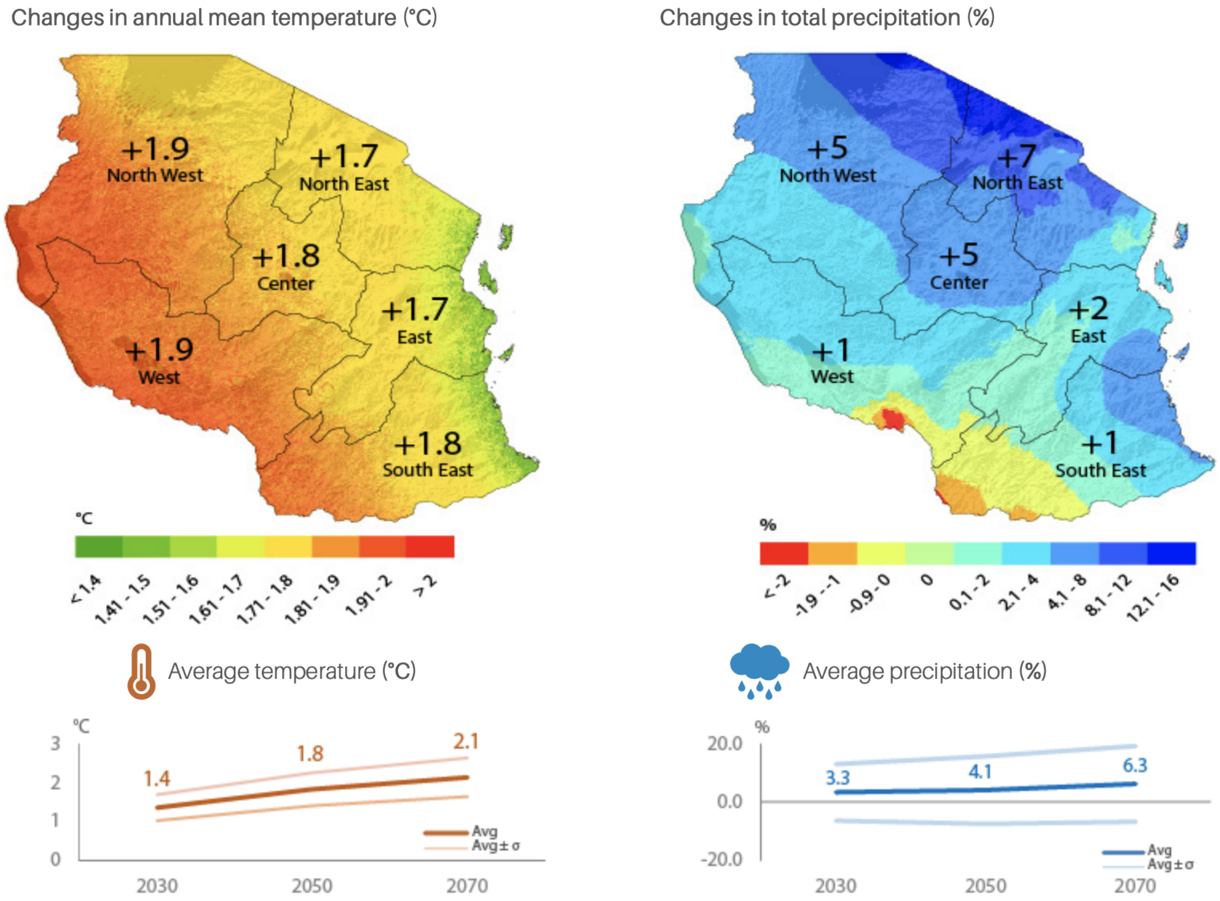

Figure 5. Weather projections for 2050 in Tanzania, by region

Source: CIAT and World Bank (2017)

Note: These regions will be the regional focus throughout the thesis.

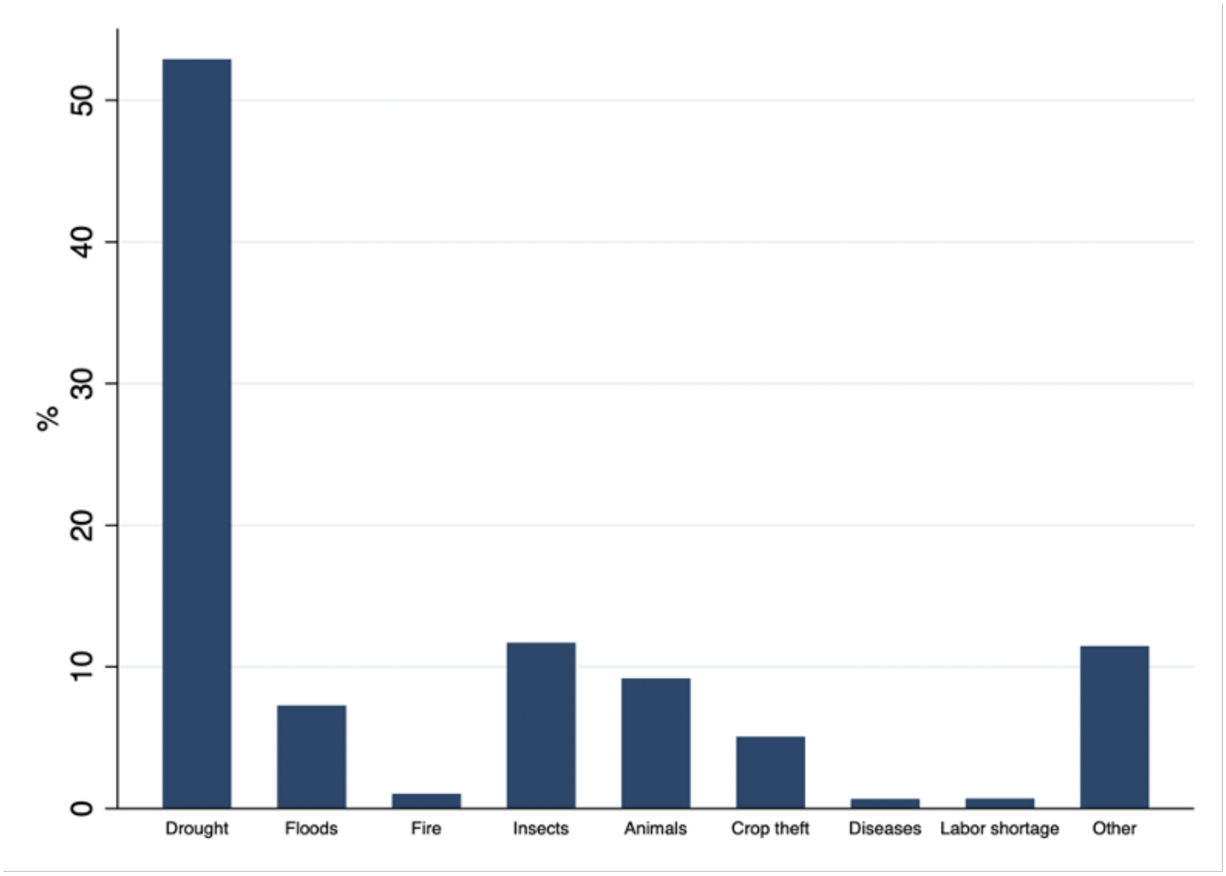

Figure 6. Reported main reason for harvest loss in Tanzania 2008-2011, in percent (%)
Source: Based on data from NBS (2009,2011) - Estimation made by the author

2.4 Operationalizing Climate-Smart Agriculture (CSA)

As mentioned in the introduction, CSA was developed in 2009 by the FAO and entails several principles, guidelines, and practices aiming to mitigate farmers to the new realities of climate change (Lipper et al. 2014). The three interlinkages of CSA (adaptation, mitigation, and productivity) serve as the main operationalization for reaching zero hunger. This is also important for achieving the second goal of the 2030 Agenda (SDG2), namely food security for all (WFP, 2021). However, since CSA has multiple entry points at different levels of analysis across various subsectors of the agricultural industry, the operationalization of the chosen CSA practices has to be broken down and explained step by step.

Firstly, CSA is often divided into four subsectors: 1) crop practices and technologies, 2) livestock subsectors and technologies, 3) fishing and aquaculture enterprises, and 4) other practices and technologies. The three CSA practices analyzed within this study (intercropping, improved seed, and inorganic fertilizer) all belong to the first subsector, *crop practices and technologies* (Lipper et al. 2014). Secondly, each subsector is further divided into different subcategories, representing the operationalization of a particular technique or innovation. In this study, these are: 1) conversation agriculture (intercropping), 2) crop management (improved seed), and 3) soil fertility management (inorganic fertilizer) (Lipper et al. 2014).

Still, what is the purpose of the three CSA practices? *Intercropping* is a practice that farmers usually implement to maximize the nutrient availability of the crops and protect plants from severe droughts. The method consists of growing a variety of crops together, allowing protection for sensitive and shallow-rooted crops from the sun in case of a peek in average temperatures (Zaefarian & Rezvani., 2016). In Tanzania, the method is often used, especially for crops such as banana and sorghum, which are both crops that benefit from growing with leguminous species such as beans, peas, clover, soybeans, or peanuts (Rioux et al. 2017; CIAT & World Bank, 2017). The data presented in Table 2 below shows that sunflower and sorghum were the main crops in 2008-2011 cultivated in an intercropped farming system (68 and 62 percent respectively).

Table 2. CSA practices applied in 2008-2011 by crop, in percent (%)

	(1) Intercropping (Pure Stand/Intercropped)	(2) Improved Seed (Traditional/Improved)	(3) Inorganic Fertilizer (No Application/Application)
Maize	50/50	95/5	72/30
Beans	48/52	93/7	70/28
Rice/Paddy	88/12	94/6	81/19
Cassava	70/30	89/11	92/8
Sunflower	32/68	95/5	65/35
Sorghum	38/62	97/3	89/11
Banana	92/8	98/2	99/1

Source: Based on data from NBS (2009,2011) – Estimation made by the author
Note: Numbers are rounded off.

Improved seed, on the other hand, is a practice attributed to the development of strong and stabilized crop varieties. As well as this practice boosting production by improving the quality of the seed. The seeds are also more tolerant to drought, flood, and salinity and grow more efficiently than the traditional seed despite the absence of precipitation (Rioux et al. 2017; Basnyat, 2017). While improved seed is usually applied on higher yields under a shorter period of time, which consequently intensify the production, the traditional ones are natural seeds used with low yield. This is also seeds that mature later and requires low use of pesticides, fertilizers and irrigation. The most common implementation of improved seeds is within cassava production since this crop tends to be less productive when using traditional seeds (CIAT & World Bank, 2017).

Inorganic fertilizer, which falls under soil fertility management, is a compost and farmyard management method. Efficient fertilizers, whether organic or inorganic, maximize the plant's growth by providing the soil with nutrients necessary for its respiration of oxygen in periods of droughts when oxygen tends to be lower. The difference between organic and inorganic fertilizers is that the inorganic technique is designed to spread synthetic chemicals containing minerals instead of organic material. Despite the inorganic method being less effective for increased productivity in some climatic zones, Miller (2018) highlight it as a much more environmentally friendly tool that stabilizes the crop to extreme weather by providing plants with a higher level of minerals.

However, the debate on the link between the inorganic method and sustainable agriculture has come to be highly polarized. While one camp argues that the inorganic method is the main solution to address a worsened soil fertility (Miller, 2018; CIAT & World Bank, 2017; Arslan et al. 2015), others are prohibiting inorganic fertilizer use and advocates for pure organic farming (Akinnfesi, 2018). The latter view, highlight the consequences of spreading minerals into the soil due to its harmfulness to both human health and soil. The widespread utilization of pesticides and chemical fertilizers might impact biodiversity by affecting crops dependent on pollination. On the other hand, despite the critical debate around the side-effects of synthetic fertilizer, scholars have also stressed it as an agricultural practice that incentivizes farmers to specialize on a few crops, leaving traditional labor-intensive and knowledge-based soil fertility management practices. This further intensifies the production while increasing the output of crops essential for nutrition and human food security (Akinnfesi, 2018; FAO, 2018b). In Tanzania, the method is commonly used for beans and maize, requiring integrated soil fertility management to be productive (CIAT & World Bank, 2017). Despite Table 2 showing that the method was mainly used on sunflower, it is clear that a large share (approximately 30 percent) of cultivated maize in 2008-2011 was processed through inorganic fertilization.

2.4.1 Current policy measures in Tanzania

Despite the CSA approach being introduced relatively recently, the Tanzanian government has adopted several policy measures to boost agricultural productivity. Today's main challenge is understanding how this can best be implemented in varying regions and AEZ (Rioux et al. 2017). The scaling up of CSA requires a broad collaboration between governments, NGOs, research partners, private sectors, farmers, and media. While the government builds capacity and awareness, NGOs provide technical assistance and promote indigenous CSA practices, technologies, and knowledge. Research partners, on the other hand, conduct participatory research and engage in collaborative learning. The private sector develops the markets, identifies opportunities and risk management strategies, engages in farmers' communities, and provides necessary inputs to research and collaborate through farmer field schools (FFS). Finally, the media disseminate and solicit researched information and raise awareness of these guidelines on important platforms (Rioux et al. 2017; CIAT & Worlds Bank, 2017; TaCCIRe, 2012; URT, 2009).

As highlighted in the Environmental Management Act (EMA) of 2004 (URT, 2009), policy formulation and environmental planning at a national level are mainly executed by the Division of Environment of the Vice President’s Office (VPO). Since 2012, Tanzania has had an environmental strategy to scale up and include necessary stakeholders (TaCCIRe, 2012). Through this initiative, the Tanzanian Climate-Smart Agriculture Alliance (TCSAA) was established to integrate an improved dialogue, coordination, and information sharing on CSA. Through public-private partnerships (PPP), farmers organizations in Tanzania have received access to credits and investments to implement CSA practices (Rioux et al. 2017; CIAT & Worlds Bank, 2017). Nevertheless, there still lacks a wider adoption of these practices, and administrative, financial and technical support towards CSA implementation is still relatively low. For further adoption of productive methods, Rioux et al. (2017) and CIAT and World Bank (2017) highlight the importance of facilitating extension services that account for site-specific variations in climatic conditions. Moreover, conducting farmer field trials to enhance availability to CSA-related output and input markets while testing various CSA practices is stressed as a major priority for both researchers, institutions, and the financial sector within the country (CIAT & World Bank, 2017). To understand the complexity of this upscaling, it is necessary to undergo an in depth analysis of the literature within this field.

3 Literature Review

Climate-smart agriculture (CSA) has been widely explored within the SSA context. Since the research on CSA is relatively recent after it was introduced in 2009, it is an area that remains understudied with a diverse body of literature. To get an overview of the literature, three main approaches have been identified, whereas the approach *productivity implications and the impact on crop yields* (section 3.2.3) is the research angle of this study. Before going into the literature of CSA, general implications regarding adapting the agricultural sector to climate change must be discussed.

3.1 Adapting agriculture strategies to climate change

According to Amos et al. (2015), the Tanzanian government has adopted several strategies to make farmers more resilient to climate change. This entails well-functioning weather stations across the country which aim to prepare and warn farmers for extreme weather. Moreover, these stations seek to strengthen farmers by giving long-term projections on drought, soil quality, and water availability and thus indicate what methods will be necessary for a given period. The government supports research, capacity building, and education of farmers to accelerate the implementation of new technologies and long-term solutions for sustainable land management (Amos et al. 2015).

More specifically, the literature has touched upon four important strategies for making agriculture more sustainable. Hisali et al. (2011) highlight the importance of improved labor supply, reduced consumption levels, increased financial savings besides the need for innovative technologies. Although Tanzania has increased its investments in sustainable agriculture and is supporting projects seeking to adapt the agricultural sector to new challenges, much more needs to be done. In terms of innovative technologies, the CSA approach has been highlighted as a strategy that educates the farmer beyond agricultural methods. It creates a network between Tanzanian farmers and stakeholders on both a national and international level. While national NGOs such as Sustainable Agriculture Tanzania (SAT) and National Networks of Farmers' Groups in Tanzania (MVIWATA) mainly supports CSA promotion by raising climate awareness, international institutions such as IEDS, IFAD, and AGRA[7] allocates more than 35 percent of the budget to mitigation activities (CIAT & World Bank, 2017). Each stakeholder promotes investments through their mandated actions - directly or indirectly - in one or all three pillars (adaptation, mitigation, productivity) within CSA. This network puts more emphasis on the farmers' communities (CCAFS & UNFAO, 2014) and leads to improvement of their techniques in becoming resilient and less carbon-intensive (FAO, 2018a).

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[7] Institute for Environment, Climate, and Development Sustainable (IEDS), International Fund for Agricultural Development (IFAD), Alliance for a Green Revolution in Africa (AGRA)

3.2 Climate-Smart Agriculture (CSA)

In this subsection, the three main research angles on CSA will be discussed, and important debates highlighted. Each approach will be analyzed separately, and in connection to section 3.2.3, the contribution of this study will be addressed.

3.2.1 Impact on poverty, income, and food security

This research angle discusses mainly the variants of CSA and its effect on food security and poverty levels among farmers' households. In general, two main approaches have been localized. While some scholars emphasize the farmers' role in combining efficient CSA techniques properly to maintain a stable food supply (Abdulai, 2016; Cholo et al. 2019), others argue that the main way to increase food supply stems from governmental interventions (Samberg et al. 2016; Di Faco & Veroness, 2013; Hoegh-Guldberg et al. 2018).

Abdulai (2016) studied conservation agriculture (CA)[8] and the adoption of CA practices within farmers' households in Zambia. The study provides insights from a micro-perspective on how increased household income ensured stable access to food since increased financial liquidity gave families more opportunities to invest in efficient CA methods. As explained in section 2.4, intercropping is considered a CA method and beneficial for protecting shallow-rooted crops from severe sunlight.

Along similar lines, Cholo et al. (2019) analyzed how the combination of land fragmentation and sustainable land management could increase food supply more rapidly than within households that did not use the same agricultural approaches. Their study found that families using new methods of farming, such as CSA, were incentivized to collaborate with other farmers through projects where they could exchange ideas and improve their implementation strategies. Although Samberg et al. (2016) touch upon these arguments, their study differs from the previously mentioned, as it focuses rather on the importance of well-directed strategies from the public sectors as the main driver for increased food security. By understanding farmers' vulnerability to climatic shocks, investments can be prioritized more efficiently. Samberg et al. (2016) also stress that empirical evidence, mainly through quantitative estimates, gives a broad understanding of the farmers' situation. Empirical evidence highlighting the link between climate change and food security increase our understanding of direct and indirect effects on poverty (Samberg et al. 2016). In contrary to Abdulai (2016) and Cholo et al. (2019), Samberg et al. (2016) emphasize the role of the state as a provider of efficient agricultural strategies rather than the ability of the farmer in implementing methods of combined land-management approaches.

In addition, Di Faco and Veroness (2013) and Hoegh-Guldberg et al. (2018) add to the debate by examining how the holistic approach within CSA affects not just short-term trends on human wellbeing. A coherent approach to farming, both through public services and farmers' organizations, gives a broader understanding of interlinkages between sectors and the relationship between sustainable production, biodiversity, and poverty. Their study suggests that farmers who were willing to change their methods and use new techniques improved the capability of handling future crises. However, increased support from both the private and public sectors gave them more confidence in adapting to innovative techniques. The scholars mentioned above took different standpoints to examine the topic, although all agreed that the link

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[8] Conversation agriculture is a method within CSA which seeks to minimize soil disturbance by increased species diversification and soil protection from organic material (FAO, n.d). Intercropping is a method considered as a CA method.

between climate change, human wellbeing, and local policy-making is of utmost importance. Overall, CSA educates farmers in using innovative methods that increase food security and improve the quality of life.

3.2.2 Trade-offs and economywide effects

Many scholars have also taken a cross-sectional approach to examine the impact of extreme weather on the agricultural sector (Sachs and Warner 1997; Gallup et al. 1999; Nordhaus 2006). For instance, Mwongera et al. (2017) discuss when trade-offs appear as a result of implementing CSA in practice. More specifically, a trade-off is when one mechanism within CSA:s 'triple win' is fulfilled at the expense of other important achievements and, therefore, degrades the entire implementation quality. To target these undesirable effects, an economy-wide approach that takes other sectors into account is of relevance according to Mwongera et al. (2017). Moreover, a study by Robinson et al. (2012) discusses trade-offs by analyzing the inconsistency of increasing irrigation while extending rural road networks. A situation that increases productivity while also limiting farmers from expanding their production due to infrastructural building. Another example of this is when policies towards protecting biodiversity are implemented while governments also support irrigation through extended land, threatening certain species. Other scholars use the same arguments as Robinson et al. (2012) but go beyond the context of land management and analyze trade-offs through the lens of steered investments and economic efficiency (Robinson & Willenbockel, 2011; Gebreegziabher et al. 2016; Yalew, 2016; Komarek et al. 2019).

In comparison to the scholars above, Shilomboleni et al. (2020) provide a new approach by highlighting the positive effects of CSA on the social and inclusive economy. The social economy is defined as "the set of associations, cooperatives, mutual organizations, and foundations whose activity is driven by values of solidarity, the primacy of people over the capital, and democratic and participative governance" (Noya & Clarence, 2007, p.32). Shilomboleni et al. (2020) argue that investing in long-term approaches requires cooperation from several stakeholders, creating a collaborative environment in emerging economies. Thus, since CSA includes several sectors, it has created a platform of ideas, incentives, public-private partnerships (PPP), and further support for climate-smart agriculture, both locally and globally. In similar lines, Newell et al. (2019) also stress the social values of CSA by highlighting it as an operationalization of the SDG2 within the 2030 Agenda, about zero hunger, and that it puts pressure on African governments to fulfil the UN goals for sustainable development. Therefore, according to Newell et al. (2019), CSA is more than just an innovative approach to farming; it is a form of political pressure and stresses the importance of adapting African economies to current global goals and achievements.

3.2.3 Productivity implications and the impact on crop yields

Several studies have used micro-level evidence to understand the net effects of climate change on a series of sectors within Sub-Saharan countries (Adams et al. 1990; Mendelsohn et al. 2001; Schlenker & Roberts, 2006; Deschenes & Greenstone, 2007). In similar lines, the productivity implications of CSA on the agricultural sector has been analyzed using case studies, where the majority of the literature have agreed upon its efficiency of increasing crop yield output (Arslan et al. 2015; Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998). In addition, others argue that CSA is efficient when implemented in countries closer to the equator where the climate is tropical and monthly temperatures stabilized throughout the year (Bell, Jones, & Olken, 2012; Weather & Climate, 2021). Although most studies agree upon its benefits, it is still a general debate regarding which circumstances this is the case. Lal (2009) suggests that CSA methods such as *mulching* improve soil conditions because the method requires lower labor inputs and thus makes it easier for the farmer to take care of the land. It is not the method per se that increases the output and resilience to shock, but because it is more time-efficient and requires lower input (Lal, 2009).

However, to examine these concerns further, a meta-study focusing on 217 CSA projects implemented regionally across SSA was conducted by Branca et al. (2011). Their analysis focused on various CSA practices such as crop rotations, improved varieties, and mulching and concluded that these practices improved the cereal yields by 116 percent on average. Similar to Branca et al. (2011), Pretty et al. (2006) quantitatively analyzed the implementation of CSA in a set of developing countries and concluded that CSA methods implemented in Sub-Saharan countries increased crop productivity by 100 percent on average over their sample period. Both Branca et al. (2011) and Pretty et al. (2006) found strong positive effects for practices related to crop management – such as improved seeding. On the other hand, methods included in crop management (such as intercropping) and soil fertility management methods (inorganic fertilizer) showed a less strong impact, although the magnitude was positively associated to crop yield output. It should, however, be noted that these two studies were conducted to examine specific CSA projects of "best practice" where CSA was not spontaneously implemented by the farmer, which potentially leads to self-selection bias since it reveals a positive image of CSA.

To avoid self-selection bias, this thesis is inspired by Arslan et al. (2015) which looked at cases where CSA was spontaneously implemented by the farmers. They conducted a case study of small-scale farmers in Zambia and looked at different climatic conditions across regions and AEZ concerning implemented CSA methods. Their study suggests that methods such as minimum soil disturbance and intercropping have no significant effect on agricultural productivity, while inorganic fertilizers and improved seed are sensitive to weather changes but had positive effects on output. Nonetheless, few studies have used this approach on Tanzania from a micro-level perspective. Although a study by Mugabe (2019) conducted a case study in Tanzania by analyzing successful CSA practices, this study focuses on constructing efficient policies and not on the direct impact of climatic shocks on the crop yield. The author concluded that most of the methods used under normal circumstances (no climatic shocks) did, nevertheless, improve agricultural productivity for Tanzanian farmers.

In closing, scholars have taken several different approaches to analyzing the implementation of CSA. However, most studies took a wider approach or used case studies of "best practice" where farmers have incentives to use sustainable farming methods. The studies mentioned (Branca et al. 2011; Pretty et al. 2006; Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998; Arslan et al. 2015; Mugabe, 2015) were also collected mainly on a household-level while this thesis analyzes plot and crop level. This thesis seeks to contribute by providing evidence on a new level of granularity while the data used were collected to understand the link between poverty and innovative techniques. Thus, it was not collected with the aim of specifically evaluate CSA. Additionally, by examining these methods over a short period, this thesis provides evidence of the efficiency of CSA when unpredictable and short-term weather shocks appeared during the sample period (2008-2011).

4 Data

This part covers the data used in this study. Firstly, the construction of the data will be described, including a discussion of how the panel data was established and what level of granularity this study is based on. Secondly, a description of relevant limitations when undergoing the data analysis will be outlined.

4.1 Household survey project - LSMS ISA

The panel data used in this study is collected from the World Bank database, which together with the National Bureau of Statistics (NBS) in Tanzania implemented a project called "Living Standard Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA)" (NBS, 2009, 2011). The project aimed to foster innovation and promote sustainable agriculture and its link to poverty and food security in the region. The data covers the period 2008-2011 where 7 204 households across all regions and districts, both in Zanzibar and on the mainland were visited during two "waves". The first wave (October 2008-October 2009)[9] includes 3 280 households, while the second wave (October 2010-November 2011)[10] re-visited these households and added 644 households to the sample.[11] The survey includes information on crop production, livestock, and fishery divided into a household-, geospatial and agricultural survey. The household survey links economic and socioeconomic factors to the farmers' household[12] while the geospatial survey stresses distances and infrastructural aspects such as the household or plot distance to the nearest major road or agricultural market. The agricultural survey provides information about production-specific factors such as methods used, crops, harvest losses, and climatic conditions.

The panel data has been established by merging the two waves on the plot level where each wave reports a unique household identifier. However, since most households own more than one landholding, linking data to the household level would not be feasible as there would always be a repetition of household identifiers across lines. Therefore, a new key variable was created which links the number of plots owned within each household. The data collected on a crop level were collapsed and merged on the household identifier. Although the panel links similar information across waves, differences in observed attribution at the individual level and the inclusion of additional information in some enumeration areas are aspects that hinder a perfect linkage. All necessary information needed to answer the research question could, nevertheless, be found in both waves. Moreover, important covariates to measure agricultural productivity are economic, socioeconomic, infrastructural, production-specific, and climatological factors. Further explanations of included variables will be analyzed in more depth under section 5.1 about descriptive statistics.

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[9] National Bureau of Statistics (NBS). (2009)Tanzania National Panel Survey 2008-2009 (Round 1). Ref. TZA_2008_NPS-R1_v03_M. Dataset downloaded from http://microdata.worldbank.org on [date].

[10] National Bureau of Statistics (NBS) [Tanzania]. (2011). Tanzania National Panel Survey Report (NPS) - Wave 2, 2010 - 2011. Dar es Salaam, Tanzania: NBS. (www.nbs.go.tz)

[11] For a visual understanding of the sample distribution, please see Appendix B.1.

[12] See Appendix D.1 for information on the variables and the household survey categories.

4.1.1 Data limitations

Although the LSMS team claims that the collected data has been produced from reliable sources, there is no warranty regarding reliability, legality, or adequacy (NBS, 2009, 2011). However, by combining the waves where the same households were re-visited, the farmers chosen for the project were trustworthy individuals. Firstly, they had a close relationship with the LSMS team and gave their approval of being re-visited over time, which arguably revealed a sense of interest in contributing to the LSMS-ISA project. Secondly, when going through the different waves, it is clear that the re-visited households have shared a wide range of details about the production process which varied between the waves, therefore, did not give the same motivation every year. Hence, since the household faced different obstacles and shocks over the sample period it would be unreliable if the information were repeated. Thirdly, it can be argued that the development pattern of each household is well-documented and follow-up questions between each wave were conducted to avoid missing values (NBS, 2009, 2011).

Despite these motivations, the LSMS-ISA data is, nevertheless, highly limited with many missing values. Therefore, when establishing the sample, relevant variables were included after availability. The reader has to bear in mind that there might be several other factors that influence productivity and that weather shocks are only a part of the impact. To solve parts of this problem, the econometric models include various factors that might influence the explanation capacity and thus limit the chance of omitted variable bias. To increase the reliability of the estimations, several robustness checks have been conducted (Creswell., 2013; Arslan et al. 2015).

In terms of representativity, the data is relevant because this study seeks to analyze farmers that spontaneously implemented CSA practices on a household-level. This household survey was chosen to avoid self-selection bias since it aimed to map various factors beyond agricultural production, such as non-farm activities, tenure insecurity, or access to electricity. The focus was, therefore, not primarily put on the production and implementation of CSA, but also on the livelihoods of the household. Additionally, since the data maps several regions and AEZ, the issue of generalizing CSA can be prevented. Although this study would have reached greater validity if additional data were collected to fill the gap of missing data, it would not increase the understanding of the plot level. This study aims to provide insights on productivity implications on a disaggregated level. Therefore, including additional data which does not capture the same granularity would decrease the representativity and validity of the study.

5 Empirical Strategy

This chapter discusses the empirical method and justifies the econometric models that have been used to estimate agricultural productivity. Before describing the details about the estimation method it is essential to get an overview of the sample and the variables of interest. Therefore, this chapter begins with descriptive statistics, shortly followed by the estimation methods used and finally, the construction of the models.

5.1 Variables and descriptive statistics

This section will give an overview of the variables included, aiming to examine the differences in adapted CSA practices in Tanzania. The chosen variables were inspired by scientific literature mentioned in the theory section (chapters 2 and 3). A detailed overview of the expected sign for each variable and how they were created can be found in Appendix D.1.

5.1.1 Dependent variable

Agricultural productivity [$Ycpait$]

As mentioned previously in this thesis, *agricultural productivity* can be defined as "the ratio of outputs (O) to inputs (X), expressed either in volumes or, when possible, in physical quantities (kg, tons, etc.)'' (FAO, 2018b, p.2). To measure productivity, we thus need to look closer into its mathematical definition. A general definition of agricultural productivity can be expressed as:

$$Prodt = Ot\,/\,Xt, \qquad [1]$$

where the growth in productivity (*Prodt*) at period *t* is equal to the difference between input and output growth respectively *O* and *X:*

$$Prodt \cong Ot - Xt, \qquad [2]$$

In other terms, productivity growth also explains the growth in outputs not defined in the growth of inputs or the growth of residuals (Solow, 1957). Since this thesis is measuring the performance of the crop yield, the quantification of productivity is measured by relying on a *stochastic production frontier* method. This production function quantifies the output produced (Yi,t) to a set of inputs (Xi,t), which in this study emphasizes CSA practices and covariates that influences farmers' output. Through the stochastic production model, this relationship is usually expressed as:

$$Yit = \alpha + \beta xit + \varepsilon it, \qquad [3]$$

where *i* represent a farm or plot and *t* a given period (FAO, 2018b). To proxy the factor of *agricultural productivity* [$Ycpait$], this study relies on a common approach developed by Fermont and Benson (2011) which measures the yields in kilogram per acre. In addition, by following the structure developed by Reynolds et al. (2015), the weight (in kg) of a harvested crop is divided by the total acre of a given plot area (kg/acre). This method will consider that a farmer might experience harvest loss that occurs between planting and harvest. Theoretically, exogenous shocks (such as climatic shock) that cause this unknown loss in production are usually captured by the error-term (εit).

However, one crucial aspect to keep in mind is that model [3] assumes that output is only affected by the inputs. To account for this, a variety of other factors have been added to the econometric analysis which includes factors pertaining to a specific crop yield. In practice, this could be both the site-specific climate condition and the physiography. It could also be the experience of the labor and landholder, the level of CSA guidance provided, or infrastructural aspects such as plot distance to a major road or market. Hence, factors that influence proper, but also inadequate decision-making when it comes to input use.

Lastly, technical inefficiencies in the production process (e.g. access to agro-ecological techniques, diffusion of innovations, or distance to efficient producers and markets) are within the theoretical model included by adding the factor $\mu i,t$ ($\mu i,t \geq 0$) to model [3]. However, since this study accounts for observed technical inefficiencies by using covariates on infrastructure, technology and production, this term will not be added to the econometric model (FAO, 2018b, p.2). Further explanation about the models used within this study and how they serve as a tool to measure productivity levels will be discussed in section 5.2.

5.1.2 Key explanatory variables

CSA practices $[CSA_{cpait}]$

The key explanatory variables of this study are the three CSA practices*; intercropping, improved seed, and inorganic fertilizer.* By relying on sources presented in chapter 2, the evidence shows that these practices improve agricultural productivity, however, it is a debate under which circumstance this is the case. In the sample of households included in this study, each farmer answered "yes" or "no" if the practices were applied on the plot. By creating dummy variables (see Appendix D.1), the explanatory variables could be included in an econometric model. Since a wide range of other factors influences agricultural productivity, a set of covariates were carefully studied and supported through relevant literature. These will be highlighted below.

5.1.3 Covariates

Economic factors $[ECit]$

Scholars have suggested that the farmer's economic situation influences the productivity of the plot (Nkonya et al. 2004; Scherr & Hazell, 1994; Clay et al. 1998; Reardon et al. 1994). Studies have shown that farmers involved in non-farm activities can use income provided from other businesses and invest in knowledgeable labor and improved CSA techniques (Clay et al. 1998; Reardon et al. 1994). Nkonya et al. (2004) argue that farmers reporting participation in non-farming activities – e.g. running a company or engaging in economic associations outside the farm, are likely to sell their crops at higher prices. Scholars suggest that higher liquidity gives the farmers advantages in decisions with high-risk management (Nkonya et al. 2004).

On the other hand, Scherr and Hazell (1994) showed that the opportunity costs of labor made farmers' households less willing to invest in land management practices if they already had a stable off-farm income (Scherr & Hazell, 1994). Additionally, studies have shown that farmers who own more physical assets and more land that can be sold at a higher price increase the household's wealth. It provides greater mental well-being of the household members through financial security, increases the possibilities of liquidating assets owned, implements better production standards, and increases agricultural investments (Nkonya et al. 2004;

Scherr & Hazell, 1994). By including the variables, *off-farm income, assets, land size* and *plot value*, the model accounts for the high-risk strategy the farmer is willing to take.

Socioeconomic factors $[SOCit]$

Other relevant variables to consider when measuring agricultural productivity are human capital which has proven to be a significant factor of influence in many studies (Nelson & Phelps, 1966; Feder et al. 1985; Asadullah & Rahman, 2009). In this study, the following five variables have been considered: *certificate* (*agricultural training), age of the household head, the number of household members*, *hired labor,* and *sex* (*female head*) (Nelson & Phelps, 1966).

Firstly, continuous agricultural training through farmers learning hubs or CSA workshops usually reward Tanzanian farmers through a *certificate* (CIAT & World Bank, 2017). This certificate has proven to translate production into efficient decision-making since it helps the farmers understand problems and capture important information about new technologies (Asadullah & Rahman, 2009). Receiving a *certificate* due to a completed agricultural training means that the farmer has received technical assistance. As explained in the section about policy measures towards CSA, access to information via platforms and assistance through extension services are of utmost importance. By giving the household extensive support for agricultural practices, which tend to be knowledge-intensive, the farmer can be more confident when implementing CSA practices on the plot (Swinkels & Franzel, 1997; Barrett et al. 2002; (Nkonya et al. 2004).

Secondly, according to Nelson and Phelps (1966), older household heads had more years to increase their experience in meeting climatic shocks and harvest losses. However, even if older farmers means more years of experience, physical limitations could also hinder the ability to maintain a stable production of the plot since the harvesting among Tanzanian farmers is usually implemented through cattle-driven ox plows or by hand. Older farmers with high experience are, nevertheless, more prone to invest in new technology since they have life experience in analyzing and deciding whether an innovation is promising or not (Nelson & Phelps, 1966; Deiniger & Okidi, 2001; Barret et al. 2001; Feder et al. 1985; Nkonya et al. 2004).

Thirdly, when it comes to the *number of household members*, studies show that while a bigger household has a workforce able to work on the plot, it also means higher expenditure on food, education, and transportation - something which potentially reduces the investments in agricultural methods such as CSA practices (Feder et al. 1985). Fourth, *labor availability (hired labor)* is a factor that generally increases agricultural productivity. Increased labor endowment per unit of land means that labor is used intensively in agricultural production (Feder et al. 1985). Fifth, one last socioeconomic covariate added to the analysis is whether the household head is a male or a female. According to Ragasa et al. (2013), *sex* plays an important role in the access to extension services and income needed when implementing agricultural practices. To account for this, the variable *sex* has been coded as female-heads which according to Ragasa et al. (2013) usually decreases in productivity compared to male-headed households.

Production specific factors $[PRODpait]$

To account for agricultural methods that are not considered as CSA practices, this study includes the variables: *organic fertilizer, pesticides*, and *irrigation.* Arslan et al. (2015) argue that accounting for other production-specific factors is important when analyzing the impact of CSA. Investments towards proper irrigation systems and methods hindering harvest losses improve the output of the yield and stabilize the quality of market supplies. Furthermore, it also strengthens the farmers to climatological variability and mitigates the risk of droughts and insect invasions while reducing the dependency on rain-fed agriculture (Nkonya et al. 2004; Hanjra et al. 2009).

Infrastructural factors $[INFRit]$

The transport infrastructure and availability of agricultural markets are further aspects that influence agricultural production. This study accounts for the plot distance to *major roads* and the plot distance to *agricultural markets*. By reducing the travel distance, farmers can easily connect with consumers and producers while avoiding the frequency of transport damage. Consequently, access to major roads and markets increases the inputs in agricultural methods while capital intensity raises the profitability through greater consumer demand (GTZ, 2005; Llanto, 2012). Another aspect with improved connectivity is that households closer to urban areas have more opportunities for high-quality education and business networking (Reardon, 1997; Barrett et al. 2001).

Climatological and agro-ecological factors $[CLIMit]$

To account for the adverse impact of climatological conditions that vary across regions and AEZ, various factors have been identified (for geographical details on AEZ, see Figure 3 and 4). The variables *climatic shocks* (droughts or floods) and *shock length* (measured in months) have been included to control for extreme weather (Arslan et al. 2015). Moreover, to account for site-specific soil characteristics, variables on *soil quality* (good and bad soil quality) and *moderate nutrient constraint* taken into account (Ardö & Yengoh, 2020). Other climatological factors encompass *temperature, precipitation, rainfall pattern change,* and *false onset rainy season.* The latter mentioned, measures when a farmer has faced a rain season that did not start as usual, either too early or late from the average start of the AEZ. The value represents the time difference between the average start of the rain season and the actual start, concerning each AEZ. Since it is coded as a dummy variable, value 1 means that the farmer experienced a difference that was above the mean of the AEZ. Similarly, the rainfall pattern change is a dummy variable and measures if the seasonal rainfall (in mm) is above (dummy=1) or below (dummy=0) the mean of the AEZ (Arslan et al. 2015).

Table 3. Descriptive statistics

Variable	Obs	Mean	Std. dev.	Min	Max
Dependent variable					
Agricultural productivity, log (kg/acre)	5,294	5.63	1.34	0.51	11.70
CSA practices					
Intercropping (1=Intercropped	5,301	0.12	0.34	0	1
Improved seed (1=Yes)	5,301	0.13	0.12	0	1
Inorganic fertilizer (1=Application)	5,301	0.21	0.41	0	1
Economic factors					
Off-farm income, log (TZS)	3,602	8.98	0.32	5.65	13.26
Value plot, log (TZS)	5,299	12.01	0.98	4.59	13.59
Assets, log (TZS)	3,566	9.63	0.32	3.81	11.82
Land size, log (Acre)	3,526	0.62	0.64	0	3.91
Socioeconomic factors					
Age of household head	5,301	47.59	15.03	19	97
Number of household members	5,301	5.27	2.73	1	12
Hired labor (1=Yes)	5,301	0.33	0.48	0	1
Certificate/Training (1=Yes)	5,301	0.69	0.46	0	1
Sex (1=Female)	5,301	0.24	0.43	0	1
Production-specific factor					
Organic fertilizer (1=Application)	5,301	0.17	0.39	0	1
Pesticide use (1=Yes)	4,961	0 .75	0.86	0	1
Irrigated (1=Yes)	5,301	0.12	0.33	0	1
Infrastructure					
Plot distance road (km)	5,299	2.21	3.80	0	80
Plot distance market (km)	5,301	8.98	11.54	0	134
Climatological and agro-ecological factors					
Shock length (months)	2,323	5.84	2.10	0	12
Climate shock (drought or floods)	5,301	0.022	0.15	0	1
Erosion (1=Yes)	5,301	0.21	0.41	0	1
Good soil quality (1=Yes)	5,001	0.43	0.49	0	1
Bad soil quality (1=Yes)	5,001	0.17	0.38	0	1
Temperature, annual (°C*10)	5,301	230.26	18.81	154	390
Precipitation, annual (mm*10)	5,301	1137.97	202.96	544	2372
Moderate nutrient constraint (1=Yes)	5,301	0.09	0.29	0	1
False onset rainy season (1=>AEZ mean)	5,301	0.97	0.16	0	1
Rainfall pattern change (1=>AEZ mean)	5,301	0.81	0.39	0	1

Note: This table considers both waves simultaneously, wave-specific tables can be found in Appendix D.4-5.

As mentioned previously, the panel data consists of 7 204 households across Tanzania visited during 2008-2011. The variables above have been included in an econometric sample which can be seen in Table 3. The dependent variable, *agricultural productivity*, is transformed into a logarithmic variable consisting of 5,294 observations ranging from 0.51 and 11.70. As seen in Table 3 and Appendix B.2, the variable is normally distributed with a mean of 5.63 with a standard deviation of 5.63. To further illustrate the variation across regions and AEZ and crops, a boxplot of agricultural productivity has been included in Appendix B.3. Although the boxplots show that productivity has a minimal variation between the years, year 2 (2010-2011) shows a slight increase in productivity. When measuring productivity across regions and AEZ, the boxplot also reveals that the northwestern and western regions have a higher productivity level while the difference between AEZ is small. When it comes to the variation between crops, the boxplot reveals that the productivity is higher for cassava and rice (paddy), which produces above 6 percent in yields (kg/acre).

Regarding the implemented CSA practices, Table 3 shows that the use of improved seeding and intercropping is lower than the use of inorganic fertilization when looking at the mean. However, as seen in the figures in Appendix B.5-7, the use of intercropping and improved seeding increased between year 1 (2008-2009) and year 2 (2010-2011). While intercropping increased from 15 to 19 percent between year 1 and year 2, the utilization of improved seeding increased from 2 percent to 15 percent in 2011. The share of Tanzanian farmers using inorganic fertilization on the plot remains similar throughout the sample period. In general, the sample ranges from 2,323 to 5,301 and shows evidence of interesting variations within chosen variables.

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5.2 Estimation method

As explained, the sample is based on panel data totalizing 5, 301 observations over 2 years. This data has been collected and measured through the statistical software STATA. Moreover, since this study seeks to estimate the productivity level of a given plot across several regions, AEZ, and crops, a model which accounts for these dimensions needs to be constructed. Let us, therefore, consider the following model needed to test the first hypothesis (H1):

H1: Agricultural productivity increases when CSA practices are implemented

$$Ycpait = \alpha + \beta 1CSAcpait + \beta 2ECit + \beta 3SOCit + \beta 4PRODpait + \beta 5INFRit + \beta 6CLIMit + \varepsilon cpait, \qquad [4]$$

where $Ycpait$ refers to agricultural productivity proxied by the yield of crop c measured in kilograms per acre of land (kg/acre) on plot p owned by a household i at time t. $CSAcpait$, is a vector of given CSA practices (intercropping, improved seed, inorganic fertilizer) is structured as dummy variables indicating if a given plot or crop was cultivated with any of these practices at time t. $ECit$ denotes economic factors and is a vector for off-farm income, the total value of the plot, assets owned, and land size. $SOCit$ refers to socioeconomic variables such as the age of the household head, the number of household members, hired labor, certificate/training, and sex. $PRODpait$ encompasses applied production-specific factors such as organic fertilizer, pesticides use, and irrigation. The $INFRit$ parameter represents infrastructural factors like the plot distance to major roads and the agricultural market. Lastly, the $CLIMit$ is the vector that includes climatic variables influencing the plot. As mentioned previously, these are climate shock (drought or flood), length of a given shock (measured in months), erosion, soil quality, temperature, precipitation, moderate nutrient constraint, false onset rainy season, and rainfall pattern change (measured in mm). The $\varepsilon cpait$ is the error term that captures all of the clustered errors and unobserved values in the sample.

Model [4] and [5] allows an estimation with ordinary least squares (OLS) with fixed effects. OLS is an estimation method for linear regression models that minimizes the sum of squared residuals which is the difference between the observed and fitted values (Kennedy, 2008). Applying fixed effects to models [4] and [5][13], reduces problems with omitted variable bias by removing the time-invariant components of the error term. This will prevent the models from generating inconsistent results. However, since the data in this thesis already control for the geographical location of the plot, all time-invariant geographical components are controlled for and will therefore change slightly (Kennedy, 2008).

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[13] For a detailed description of the procedure behind fixed effects, please see Appendix D.2

To test the second and third hypotheses (H2 and H3) which focuses on climatic shock and geographical variability, an additional model can be formulated as follows:

H2: Farmers utilizing CSA practices are more resilient to climatic shocks
H3: The effect of the given CSA practices varies across:
  A: Regions
  B: Agroecological zones (AEZ)
  C: Crops

$$Ycpait = \alpha + \beta 1[CSAcpait \cdot CLIMit] + \beta 2ECit + \beta 3SOCit + \beta 4PRODpait + \beta 5INFRit + \varepsilon cpait, \qquad [5]$$

Model [5] adds an interaction term between the implemented CSA practices $[CSAcpait]$ and climatological factors $[CLIMit]$. If agricultural productivity or the output variation is smaller for farmers applying CSA practices on their plot than those farmers who did not, H2 would be confirmed since CSA then would be associated with farmers' resilience to climatic shocks. Moreover, if the magnitude and significance of CSA vary across given regions, AEZ, and crops, H3A-C would be confirmed since the CSA practices would be associated with different effects under certain circumstances. In contrast, H1 would be accepted if $Ycpait$ in the model [4] shows a positive and significant relationship when adding given CSA practices, meaning that CSA is associated with improvements in crop yield output or agricultural productivity.

Equation [5] could similarly to [4] be estimated with OLS using fixed effects. Additionally, since the data was collected both at a household, plot and crop level and the level of granularity is based on the plot level, clustering errors on the household level were made when running the two regressions with fixed effects. Clustering is usually used when clusters of units are attached to a treatment, which in this thesis is the applied CSA practice. A given treatment was assigned both at the household, plot and crop level. By clustering all errors that appear when controlling for the plot and crop level, the data analysis accounts for the treatments assigned to the household level. Finally, adding fixed effects when there is heterogeneity in the treatment effect gives proper controls for these cluster adjustments (Kennedy 2008).

5.2.1 Robustness tests

Four main robustness tests have been performed to justify the results from the estimations with model [4] and model [5]. Firstly, when examining the determinants of agricultural productivity, a *"stepwise"* analysis was applied in Table 4. By adding the covariates in a stepwise order, the change in magnitude of CSA practices between each step could easily be targeted and critically analyzed.

Secondly, since this data does not capture a natural experiment, *propensity score matching (PSM)* was applied since it captures individuals in the treatment group and compares these with their untreated counterparts (Leuven & Sianesi. 2003; Rosenbaum & Rubin. 1983). The "treatment", refers to the applied CSA practice where any difference in the scores of the treated and their untreated counterparts will be attributed to the treatment. When measuring the propensity score, the parameter of interest is the "average treatment effect of the treated" (ATET) which gives us the actual effect of the treated (Caliendo & Kopeinig, 2005). This is a method that solves complexities within household survey data.

Thirdly, *Average Marginal Effects (AME)* is applied to understand how the dependent variable (agricultural productivity) changes when the CSA practices are applied under climatic shocks. The variables, *drought and floods, false onset rain season,* and *rainfall patterns change* was applied for model

[5] as interactions with given CSA practices (Caliendo & Kopeinig, 2005). Fourth, performing *regional tests* where both regions, crops, and AEZ are taken into consideration are seen as a robustness test per se. By capturing the crop yield within each of these contexts allows for an in depth understanding and prevents generalization.

6 Results

This chapter presents the results of the estimated models and discusses the robustness of the findings after following the procedure of the used methodological framework. As mentioned previously, this thesis addresses the following research question: *Can differences in agricultural productivity be explained by CSA practices, particularly when testing for the impact of climatic shocks?* This question has then been addressed through *three* different hypotheses which will be examined separately in this chapter.

6.1 Determinants of agricultural productivity

H1: Agricultural productivity increases when CSA practices are implemented

This section will address the first hypothesis and present the general findings for the efficiency of CSA in increasing agricultural productivity in Tanzania. The main regression results related to this section are presented in Table 4. This table was constructed through a stepwise procedure where each covariate was added one by one. As a first step, *CSA practices* were added without fixed effects. Column (2) further adds *economic* and *socioeconomic factors.* Column (3) includes *production-specific* factors followed by *infrastructural factors* in column (4). Finally, column (5) includes *climatological* and *agro-ecological* factors. The last step includes all variables of interest, with fixed effect, and is the complete baseline model used to test H1.

As shown in Table 4, the CSA indicators, key to test the assumption of H1, are positively associated with agricultural productivity regardless of included covariate, evidence which supports the confirmation of H1. Looking at the stepwise procedure of the table, it is clear that both *intercropping* and *inorganic fertilizer* increase in magnitude between columns (1) and (5) when all variables are included. These indicators further remain positive and statistically significant at a five percent significance level, meaning that their determination to agricultural productivity is possible to interpret. More specifically, the coefficient for *intercropping* in column (5), suggests that utilizing *intercropping* on the plot is associated with an average increase of 58.5 percent in crop yields (kg/acre) compared to plots where this technique was not utilized - holding all other variables constant. Similarly, *inorganic fertilizer* also shows a significant impact on crop yields. When adding all covariates in column (5), findings suggest that using *inorganic fertilizer* on the plot is associated with an average increase of 54.3 percent in crop yields compared to plots where this technique was not employed – holding all other variables constant.

Table 4. Determinants of agricultural productivity

y=Agricultual productivity, in kg/acre (log)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
CSA practices					
Intercropping	0.412***	0.036*	0.069	0.067	0.585**
Improved seed	0.487***	0.471*	0.539**	0.577*	0.067*
Inorganic fertilizer	0.542***	0.510***	0.481	0.480	0.543**
Economic factors					
Off farm income *(TZS)*		0.033	0.025	0.024	0.079***
Value plot *(TZS)*		0.151***	0.132**	0.121**	0.791***
Assets *(TZS)*		0.075	0.076	0.085	0.647***
Land size (acre)		-0.603***	-0.578***	-0.564***	0.003
Socioeconomic factors					
Age head		-0.002	-0.003	-0.003	0.275***
Number of household members		-0.024	-0.021	-0.021	-0.322***
Hired labor		0.339***	0.346***	0.345***	0.103***
Certificate		0.198	0.246	0.242	0.022
Sex (1=Female)		-0.241**	-0.243**	-0.250**	-0.393***
Production-specific factors					
Organic fertilizer			0.369***	0.351***	-0.946
Pesticides			0.104	0.108	0.095***
Irrigated			-0.113	-0.119	-0.529
Infrastructure					
Plot distance road (km)				-0.016**	-0.059*
Plot distance market (km)				-0.008***	-0.039**
Climatological and agro-ecological factors					
Shock length (months)					-0.013
Climate shock (drought or flood)					-0.533***
Erosion					-0.749
Good soil quality					0.103***
Bad soil quality					-0.675
Moderate nutritient constraint					-0.004
Temperature (℃*10)					-0.023***
Precipitation (mm*10)					0.004
False onset rainyseason					0.091***
Rainfall pattern change					0.111**
Fixed effects	No	No	No	No	Yes
Constant	5.39***	4.42***	4.57***	4.83***	72.25**
Observations	1,533	1100	1100	1100	1100
R² within/(overall)	0.049	0.236	0.863	0.853	0.875
	(0.056)	(0.228)	(0.005)	(0.252)	(0.273)
Number of id	1,058	784	784	784	784

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

Source: Based on data from NBS (2009, 2011)

Note: A table with standard errors is included in Appendix D.3.

Improved seed, on the other hand, shows a less significant effect on agricultural productivity throughout this stepwise procedure. Yet, compared to the other CSA indicators, *improved seed* remains statistically significant in each column. In column (1), *improved seed* is positively associated with agricultural productivity when only controlling for the explanatory variables (CSA practices). When adding covariates to the model, the magnitude of *improved seed* does, however, become weaker. Although the magnitude is less in column (5), *improved seed* is still positively associated with agricultural productivity, increasing crop yields by 6.7 percent on average compared to plots not subjected to this method – holding all other variables constant.

Considerable differences between the estimated results for each column prove the relevance of applying fixed effects. When excluding time-invariant factors in column (5), controlling for unobserved heterogeneity, the within R-squared increased slightly while the CSA-coefficient became significant. The estimation results for column (5) with fixed effects will therefore only be taken into account when looking at the results of the covariates.

Looking at the *economic factors*, the results show that all covariates are positively associated with agricultural productivity. Nevertheless, *land size* is not statistically significant. In particular, the *plot value* and *assets* owned by the farmer had major importance for an increase in crop yields. This finding suggests that valuable plots and farmers' households with higher liquidity give more opportunities to invest in labor and extension services. Moreover, the covariate *off-farm* income is also having a positive and significant impact on crop yield output. This implies that plots owned by farmers who are engaged in non-farm activities give them more liquidity in making high-risk decisions in innovative technologies such as CSA, as suggested by Clay et al. (1998) and Reardon et al. (1994)

Regarding *socio-economic factors*, all variables except for the *certificate* are significant. Both the *number of household members* and *sex* are negatively associated with crop yields as expected (see Appendix D.1). These results imply that an additional increase in the *number of household members* is potentially increasing household expenditures on basic needs (e.g. food, water, and electricity) and thus decrease expenditures on efficient land-management methods, as highlighted by Feder et al. (1985). Similar findings as in Ragasa et al. (2013) is further reflected through Table 4. The variable *sex* (female-headed farmer) is negatively associated with yield output in all columns, suggesting that females receive limited access to extension services when implementing new agricultural practices. In contrast, *hired labor* on the plot and the *age of the household head* is having a positive effect on crop yields,. This suggests that labor insensitivity on the plot and life experience of the head plays a significant role in agricultural productivity as highlighted by Nelson and Phelps (1966).

When looking at *production-specific factors,* only *pesticides* are positive and statistically significant, implying that using pesticides on the plot protects the crops from insects, which were reported as the third most common reason for harvest loss in 2008-2011 among Tanzanian farmers (Figure 6). For *infrastructural factors,* both the *plot distance to a major road* and *plot distance to market* is negatively linked to an increase in crop yields, a finding that was further confirmed within the literature (GTZ, 2005; Llanto, 2012).

Lastly, the climatological and AEZ factors positively influencing crop yields are *good soil quality* and *rainfall pattern change* that appears more often, above the mean of the AEZ. The covariates *climatic shocks* (drought and floods) and *temperature* are, in contrast, factors that are negatively associated with agricultural productivity, as expected in Appendix D.1 and as highlighted by Arslan et al. (2015).

To further test the robustness of these findings, propensity score matching (PSM) was applied in Table 5 below. When applying PSM, it is, furthermore, important to choose proper covariates in line with two basic principles (Heckman et al. 1999). Firstly, only the covariates that influence the outcome variable (agricultural productivity) and the participation decision (CSA practices) simultaneously should be included. Secondly, only variables that are not affected or changed by participants should be included (Caliendo and Kopeinig, 2005). Taking these criteria into account, the PSM-test included the following variables: *off-farm income, land size, plot value, plot distance to major road, length of a shock, sex, and age of the household head*. These variables are representative covariates since these fulfill the criteria stated above.

When performing the PSM-test, a p-value two-sample test for the covariates was made where the pre-treatment observable should be divided by the group as seen in Appendix A.1 (Caliendo & Kopeinig, 2005). This test implies that the smaller the p-value, the more surprisingly it would be to have differences in the population mean, which we do not want when estimating the population means. When performing the test in Appendix A.1, the p-values for *agricultural productivity* and *plot distance to major roads* equals zero. This suggests that it is unlikely to find differences in the sample and population mean.

Further, the matching process should balance the distribution of the relevant variables in both the treatment and the control group (Caliendo & Kopeinig, 2005). To test if the "balancing condition" (Caliendo & Kopeinig, 2005) and the PSM fulfilled the assumptions, several balancing tests were performed in Appendix A.2-A.4. All CSA variables have a mean bias below 5 percent, which is desirable when performing this test. The figures in Appendix B.4 further test the overlap assumption graphically. Since the three figures are shown in Appendix B.4 (treated vs. untreated) overlap for each of the three CSA practices, the findings of a balanced distribution are confirmed.

Table 5. Efficiency of CSA practices - Robustness Checks (Propensity Score Matching)

	(1) Intercropping (Intercropped vs Pure Stand)	(2) Improved Seed (Improved vs Traditional)	(3) Inorganic Fertilizer (Application vs No Application)
ATET	0.366**	0.250**	0.488***
	(0.111)	(0.181)	(0.112)
FE baseline results	0.585**	0.067*	0.543**
	(0.231)	(0.706)	(0.543)
Observations (PSM)	1, 117	1,117	1,117

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

Source: Based on data from NBS (2009,2011)
Note: Average Treatment Effect on the Treated = ATET

The results from the PSM are presented in Table 5 where the coefficient ATET is compared to the coefficients found from the baseline model with fixed effects in Table 4 column (5). The positive impact of all CSA practices is strongly supported. Interestingly is that *improved seed* shows a stronger magnitude than found in the FE baseline results. Therefore, the results of the ATET-coefficient are contradicting the findings in Table 4. According to the PSM-test, the average treatment effect on the treated (farmers who utilized improved seed), compared to the untreated (farmers who utilized traditional seeds), is 0.250 suggesting that utilizing *improved seed* is associated with an average increase of 25 percent in crop yields, compared to farmers who used traditional seeds.

Moreover, the results found for *inorganic fertilizer* and *intercropping* in the PSM support its significant and positive effect on agricultural productivity. Still, the magnitude is weaker compared to the FE baseline results. The PSM results imply that the ATET for *intercropping* and application of *inorganic fertilizer* is associated with an average increase of 36.6 percent and 48.8 percent in crop yields, respectively. The difference between these results implies that there might be several other factors that influence the impact of CSA practices. At the same time, the effect might differ across geographical areas or crops grown. A detailed analysis of why the results might differ will be provided in the next two sections when testing for climatic shocks.

6.2 The impact of climatic shocks

H2: Farmers utilizing CSA practices are more resilient to climatic shocks

Although findings in the previous section suggest that CSA practices generally have a positive and significant effect on agricultural productivity, it is essential to test if farmers utilizing CSA become more resilient under climatic shocks. To test H2, three main interactions were chosen for the analysis. While *climatic shocks* refer to droughts and floods, *false onsets rain season* represent the time difference between the average start and the actual start of the rain season. The variable *rainfall pattern change* reveals if the farmers experienced an increase in rainfall (in mm) higher than the mean of the AEZ.

Table 6. The efficiency of CSA practices in interaction with climatological factors - Average Marginal Effects (AMEs)

	(1) Climate shock interactions (droughts or floods)	(2) False onset rain season interactions	(3) Rainfall pattern change interactions
Intercropping			
Without shock	0.583***	0.477*	0.321***
With shock	0.482***	0.242***	0.241**
Improved seeds			
Without shock	0.332**	0.490**	0.551**
With shock	0.371	0.333	0.220
Inorganic fertilizer			
Without shock	0.321***	0.542***	0.491***
With shock	0.301***	0.351**	0.296
Observations	3, 559	3, 559	3,559

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

Source: Based on data from NBS (2009, 2011)

As mentioned previously, model [5] includes an interaction term [$CSAcpait \cdot CLIMit$] applied for each of the three variables in Table 6. To make interpretation more accurate, *Average Marginal Effects* (AME) were used to test the magnitude of CSA practices *without shock* (climatological factor equals zero) and *with shock* (climatological factor equals one)[14]. Findings in Table 6 above suggest that, under normal circumstances (without a shock), *intercropping, improved seed,* and *inorganic fertilizer* are associated with higher productivity which further confirms the findings in the previous section. Therefore, plots subjected

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[14] For a detailed understanding of how these indicators were created, please see Appendix D.1.

to CSA practices are on average more productive than plots where these practices were not used. When controlling for climatic shocks, *intercropping* and *inorganic fertilizer* are still associated with higher productivity. *Improved seed*, however, is not statistically significant in any of the columns when controlling for extreme weather.

Findings in column (1), when controlling for no shock of drought and floods, suggest that plots subjected to *intercropping* are associated with an average increase of 58.3 percent in crop yields. This association remains positive when controlling for a shock, implying that plots where farmers utilize *intercropping* are on average 48.2 percent more productive than plots where this technique was not employed. A similar trend was found for the false onset rain season and rainfall pattern change interaction. With significant changes in the start of the rain season and rainfall patterns (column 2 and 3), farmers who applied *intercropping* are still associated with an average increase in crop yields, that is approximately 24 percent (24.2 and 24.1, respectively) higher than plots where *intercropping* were not utilized.

In addition, plots subjected to *inorganic fertilization* under periods of drought and floods are also positively associated with higher productivity than farmers who used other fertilization techniques (e.g. organic fertilization). More specifically, the AME-coefficient for the interaction with false onset rain season in column (2) implies that the output is halved under sudden changes in rain season. Still, while *inorganic fertilization* was associated with 54.2 percent higher productivity before the shock, with a shock, the plots are on average 35 percent more productive than plots where this technique was not implemented. The association for *inorganic fertilization* also remained positive when testing for droughts or floods. It was, however, not statistically significant when controlling for changes in rainfall patterns.

The findings in Table 6 suggest that plots subjected to the CSA practices *intercropping* and *inorganic fertilizer* are generally more productive on average than plots where these practices were not used, even when all the plots are subjected to climatic shocks. Therefore, findings suggest that CSA practices are not only associated with greater productivity. They are also associated with greater output resilience since the output of the plot remained positive and varied less, even when controlling for shocks. Given the results, that crop yield output decreased less for plots where CSA practices (*intercropping* and *inorganic fertilizer*) were employed, H2 is accepted. This hypothesis can, nevertheless, not be confirmed for *improved seed* due to insignificant results. To further support the findings, Figure 7 on the next page, provides a visual representation of the average marginal effects but does also account for the effect over time between year 1 (2008-2009) and year 2 (2010-2011). As seen in the figure, the productivity was generally higher for year 2, and the AME for *improved seed* is not significant when controlling for extreme weather since the AME-lines are merged when the indicators equal 1. These findings will be further analyzed through the lens of the literature in the discussion in chapter 7.

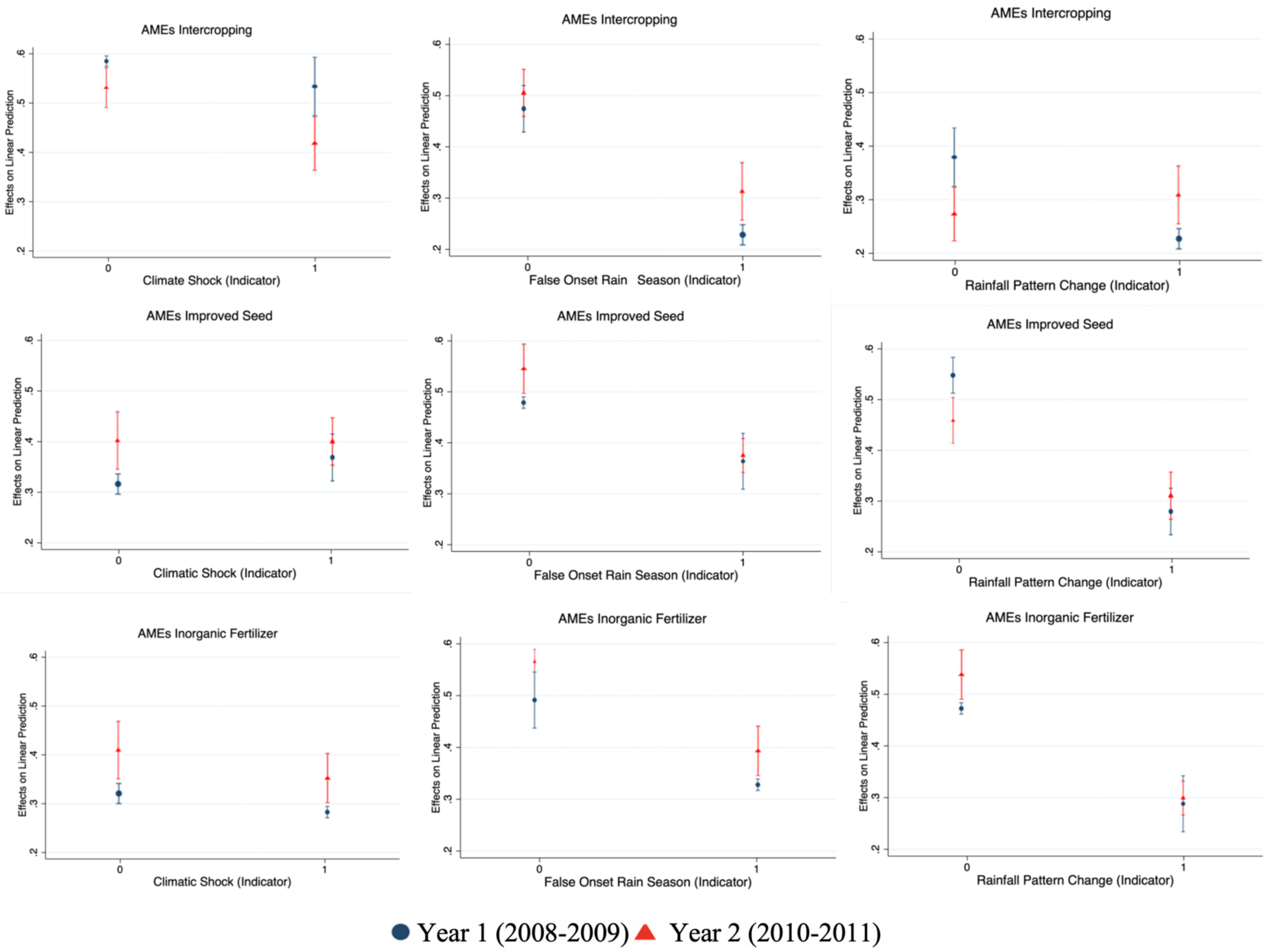

Figure 7. Predicted Average Marginal Effects of Climatological Factors
Source: Based on data from NBS (2009, 2011)
Note: Predictive Margins on 95% Confidence Intervals (0=Without shock 1=With shock).

6.3 Differences across regions, AEZ, and crops

H3: The effect of the given CSA practices varies across:
A: Regions
B: Agro- ecological zones (AEZ)
C: Crops

Due to variation in physiographic and climatic conditions in Tanzania where farmers cultivate a wide range of crops, H3 has been divided into three subparts and tested separately. Each part has controlled for *with shock* and *without shock* to account for potential differences in the efficiency of CSA and provide further evidence of farmers' resilience. This section will present the results in three steps and based on the findings independently reject or accept A, B, and C.

6.3.1 Regions

As seen in Table 7, it still seems that CSA practices positively affect agricultural productivity and that the association remains positive for *intercropping* and *inorganic fertilizer* when controlling for climatic shocks (panel B). No significant effect for *improved seed* was found, although the magnitude of the coefficients varies from being both positively and negatively associated with agricultural productivity in panel B.

The coefficients for *intercropping* in Table 7, are all significant at a 5 percent significance level and positively associated with agricultural productivity across all six regions. This result applies to both panel A and B. Regarding the magnitudes of the coefficients, it differs especially for the northwestern and southeastern regions. Farmers living in the northwestern and southeastern regions and utilized *intercropping* on their plot are approximately 25 (northwestern) and 6 (southeastern) percent more productive than plots where this technique was not employed. Although the magnitude of *intercropping* is stronger for the northwestern region, the variation in output was less for the southeastern region since the coefficient only changed slightly (from 0.066 to 0.065) between panel A and panel B. In addition, a smaller output variation could also be found for plots subjected to *intercropping* in the eastern region. Hence, farmers using this technique on their plot are on average 12 percent more productive than plots where this method was not implemented, regardless of climatic condition.

Regarding the impact of *inorganic fertilization* on crop yields, a significant effect could only be found for the central, the southeast, and the western regions. The impact does, however, remain positively associated to agricultural productivity regardless of climatic condition. Further, the difference between those who reported that they utilized the practice compared to those who did not are especially of significance in the western region. When controlling for a climatic shock (panel B), plots located in the western region are on average 11 percent more productive than plots that was not subjected to this technique. *Inorganic fertilizer* (under climatic shocks) are weaker in magnitude when applied on plots located in the central and southeastern region. Still, plots within these two regions are on average 6.3 (central) and 5.6 percent (southeastern) more productive than farmers that did not implement this *inorganic fertilization* on their plot, even when controlling for extreme weather.

In closing, the output variation between regions implies that CSA practices have different significant effects on farmers' plots depending on where they are located. However, no significant effect could be found for *improved seed*. Given the findings, *intercropping* is positively associated with agricultural productivity within all six regions. Its efficiency in maintaining a surplus in yield output under climatic shocks was confirmed, especially for the northwestern (+25.1%) and eastern region by the coast (+12.2%). The *inorganic fertilizer*, on the other hand, shows a significant difference in magnitude for the western region compared to the central and southeastern regions. Based on this evidence, H3A suggesting that the effect of CSA varies across regions is thus possible to confirm for *intercropping* and *inorganic fertilizer* but not for *improved seed* due to insignificant results.

Table 7. Determinants of Agricultural Productivity by Region

	(1) Central	(2) Northwest	(3) Northeast	(4) East	(5) Southeast	(6) West
A: without climate shock						
Intercropping	0.105***	0.258**	0.106**	0.123**	0.066**	0.184**
	(0.162)	(0.172)	(0.480)	(0.254)	(0.162)	(0.168)
Improved seed	0.032	0.328	0.766	0.072	0.041	0.063
	(0.321)	(0.177)	(0.217)	(0.221)	(0.158)	(0.169)
Inorganic fertilizer	0.072***	0.221	0.163	0.270	0.087***	0.609***
	(0.224)	(0.221)	(0.333)	(0.265)	(0.143)	(0.146)
Observations	1,249	1,254	1,432	1, 112	1,249	1, 132
R²	0.1344	0.2391	0.1666	0.1232	0.1542	0.1652
B: with climate shock						
Intercropping	0.021**	0.251**	0.002**	0.121**	0.065**	0.074***
	(0.361)	(0.448)	(0.231)	(0.221)	(0.281)	(0.240)
Improved seed	-0.032	0.327	0.429	-0.021	-0.035	-0.035
	(0.123)	(0.284)	(0.313)	(0.213)	(0.261)	(0.263)
Inorganic fertilizer	0.063**	0.110	0.174	0.123	0.056***	0.112***
	(0.210)	(0.278)	(0.234)	(0.142)	(0.201)	(0.162)
EC controls	Yes	Yes	Yes	Yes	Yes	Yes
SOC controls	Yes	Yes	Yes	Yes	Yes	Yes
PROD controls	Yes	Yes	Yes	Yes	Yes	Yes
INFR controls	Yes	Yes	Yes	Yes	Yes	Yes
CLIMA controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	528	465	675	243	465	379
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R²	0.2285	0.1259	0.231	0.2234	0.2051	0.1889

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

Source: Based on data from NBS (2009,2011)

6.3.2 Agro-ecological zones (AEZ)

As presented previously, this analysis looks at two categories of AEZ: major climatic zones (Table 8) and the country-specific landscape and physiography (Table 9). As in previous sections, panel A shows coefficients *without* climatic shock and panel B *with* climatic shock interactions. Beginning with Table 8 (next page), the findings imply that the efficiency of CSA practices vary between major AEZ. While *improved seed* is not statistically significant, *inorganic fertilizer* has only a statistically significant effect when the method is applied in a tropic-cool/subhumid/humid climatic zones (column 1-2). In contrast, *intercropping* is statistically significant in all four AEZ. The results in Table 8 imply that without a climatic shock (panel A*), intercropping* is positively associated with an average increase of 32 percent in crop yields when utilized in a tropic-warm/subhumid zone. When controlling for a shock (panel B), the magnitude decreases slightly but, still, it remains positively associated. More specifically, farmers applying *intercropping* on the plot under droughts or floods remains 31.6 percent more productive than plots that were not employed to this method.

Inorganic fertilizer shows a similar effect on plots located in AEZ characterized by a tropic-cool/humid climate. Without a climatic shock (panel A), the method is associated with an average increase of 22 percent in crop yields compared to plots where this technique was not utilized. When controlling for climatic shock (panel B), plots subjected to *inorganic fertilization* were, nevertheless, 20.1 percent more productive and thus more resilient when facing extreme weather.

Looking at Table 9, which shows the findings of the landscape-specific AEZ, *improved seed* is not statistically significant in any of the columns. The magnitude of the coefficient, however, implies that the association between the use of *improved seed* and agricultural productivity is positive. Furthermore, *intercropping* is strongly associated with improved crop yields in coastal areas/lowlands/alluvial plains (column 4), while *inorganic fertilizer* shows significant improvements in crop yields located in semi-arid lands at mid-altitude plateaus (column 1). Under normal circumstances (panel A) in coastal areas, *intercropping* is associated with an average increase of 14.6 percent in crop yields compared to plots employed to pure stands (not an intercropped cultivation system). Furthermore, farmers who utilized *inorganic fertilizers* on their plot are on average 52.7 percent more productive than those who did not implement the method. This result applies to AEZ characterized by semi-arid lands and mid-altitude plateaus.

When controlling for the efficiency of *intercropping* and *inorganic fertilization* under climatic shocks (panel B), they remain positively associated with crop yield output. For instance, plots located in coastal and lowland areas and employed for intercropping, the output of the crop yield is still 12.1 percent higher than plots with pure stand (no intercropping system). Similarly, farmers who own plots located in semi-arid land and mid-altitude plateaus, still maintain higher productivity if they use an *inorganic fertilizer*. Hence, using an inorganic fertilizer on the plot under extreme weather is associated with an average increase of 34.6 percent (column 1 panel B) compared to plots where no application was made.

Comparing Table 8 and 9, findings imply that *intercropping* is associated with farmers' resilience and improvements in crop yields when the climate is warm and subhumid (Table 8). This also gives plausible explanations of the impact of *intercropping* on output variation, especially in the coastal/lowland areas (Table 9) and in the eastern region (Table 7). Table 1 shown at the beginning of this thesis, suggest that a warmer climate appears by the coast, in the eastern region, where average temperature is 27 degrees (CIAT & World Bank, 2017). In addition, findings suggest that utilizing *inorganic fertilizers* on the plot are effective on semi-arid lands on mid-altitude plateaus (Table 9) which is characterized by a cool/subhumid climate (Table 8). Based on the findings in Table 8 and Table 9, CSA practices are positively associated with improvements in crop yields in the AEZ mentioned above. Still, no significant effect could be found for *improved seed.*

In conclusion, plots where *intercropping* and *inorganic fertilization* was utilized showed a significant difference in crop yield output when controlling for different AEZ. Additionally, the impact of the two CSA practices remains positively associated with crop yield output even when controlling for climatic shocks. These findings provides further evidence of farmers' resilience and a variation in magnitude when considering physiography and climate conditions. Given this output variation, H3B implying that CSA practices vary across AEZ, are therefore confirmed.

Table 8. Determinants of Agricultural Productivity by AEZ (climate)

	(1) Tropic-cool/ subhumid	(2) Tropic-cool/ humid	(3) Tropic-warm/ subhumid	(4) Tropic-warm/ humid
A: without climate shock				
Intercropping	0.128*	0.021*	0.319***	0.345*
	(0.749)	(0.134)	(0.089)	(0.123)
Improved seed	-	-0.012	0.279	0.325
		(0.121)	(0.217)	(0.234)
Inorganic fertilizer	0.535***	0.219**	0.485	0.024
	(0.133)	(0.123)	(0.104)	(0.123)
Observations	823	415	550	632
R^2 between/(overall)	0.1032	0.1069	0.1827	0.1234
	(0.1081)	(0.1345)	(0.1921)	(0.1275)
B: with climate shock				
Intercropping	0.126*	0.011*	0.316***	0.311*
	(0.361)	(0.123)	(0.376)	(0.153)
Improved seed	-	0.011	0.429	-0.012
		(0.213)	(0.313)	(0.154)
Inorganic fertilizer	0.215**	0.201**	0.315	0.012
	(0.202)	(0.184)	(0.419)	(0.231)
EC controls	Yes	Yes	Yes	Yes
SOC controls	Yes	Yes	Yes	Yes
PROD controls	Yes	Yes	Yes	Yes
INFR controls	Yes	Yes	Yes	Yes
CLIMA controls	Yes	Yes	Yes	Yes
Observations	143	221	122	243
Fixed effects	Yes	Yes	Yes	Yes
R^2 between/(overall)	0.1329	0.3817	0.5021	0.1324
	(0.1211)	(0.3412)	(0.4111)	(0.1324)

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

Source: Based on data from NBS (2009, 2011)
Note: Improved seed did not have any observed values for column (1).

Table 9. Determinants of Agricultural Productivity by AEZ (landscape)

	(1) Semi-arid lands/ Mid-altitude plateaus	(2) Semi-arid lands/ High-altitude plateaus	(3) Arid lands/ Highlands/ Mountains	(4) Coastal areas/Lowlands Alluvial Plains
A: without climate shock				
Intercropping	0.091*	0.144*	0.241**	0.146***
	(0.131)	(0.126)	(0.168)	(0.221)
Improved seed	0.012	-	0.279	0.045
	(0.112)		(0.217)	(0.224)
Inorganic fertilizer	0.527***	0.219*	0.557**	0.137
	(0.141)	(0.123)	(0.191)	(0.331)
Observations	553	415	332	222
R^2 between/(overall)	0.1159	0.1069	0.3111	0.2337
	(0.1134)	(0.1345)	(0.3022)	(0.2211)
B: with climate shock				
Intercropping	0.032*	0.051*	0.031*	0.121***
	(0.271)	(0.323)	(0.123)	(0.241)
Improved seed	-0.023	-	0.092	0.012
	(0.211)		(0.021)	(0.111)
Inorganic fertilizer	0.346***	0.221*	0.061*	-0.012
	(0.202)	(0.143)	(0.124)	(0.132)
EC controls	Yes	Yes	Yes	Yes
SOC controls	Yes	Yes	Yes	Yes
PROD controls	Yes	Yes	Yes	Yes
INFR controls	Yes	Yes	Yes	Yes
CLIMA controls	Yes	Yes	Yes	Yes
Observations	95	121	104	52
Fixed effect	Yes	Yes	Yes	Yes
R^2 between/(overall)	0.1756	0.4532	0.1112	0.1423
	(0.1724)	(0.4421)	(0.1123)	(0.1422)

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

Source: Based on data from NBS (2009, 2011)
Note: Improved seed did not have any observed values for column (2).

6.3.3 Crops

The efficiency of the three CSA practices was tested for seven food crops, highlighted by FAO (Rioux et al. 2017) as important crops for Tanzanian food security. This is also food crops with low productivity per yield measured in kg/acre (CIAT & World Bank, 2017). The results are presented in Table 10 and suggest that given CSA practices generally improve agricultural productivity when these crops are cultivated. When controlling for climatic shock (panel B), the CSA practices remain positively associated with several crop yields, although its impact varies between crops.

Primarily, *intercropping* is positively associated and show a strong effect on crop yield output where sunflowers and bananas are cultivated. More specifically, without climatic shock in panel A, the results suggest that plots subjected to *intercropping* are positively associated with an average increase in sunflower and banana yields by 22.5 and 12.1 percent, respectively, compared to plots using pure stand. Noteworthy, when controlling for climatic shocks in panel B, findings suggest that plots using an *intercropped* system on the banana crop are even likely to increase their productivity under periods of droughts and floods, by 0.04 percentage points. Hence, under climatic shocks, the banana yield is on average 12.5 percent more productive than plots that did not cultivate the bananas in an *intercropped* system.

Furthermore, the results imply that *improved seed* has a significant effect on maize and sunflower output. The magnitude of the coefficients is, nevertheless, negatively associated with maize output, regardless of the climatic situation. While *improved seed* for maize is negatively associated with maize output under normal circumstances (with an average decrease of 0.7 percent in maize yield output), *improved seeding* is positively associated to the yield output when cultivating sunflower (with 2.3 percent). When controlling for a climatic shock, the magnitude for the maize yield remains negatively associated, while farmers cultivating sunflowers using *improved seeding* is on average 1.1 percent more productive than farmers who used traditional sunflower seeds.

Applying *inorganic* fertilizer on the plot during normal circumstances (no climatic shock), the results imply that the practice is efficient when utilized on the maize and the paddy. More specifically, the practice is associated with an average increase of 9.8 percent (maize) and a 64.6 percent (paddy) compared to plots with no application of this technique. When controlling for a climatic shock (panel B), the association remains positive and significant for the maize yield while the impact on the paddy yield becomes statistically insignificant.

Given the results, CSA practices is positively associated with improvements in the maize, beans, paddy, sunflower, and banana yield. Significant results could, however, not be found for sorghum and cassava. While *intercropping* is positively associated with crop yield output for the cultivation of banana and sunflower, *improved seed* is associated with improvements in the output yield of the sunflower. In contrast, *inorganic fertilizer* seems to improve agricultural production in plots where maize is grown compared to farmers cultivating maize with other techniques (e.g. organic fertilizer). Due to this output variation of the crops mentioned, the H3C is accepted, suggesting that CSA practices is associated with different effects across crops. Still, this finding is only confirmed for the crops with significant coefficients, namely, maize, beans, paddy, sunflower, and banana.

Table 10. Determinants of Agricultural Productivity by crops grown

	(1) Maize	(2) Beans	(3) Paddy	(4) Cassava	(5) Sunflower	(6) Sorghum	(7) Banana
A: without climate shock							
Intercropping	0.018**	0.066**	0.033	0.453	0.225**	0.324	0.121**
	(0.221)	(0.432)	(0.444)	(0.231)	(0.128)	(0.134)	(0.112)
Improved seed	-007**	-0.178	0.254	0.042	0.023**	-0.032	-
	(0.222)	(0.177)	(0.276)	(0.212)	(0.125)	(0.231)	
Inorganic fertilizer	0.098**	0.225	0.646***	0.562	0.112*	0.023	-
	(0.213)	(0.342)	(0.332)	(0.351)	(0.421)	(0.363)	
Observations	839	332	312	101	105	212	99
R^2	0.5222	0.4435	0.1562	0.1543	0.1123	0.1562	0.1234
within/(overall)	(0.0111)	(0.2121)	(0.2222)	(0.2162)	(0.2211)	(0.2222)	(0.1232)
B: with climate shock							
Intercropping	0.017**	0.021*	0.011	0.012	0.201***	0.031	0.125**
	(0.361)	(0.111)	(0.234)	(0.443)	(0.651)	(0.432)	(0.123)
Improved seed	-0.266**	-0.165	0.245	0.035	0.011**	-0.213	-
	(0.123)	(0.284)	(0.273)	(0.321)	(0.125)	(0.125)	
Inorganic fertilizer	0.031***	-0.651	-0.214	-0.231	0.111*	0.013	-
	(0.259)	(0.129)	(0.236)	(0.221)	(0.671)	(0.432)	
EC controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SOC controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PROD controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
INFR controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
CLIMA controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	221	86	62	56	38	25	15
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.3712	0.4312	0.3241	0.2612	0.2651	0.2451	0.2712
between/(overall)	(0.2221)	(0.1321)	(0.3298)	(0.1121)	(0.2351)	(0.2512)	(0.221)

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

Source: Based on data from NBS (2009, 2011)

Note: Improved seed and inorganic fertilizer did not have any observed values for column (7).

7 Discussion

This chapter aims to discuss the results presented in the previous section. This will be done by relating the empirical results to the literature and further analyze the research question: *Can differences in agricultural productivity be explained by CSA?*. To facilitate the discussion, the results are analyzed separately in subsections related to each of the three hypotheses.

7.1 Agricultural productivity increases when CSA practices are implemented

Similar to previous literature, this study provides evidence of the general efficiency of CSA practices in improving crop yield output (Arslan et al. 2015; Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998). Like the study by Pretty et al. (2006) and Branca et al. (2011), this analysis has further proven that intercropping, inorganic fertilization, and improved seeding are positively associated with an increase in agricultural productivity (kg/acre). All three CSA practices are positively associated with crop yield output, although intercropping and inorganic fertilization show a stronger significant effect than improved seeding. Specifically, intercropping and inorganic fertilization is associated with an average increase of 54 and 59 percent in crop yields, respectively. The magnitude of improved seeding is associated with an average increase of 6.7 percent. This finding contradicts Pretty et al. (2006) and Branca et al. (2011) and proves the necessity of taking the local context into account. While these studies, with a regional focus across SSA, confirmed a strong significant impact of improved seeding, this case study show a less strong magnitude of this CSA practice in Tanzania.

The study by Lal (2009) suggests that CSA requires lower labor inputs, gives farmer support through extension services, and outlines long-term plans for land management through stabilized off-farm incomes, education, and financial instruments. Along similar lines, this thesis further confirms that socioeconomic and economic factors such as labor availability, age of the household head, and financial stability play a key role in increasing yield output. In Table 4, off-farm income, assets owned, and plot value was positively associated with output. This imply that plots owned by farmers with higher financial security give them more liquidity in making high-risk decisions in innovative technologies such as CSA, as suggested by Clay et al. (1998) and Reardon et al. (1994). Furthermore, labor insensitivity on the plot and age of the household head plays a significant role in agricultural productivity, as highlighted by Nelson and Phelps (1966). They suggest that older farmers take long-term decisions due to their life experience in facing harvest losses. Finally, as in Ragasa et al. (2013), this thesis confirms that female heads are less productive due to income differences and limited access to extension services. In general, chosen covariates showed significant impacts on crop yield output and were essential to include in order to understand other factors influencing crop yield output. In conclusion, given that CSA practices proved their efficiency in increasing productivity, especially under normal circumstances, H1 suggesting that agricultural productivity increases when CSA practices are implemented was therefore accepted.

7.2 Farmers utilizing CSA practices are more resilient to climatic shocks

As previously mentioned, the key to the current debate is to understand the extent to which CSA practices explain differences in farmers' productivity and resilience to climatic shocks. Findings suggest that CSA practices are not only associated with greater productivity which several scholars have confirmed (Arslan et al. 2015; Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998). However, they are further associated with greater output resilience since the output of the plot remained positive and varied less, even under periods of unexpected climatic shocks. Arslan et al. (2015) concluded that inorganic fertilizers and improved seeding are sensitive to weather changes, but improved seeding proved efficient in maintaining a smaller output variation. In contrast, this study found no significant result for improved seeding in any of the climatological interactions. Instead, findings imply that farmers utilizing intercropping and inorganic fertilization experienced a smaller decrease in crop yield output when controlling for climatic shocks, compared to plots that were not employed to these techniques.

Given the findings in Table 6 and in Figure 7, it is possible to see a pattern and, therefore, confirm the H2 that farmers utilizing CSA practices are more resilient to climatic shocks. However, since the finding in this paper contradict the results presented in Arslan et al. (2015) which examined Zambia, testing for local conditions proved to be essential due to these contradicting results. While improved seed is efficient in Zambia, according to Arslan et al. (2015), it does not necessarily mean that it is beneficial for increasing productivity in Tanzania. In order to understand this further, geographical controls were performed to test H3A-C. These findings will be discussed below.

7.3 The effect of the given CSA practices varies across regions, AEZ and crops

To contribute to previous literature, climatic controls were applied to regions, AEZ, and crops. Since differences in crop yield output under normal circumstances and differences in output variation under periods of shocks could be found, H3A-C[15] were confirmed. Intercropping was positively associated with crop yield output in areas where the climate is tropic-warm/humid/subhumid with higher temperatures. This finding is also confirmed within the literature, highlighting intercropping as the most efficient CSA method to apply under droughts due to its protection of shallow-rooted crops sensitive to severe sunlight (Zaefarian & Rezvani. 2016). The results in Table 10, imply that intercropping is especially effective for banana yields. More specifically, farmers cultivating bananas in an intercropping system can remain 12.5 percent more productive than farmers cultivating bananas without this technique. This finding provides plausible explanations for the positive associations in the following three tables: the eastern region (Table 7), which is characterized by a tropic-warm/subhumid/humid climate (Table 8), that usually appear in coastal and lowland areas (Table 9). Furthermore, these three factors (eastern region, tropic-warm climate, and coastal/lowland zone) are according to CIAT & World Bank (2017) and Rioux et al. (2017) also

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[15] See section 6.3 which tested H3A-C:
H3A) Regions: The magnitude when applying inorganic fertilizers on the plot is especially strong for the western region (+11.2%) while intercropping shows a strong impact for the northwestern and southeastern region (+12.1 and +6.3 %, respectively).
H3B) AEZ: Farmers applying intercropping on the plot sees an increase of 30% in crop yields in warm/subhumid/humid AEZ (often by the coast). Applying inorganic fertilizers increases crop yields by 21.5 % in cool/subhumid climate (often mid-altitudes).
H3C) Crops: Intercropping improves especially banana (+12.5%) and sunflower yields (+20.1%), inorganic fertilizer improves the maize yield (+3.1%) and improved seed the sunflower yield (+1.1%)

circumstances which provide desirable conditions for cultivating bananas. Hence, there is a read thread of which circumstances intercropping is beneficial. As shown in Table 1, bananas are usually cultivated in coastal areas where average temperatures are higher. Since intercropping is highlighted to be an efficient method to use under droughts, the magnitude of this effect may, therefore, be reflected through the intercropping coefficient for the banana yield in Table 10.

Another interesting finding was the different impacts of intercropping on the western and the eastern region. The literature suggests that intercropping tends to be less efficient when applied in areas where farmers rely on rainfed agriculture (CIAT & World Bank, 2017; Rioux et al. 2017; Arslan et al. 2015). When a climatic shock is controlled for in Table 7, farmers applying intercropping systems on their plot experienced a higher output variation in the western region than in the eastern region. A plausible explanation is that the western region has a rainfall distribution of 800-1200 mm per year compared to 400-800 mm per year in the eastern region, as shown in Table 1 (CIAT & World Bank, 2017). Thus, since the rainfall distribution is twice as big in the western region, intercropping is potentially less efficient to apply on these plots. The cultivation system in the western region relies primarily on methods applicable on moisture land – such as the inorganic fertilization technique (Rioux et al. 2017). Still, intercropping remain positively associated with crop yield output in both the western and the eastern region.

In contrast, inorganic fertilization, is positively associated and shows a strong magnitude when applied in tropic-cool/subhumid climate, usually in the mountains in the central, northwestern, and western regions. These regions and AEZ are characterized by a higher rainfall distribution and moisture land, as suggested by Miller (2018). During climatic shocks, the results in Table 7 imply that the method has a substantial impact on the inland areas around the western region. Plots subjected to this method in the western region are associated with an average increase of 11.2 percent in crop yields compared to plots using other techniques. Hence, given the results in Table 7, it is possible to confirm that intercropping is associated with improvements in crop yield output mainly the eastern region, where the temperature is higher and the rainfall distribution lower. Inorganic fertilization, on the other hand, is associated with improvements when utilized on plots located in the western areas where rainfall distribution is higher and where land is moisture.

Nevertheless, based on the weather projections of 2050 provided in Figure 5, an interesting parallel should be made for the western region and the impact of inorganic fertilization. In the figure, CIAT and World Bank (2017) suggest that temperature in the western region will rise by +1.9°C in the upcoming 30 years. This rise will be the highest in the country, a worrying trend since farmers in this area is dependent on rainfed agriculture, as stated in the previous paragraphs. Although inorganic fertilization is positively associated with crop yield output in the western region, this impact might potentially change if the weather projections become a reality. Based on the findings, intercropping is highlighted as the most efficient method to utilize during droughts (Zaefarian & Rezvani (2016), therefore, it is possible that farmers in the western region will have to adapt intercropping rather than inorganic fertilization in the future to become resilient to extended droughts and temperature rising.

On the other hand, the literature also highlights the inorganic fertilizer as a suitable method for increasing the minerals of the crop, which in turn, makes the root more resilient to prolonged periods of droughts (Miller, 2018). The evidence in Table 7 suggest that inorganic fertilizer is associated with an average increase of 60 percent in crop yield (in the western region) under normal circumstances. Farmers facing drought or floods in the western region are still on average 11.2 percent more productive if they use an inorganic fertilizer. Based on Miller (2008) and the findings in Table 7 suggesting that inorganic fertilizer has a positive impact on crop yield output, even when controlling for climatic shocks, it might, nonetheless, be an efficient method to apply in 2050 regardless of current projections.

Further, this paper has provided essential insights regarding the impact of CSA on specific crops grown. As shown in Table 2 at the beginning of this paper, inorganic fertilization was mainly applied to plots growing of maize, during the sample period (2008-2011). During normal circumstances, Table 10 showed that it is a method associated with improvements in the maize yield output, by an average increase of 9.8 percent compared to plots where it was not employed. A potential explanation regarding this is that maize requires an integrated soil fertility management to be productive and is further a crop grown in areas with moisture land, as highlighted by CIAT & World Bank (2017). As discussed by Rioux et al. (2017), maize requires stable precipitation during the two rain seasons (the "long rains" from March to May and the "short rains" from November to December). While maize is cultivated in many areas in Tanzania, despite bad soil quality (URT, 2009; CIAT & World Bank, 2017), findings in this thesis imply that farmers applying inorganic fertilization on their plot experience a smaller output variation for maize, even under climatic shocks. To improve the production of maize, inorganic fertilization might, therefore, be a useful technique, especially when facing the current agricultural yield gap in Tanzania (CIAT & World Bank, 2017).

While improved seed was negatively associated with improvements of the maize output, findings suggest that it is an efficient CSA practice to apply on the cultivation of sunflowers. This is further supported by CIAT and World Bank (2017) and Rioux et al. (2017), which confirm the use of drought-resistant varieties and improvements in sunflower yields under periods of climatic shocks. Although improved seed showed no significant effect when controlling for regions and AEZ, it showed its potential for improving the sunflower yield.

When analyzing the findings in this paper, explanations for the differences in magnitudes of given CSA practices have been supported through relevant literature. The site-specific climate, the physiography, the economic, socioeconomic, production-specific, or infrastructural situation of the farmer have been considered when testing these differences. As the results in this paper suggest which also adds up to previous debate, plots where CSA practices are being used generally remain more productive than plots that were not subjected to CSA. Therefore, CSA practices are not only associated with greater productivity, they are also associated with greater output resilience. This effect also seemed to vary when considering region, AEZ, or crops grown – a finding which could partly be supported by Arslan et al. (2015).

8 Concluding remarks

Using Tanzania as a case study, an SSA country that faces stagnation due to an agricultural yield gap, this thesis has provided insight into three CSA practices and their potential in increasing agricultural productivity. The results confirm the findings within the literature such as Pretty et al. (2006), Branca et al. (2011) and Arslan et al. (2015), arguing that CSA practices are positively associated with agricultural production. Applying intercropping or inorganic fertilization on the plot is strongly associated with this increase, while improved seeding shows a weaker impact when controlling for other covariates. This finding contradicts Arslan et al. (2015), which found no significant effect for intercropping while improved seed was strongly linked to productivity in Zambia. Therefore, climatic shocks and geographical controls taking the local conditions into account proved necessary when examining differences in CSA practices within the Tanzanian context.

Findings show that productivity decreased less in plots where CSA techniques were employed as farmers who practiced intercropping or inorganic fertilization experienced smaller output variation during droughts or floods. No significant results were, however, found for improved seeding. Significant results for improved seeding were only found for improvements in the sunflower yield.

Findings also suggest that intercropping are associated with greater output resilience when implemented in AEZ characterized by tropic-warm/subhumid climate. This result gave a plausible explanation of why farmers cultivating banana yield in the eastern region, in coastal areas, benefitted from using intercropping. The eastern region sees higher temperatures while banana production remains stable when the crop is intercropped with leguminous shallow-rooted crops that need severe sunlight protection under droughts.

In contrast, farmers utilizing inorganic fertilization on their plot face significant improvements, particularly in the western parts of the country in AEZ with mid-altitude plateaus and semi-arid lands where the climate tends to be tropic-cool/subhumid. Further, the application of inorganic fertilizers was linked to improvements in the maize yield. Plots cultivating maize while applying inorganic fertilization are generally more productive under climatic shocks than plots that were not employed to this technique.

Finally, this study has contributed to the body of literature by providing insights into the differences in CSA practices on higher granularity. This has allowed the study to delve into the plot level, overcoming challenges associated with multiplot and heterogeneous households. Additionally, highlighting the farmers-perspective, accounts for various factors such as non-farm activities, female heads, and plot distance to major roads. This study includes valuable insights about the farmers' livelihoods, contributing to policymakers' necessary understanding of local conditions of the individual. To do so, a micro-level analysis and the examination of specific CSA practices give guidelines on how to design efficient policies able to target differences in physiography, soil quality, weather changes, plot location, and other variations between farmers' households.

Alongside the overall remarks, it is essential to remember that these findings might be influenced by several other factors that were considered, including the differences in human capital, economic stability, and access to the market demand (e.g. plot distances to major roads, agricultural markets, or major cities). Given that CSA practices have proven their general efficiency in increasing agricultural productivity and resilience among small-scale farmers in Tanzania, this study has confirmed that this impact varies when controlling for regions, AEZ, and crops. CSA is site-specific and thus cannot be generalized across an entire country. Still, multiple other factors can explain this variation, especially when considering the consequences of climate change. Other measures such as improved water systems, harvest storage possibilities, extension services and timely weather information for farmers needs to complement CSA methods. After discussing the findings in this thesis it is clear that open questions remain. Differences in agricultural productivity could be confirmed and that it did pay to adopt CSA practices within certain regions and AEZ, even under climatic shocks. The magnitude of this effect and the extent to which it can be associated with itself should, however, be investigated by future research when improved data is accessible.

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Appendix A: Tables

Appendix A.1: P-value two-sample t-test for selected covariates

Variables	Intercropping (Intercropped vs Pure Stand)	Improved Seed (Improved vs Traditional)	Inorganic Fertilizer (Application vs No Application)
Dependent variable			
Agricultural productivity	0	0	0
Economic factors			
Land size	0.003	0	0
Off farm income	0	0.018	0.395
Value plot	0	0.4338	0.118
Socioeconomic factors			
Sex	0.1497	0.0002	0.0001
Age head	0.0307	0.1188	0.0112
Infrastructural factors			
Plot distance major road	0	0	0
Climatological and agro-ecological factors			
Shock (length)	0	0.0953	0

Appendix A.2: Balancing Test, Treatment = Cropping system

Variables	Treated	Control	%bias	t-test	V(T)/ V(C)
Economic factors					
Land size	.125	0.092	4.1	0.38	0.72*
Off farm income	.131	0.082	2.1	0.32	0.59*
Value plot	0.135	0.178	3.1	0.52	0.05*
Socioeconomic factors					
Sex	.223	.218	1.2	0.12	.
Age head	48.309	48.691	-2.6	-0.24	0.83
Infrastructural factors					
Plot distance major road	1.796	.092	-6.7	-0.67	2.59*
Climatological and agro-ecological factors					
Shock (length)	5.893	5.821	4.2	0.42	1.12

*if variance ratio outside [0.75;1.33]

Ps R2	Mean Bias	MedBias	%Var
0.006	3.6	4.1	30

Appendix A.3: Balancing Test, Treatment = Improved Seed

Variables	Treated	Control	%bias	t-test	V(T)/ V(C)
Economic factors					
Land size	.109	.135	-2.8	0.53	0.90
Off farm income	0.141	0.134	2.1	0.32	0.59*
Value plot	0.165	0.178	4.1	0.62	1.01
Socioeconomic factors					
Sex	.228	.218	1.2	0.12	.
Age head	49.056	49.691	-0.6	-0.14	0.83
Infrastructural factors					
Plot distance major road	1.796	2.092	-6.7	-0.62	2.59*
Climatological and agro-ecological factors					
Shock (length)	5.893	5.821	4.2	0.42	1.12

*if variance ratio outside [0.87;1.15]

Ps R2	Mean Bias	MedBias	%Var
0.001	2.4	2.6	33

Appendix A:4: Balancing Test, Treatment = Inorganic fertilizer

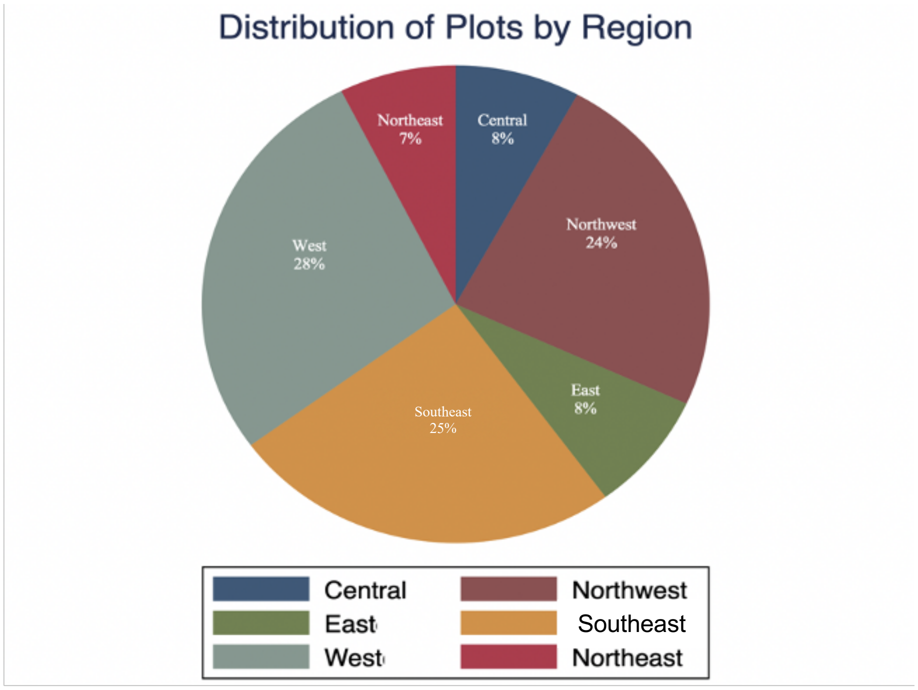
Variables	Treated	Control	%bias	t-test	V(T)/ V(C)
Economic factors					
Land size	.129	.035	4.1	0.38	0.90
Off farm income	0.141	0.134	2.1	0.32	0.59*
Value plot	0.165	0.158	4.1	0.62	1.01
Socioeconomic factors					
Sex	.268	.278	-0.9	0.17	.
Age head	49.056	49.691	-0.6	-0.14	0.83
Infrastructural factors					
Plot distance major road	2.796	2.092	-0.7	-0.12	1.59*
Climatological and agro-ecological factors					
Shock (length)	5.893	5.821	4.2	0.42	1.12

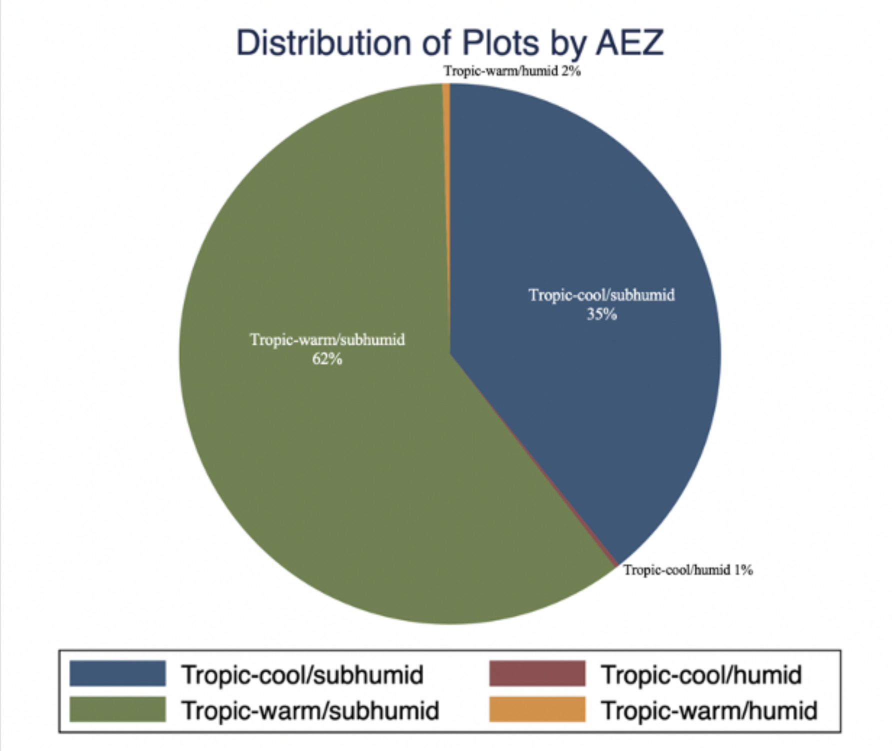
*if variance ratio outside [0.75;1.33]

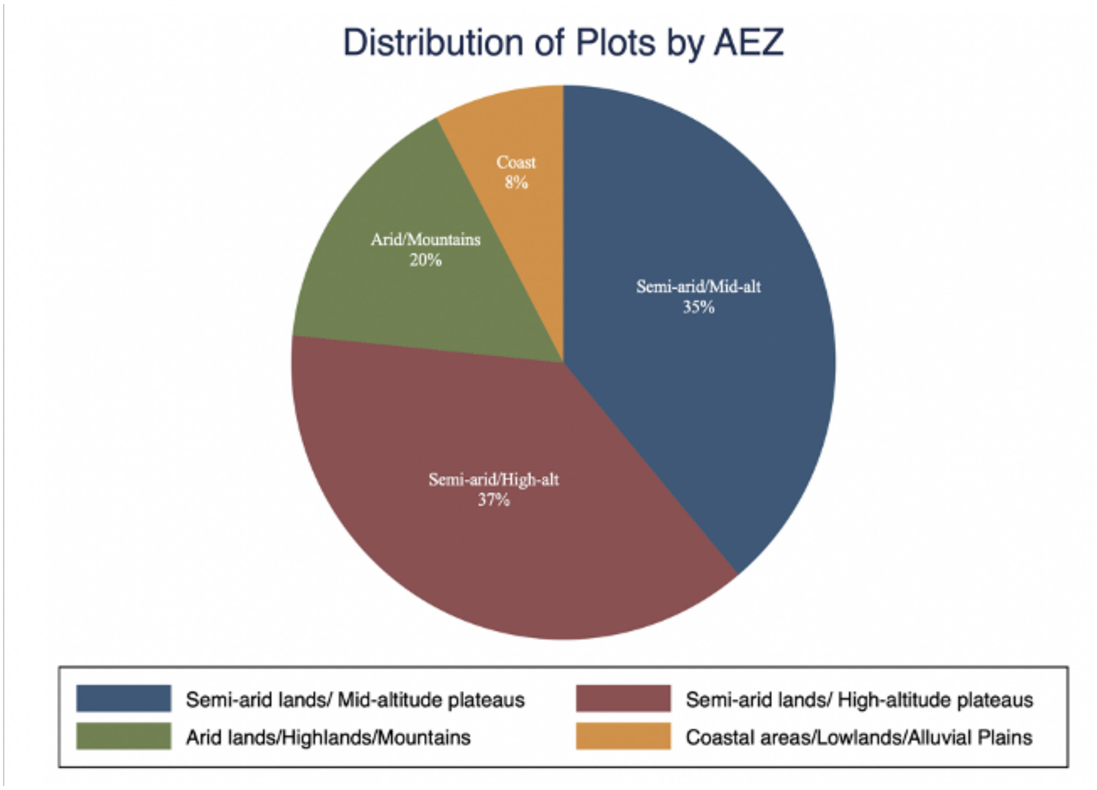
Ps R2	Mean Bias	MedBias	%Var
0.006	3.6	4.1	37

Appendix B: Figures

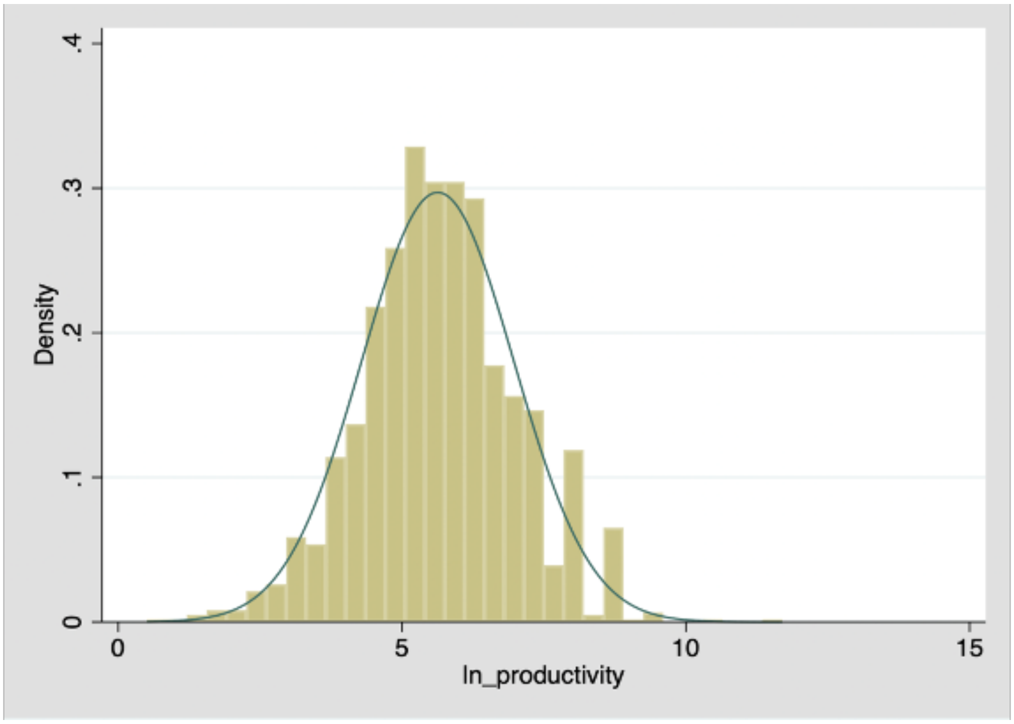
Appendix B.1: Sample Distributions (by region, AEZ)



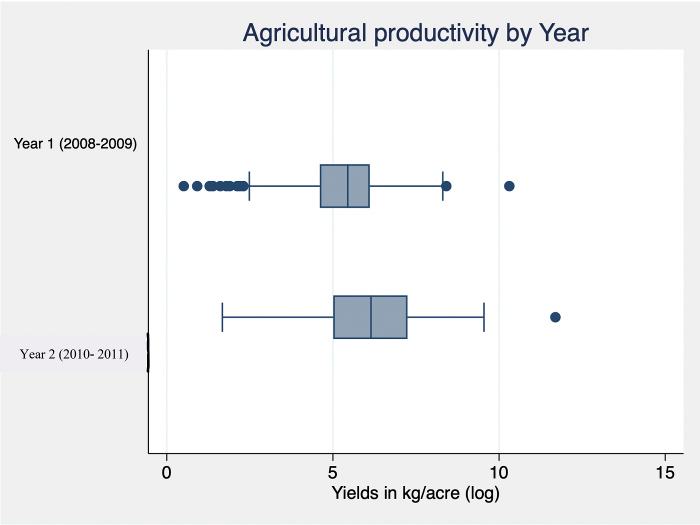


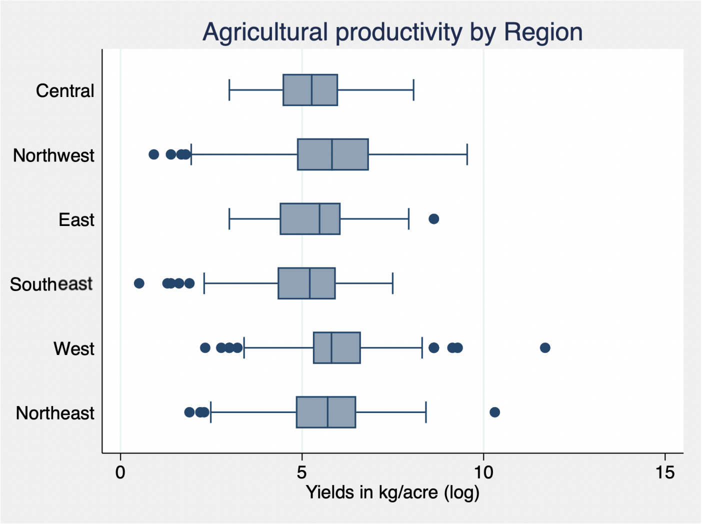


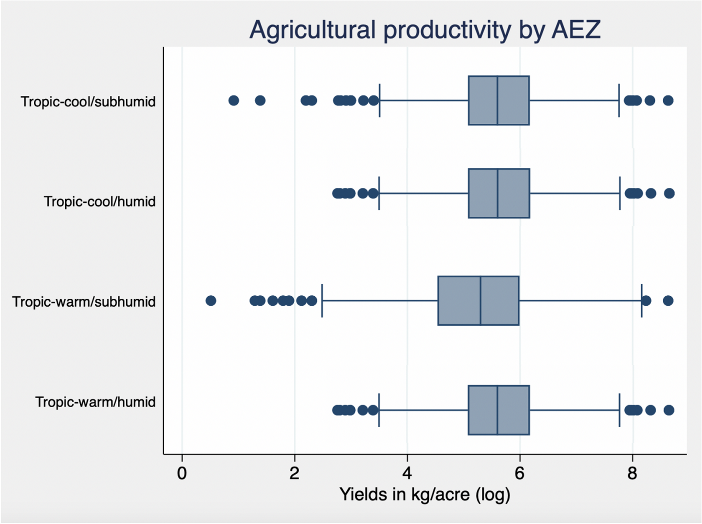
Appendix B.2: Distribution of dependent variable (ln_productivity)

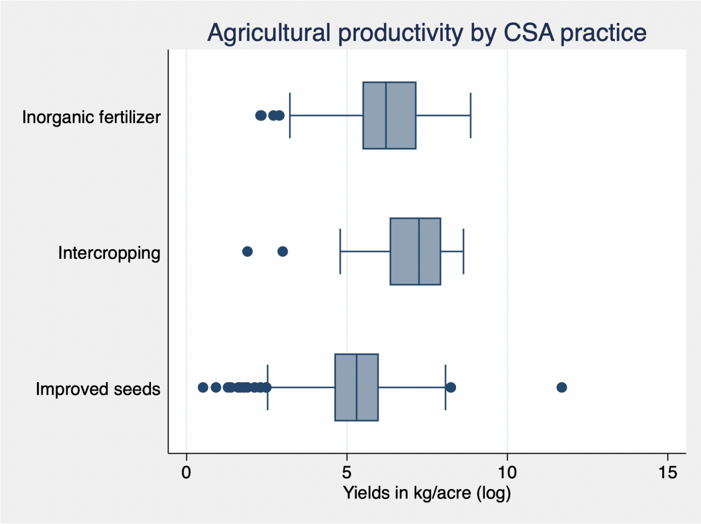


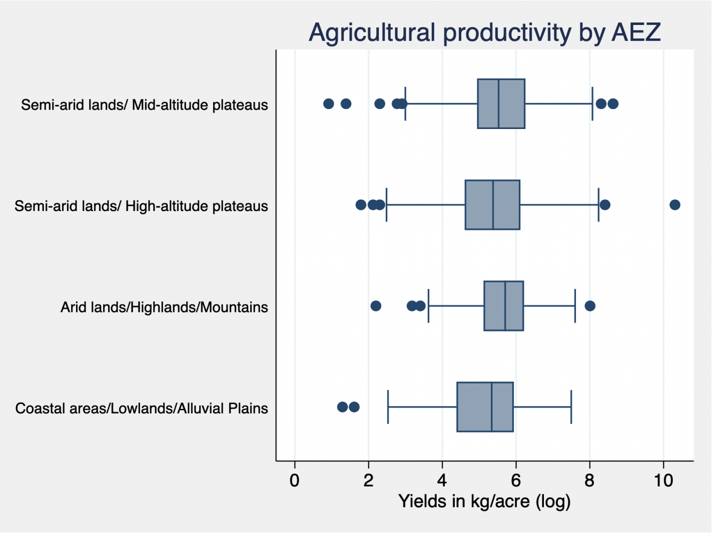
Appendix B.3: Boxplots of Agricultural Productivity

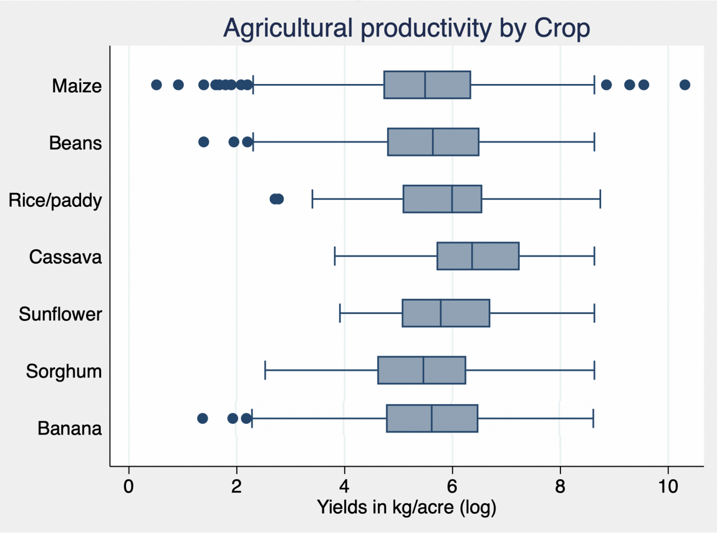




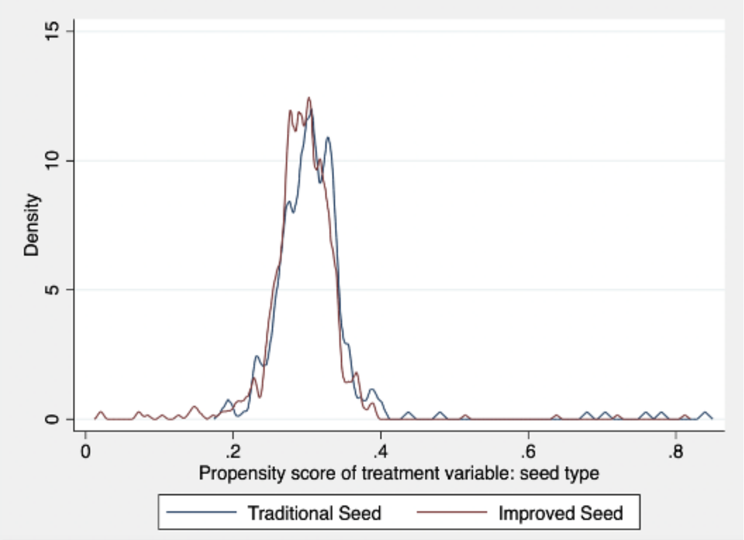


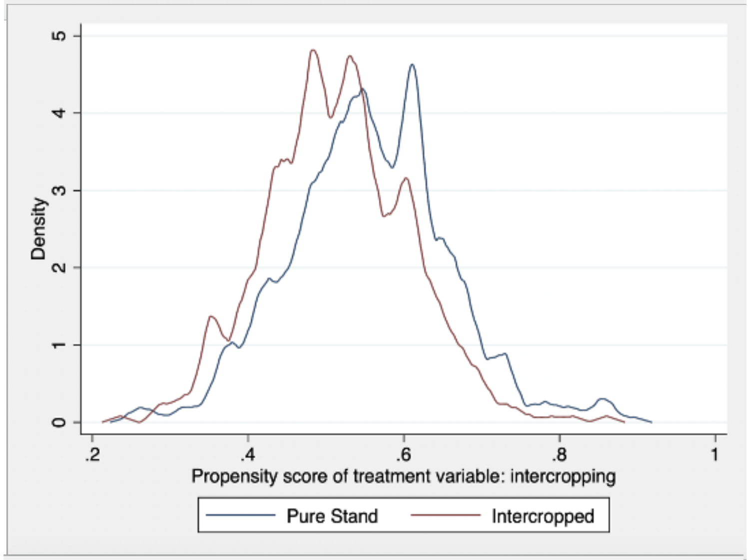


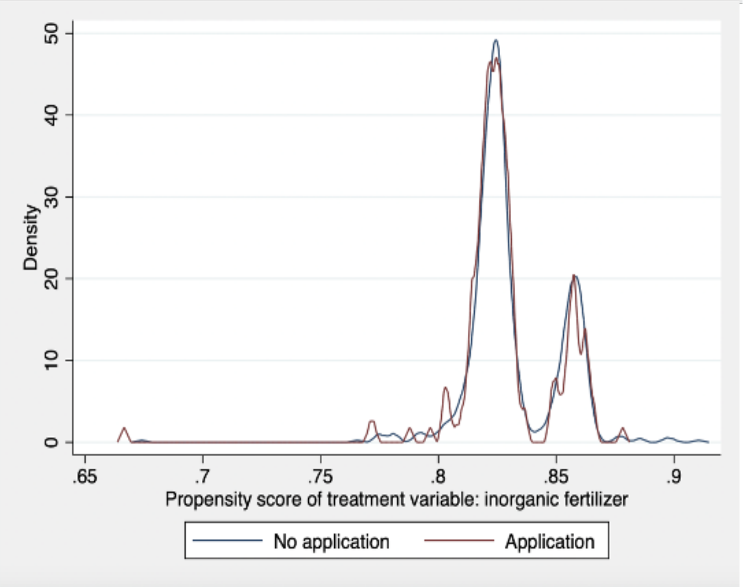

Agricultural productivity by AEZ
Semi-arid lands/ Mid-altitude plateaus
Semi-arid lands/ High-altitude plateaus
Arid lands/Highlands/Mountains
Coastal areas/Lowlands/Alluvial Plains
0
2
4
6
8
10
Yields in kg/acre (log)


Agricultural productivity by Crop
Maize
Beans
Rice/paddy
Cassava
Sunflower
Sorghum
Banana
0
2
4
6
8
10
Yields in kg/acre (log)

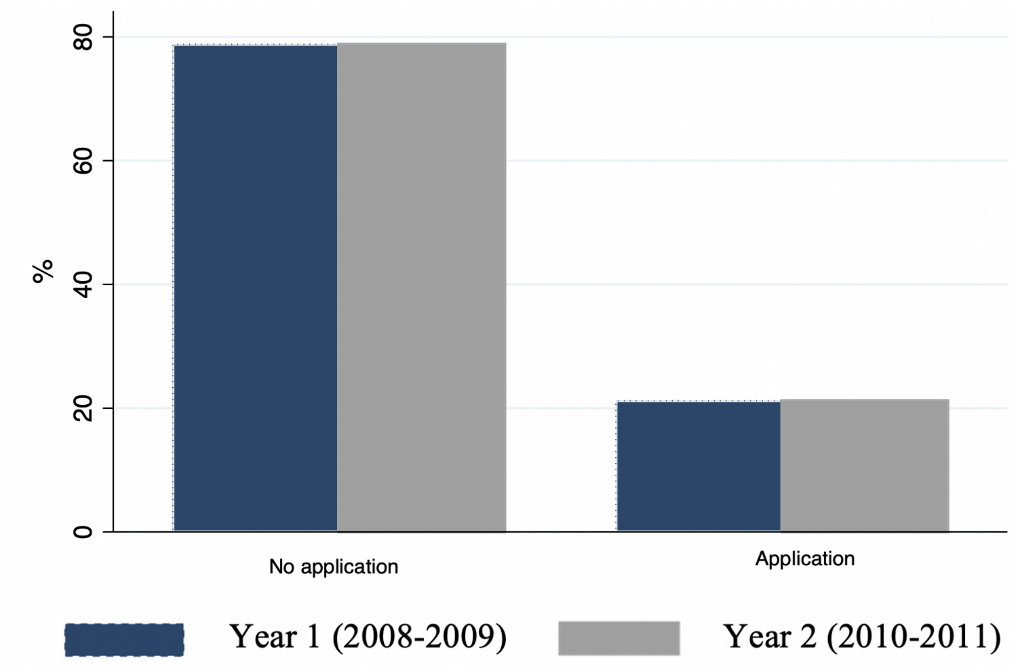
Appendix B.4: Test of Overlap Assumptions



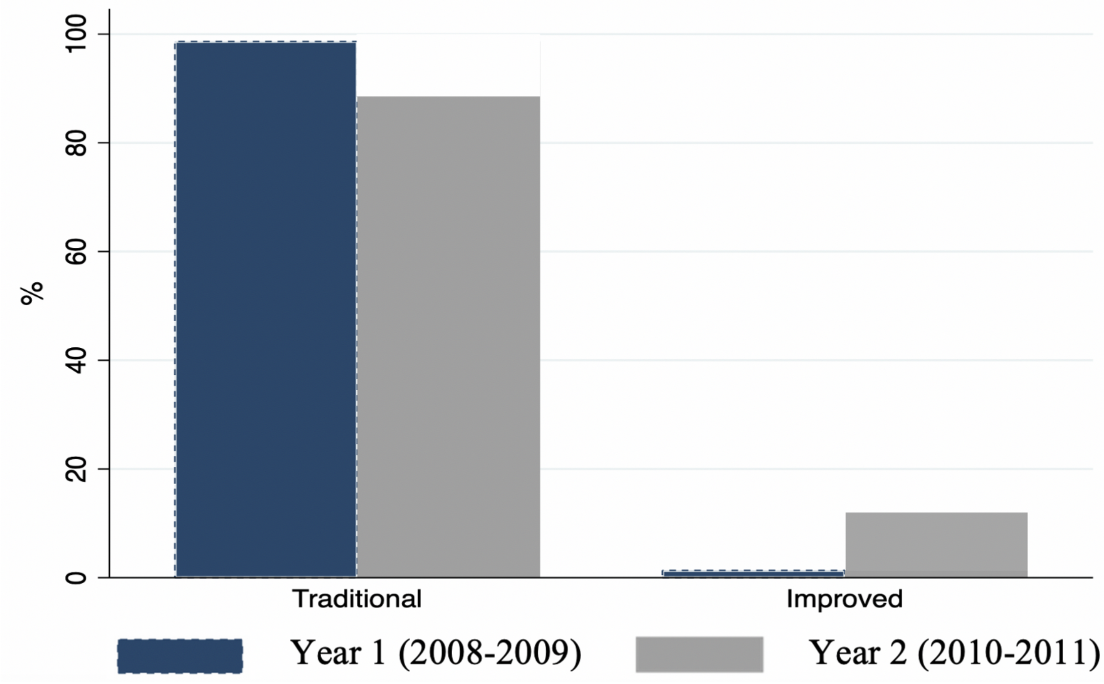




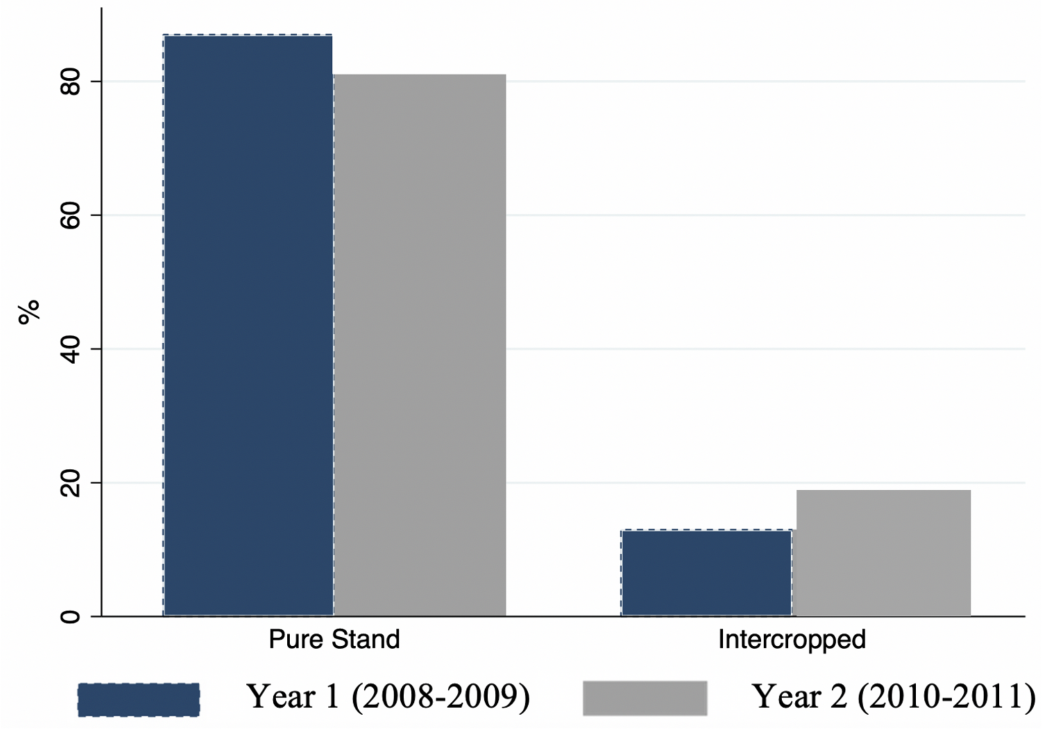
Appendix B.5: Application of Inorganic Fertilizer, in percent between year 1 (2008-2009) and year 2 (2010-2011)



Appendix B.6: Type of seed used, in percent between year 1 (2008-2009) and year 2 (2010-2011)

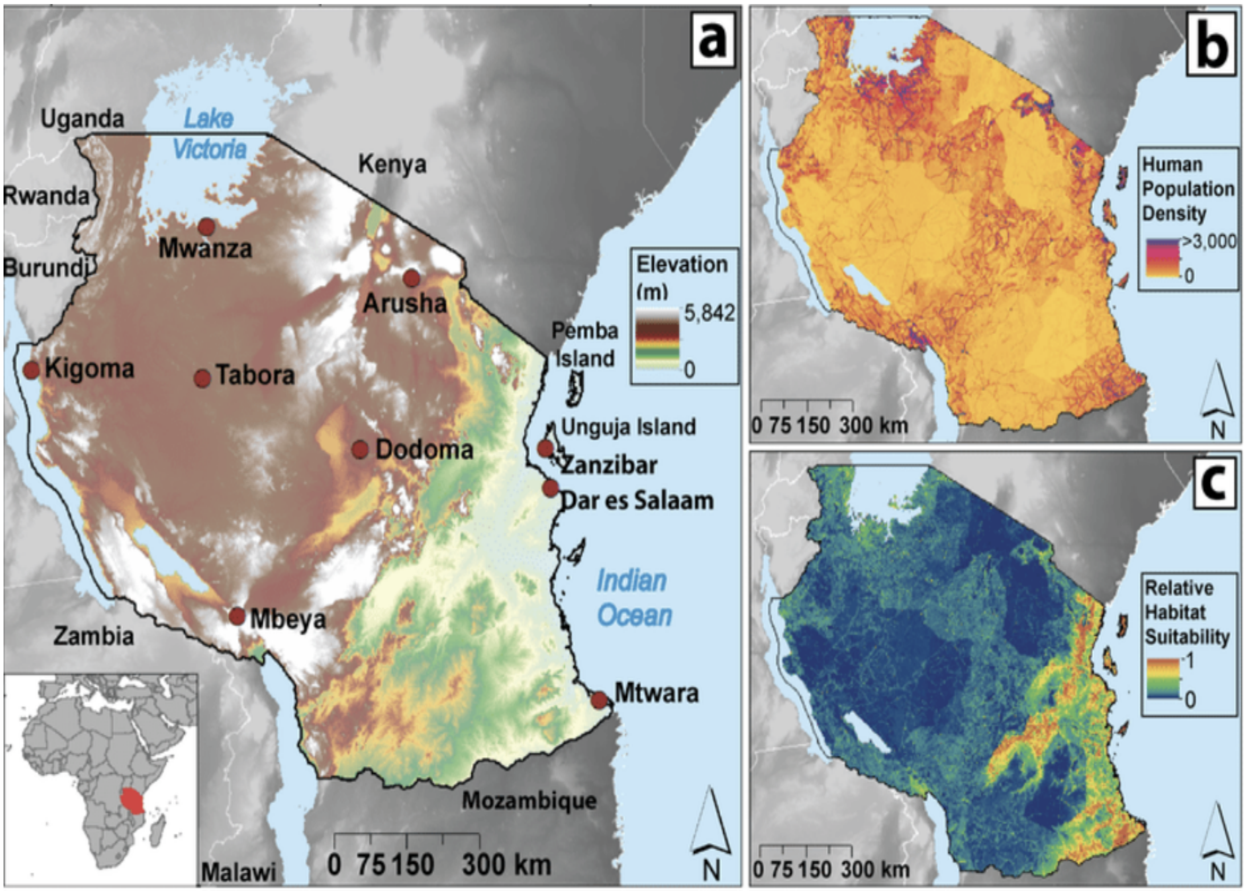


Appendix B.7: Cropping system used, in percent between year 1 (2008-2009) and year 2 (2010-2011)

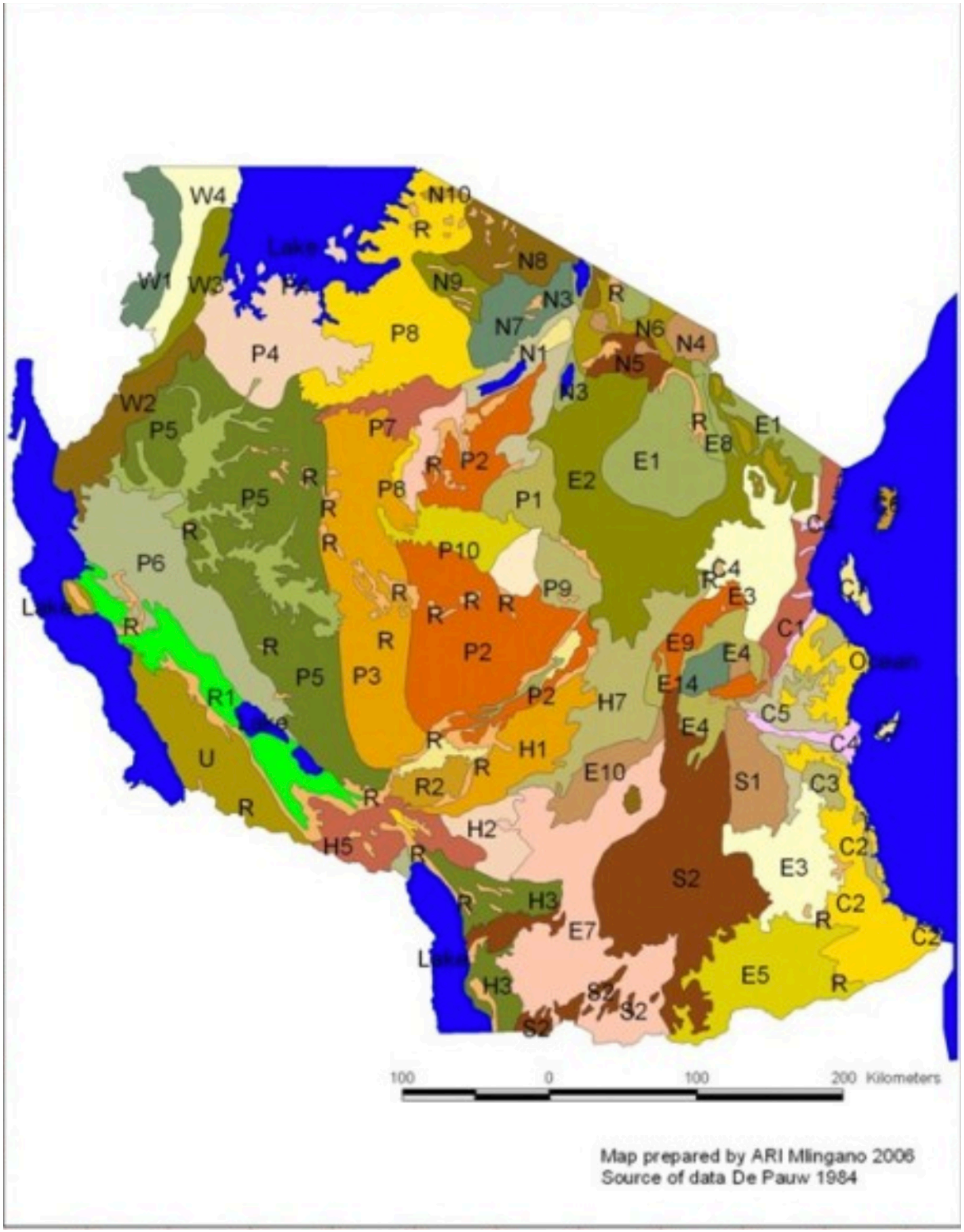


Appendix C: Maps

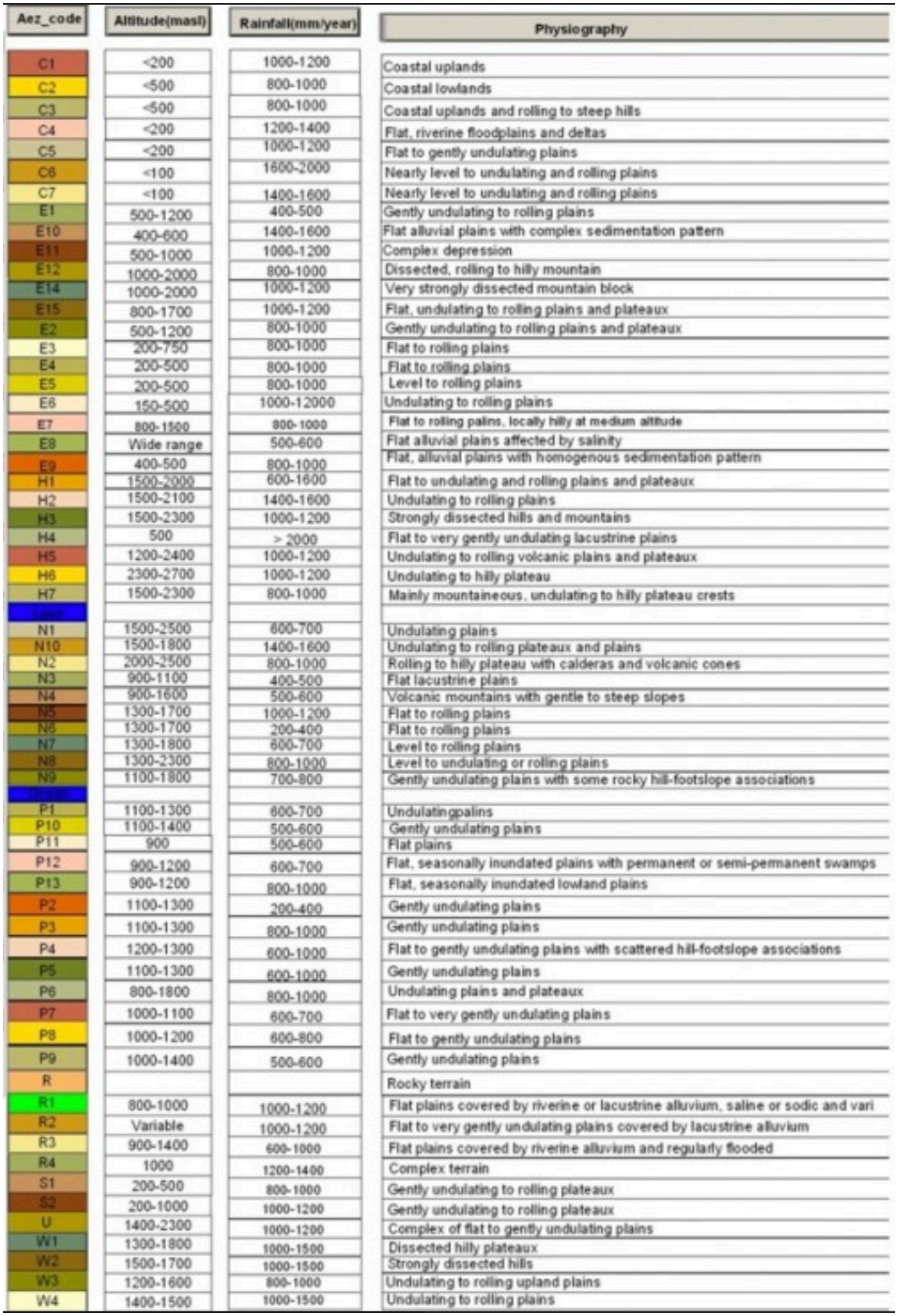
Appendix C.1: Elevation, human population density and habitat suitability in Tanzania (Source: Ardö and Yengoh, 2020)



Appendix C.2: Agro-ecological zones - detailed map (Source: De Pauw, 1984)



Map prepared by ARI Mlingano 2006
Source of data De Pauw 1984



Aez_code	Altitude(masl)	Rainfall(mm/year)	Physiography
C1	<200	1000-1200	Coastal uplands
C2	<500	800-1000	Coastal lowlands
C3	<500	800-1000	Coastal uplands and rolling to steep hills
C4	<200	1200-1400	Flat, riverine floodplains and deltas
C5	<200	1000-1200	Flat to gently undulating plains
C6	<100	1600-2000	Nearly level to undulating and rolling plains
C7	<100	1400-1600	Nearly level to undulating and rolling plains
E1	500-1200	400-500	Gently undulating to rolling plains
E10	400-600	1400-1600	Flat alluvial plains with complex sedimentation pattern
E11	500-1000	1000-1200	Complex depression
E12	1000-2000	800-1000	Dissected, rolling to hilly mountain
E14	1000-2000	1000-1200	Very strongly dissected mountain block
E15	800-1700	1000-1200	Flat, undulating to rolling plains and plateaux
E2	500-1200	800-1000	Gently undulating to rolling plains and plateaux
E3	200-750	800-1000	Flat to rolling plains
E4	200-500	800-1000	Flat to rolling plains
E5	200-500	800-1000	Level to rolling plains
E6	150-500	1000-12000	Undulating to rolling plains
E7	800-1500	800-1000	Flat to rolling palins, locally hilly at medium altitude
E8	Wide range	500-600	Flat alluvial plains affected by salinity
E9	400-500	800-1000	Flat, alluvial plains with homogenous sedimentation pattern
H1	1500-2000	600-1600	Flat to undulating and rolling plains and plateaux
H2	1500-2100	1400-1600	Undulating to rolling plains
H3	1500-2300	1000-1200	Strongly dissected hills and mountains
H4	500	> 2000	Flat to very gently undulating lacustrine plains
H5	1200-2400	1000-1200	Undulating to rolling volcanic plains and plateaux
H6	2300-2700	1000-1200	Undulating to hilly plateau
H7	1500-2300	800-1000	Mainly mountaineous, undulating to hilly plateau crests
[illegible]			
N1	1500-2500	600-700	Undulating plains
N10	1500-1800	1400-1600	Undulating to rolling plateaux and plains
N2	2000-2500	800-1000	Rolling to hilly plateau with calderas and volcanic cones
N3	900-1100	400-500	Flat lacustrine plains
N4	900-1600	500-600	Volcanic mountains with gentle to steep slopes
N5	1300-1700	1000-1200	Flat to rolling plains
N6	1300-1700	200-400	Flat to rolling plains
N7	1300-1800	600-700	Level to rolling plains
N8	1300-2300	800-1000	Level to undulating or rolling plains
N9	1100-1800	700-800	Gently undulating plains with some rocky hill-footslope associations
[illegible]			
P1	1100-1300	600-700	Undulatingpalins
P10	1100-1400	500-600	Gently undulating plains
P11	900	500-600	Flat plains
P12	900-1200	600-700	Flat, seasonally inundated plains with permanent or semi-permanent swamps
P13	900-1200	800-1000	Flat, seasonally inundated lowland plains
P2	1100-1300	200-400	Gently undulating plains
P3	1100-1300	800-1000	Gently undulating plains
P4	1200-1300	600-1000	Flat to gently undulating plains with scattered hill-footslope associations
P5	1100-1300	600-1000	Gently undulating plains
P6	800-1800	800-1000	Undulating plains and plateaux
P7	1000-1100	600-700	Flat to very gently undulating plains
P8	1000-1200	600-800	Flat to gently undulating plains
P9	1000-1400	500-600	Gently undulating plains
R			Rocky terrain
R1	800-1000	1000-1200	Flat plains covered by riverine or lacustrine alluvium, saline or sodic and vari
R2	Variable	1000-1200	Flat to very gently undulating plains covered by lacustrine alluvium
R3	900-1400	600-1000	Flat plains covered by riverine alluvium and regularly flooded
R4	1000	1200-1400	Complex terrain
S1	200-500	800-1000	Gently undulating to rolling plateaux
S2	200-1000	1000-1200	Gently undulating to rolling plateaux
U	1400-2300	1000-1200	Complex of flat to gently undulating plains
W1	1300-1800	1000-1500	Dissected hilly plateaux
W2	1500-1700	1000-1500	Strongly dissected hills
W3	1200-1600	800-1000	Undulating to rolling upland plains
W4	1400-1500	1000-1500	Undulating to rolling plains

Appendix D: Data

Appendix D.1: Overview of variables

Variable	Name	Description	Expected sign	Data source NBS= National Bureau of Statistics (Tanzania)
Dependent variable				
Agricultural productivity	ln_productivity	Yields, kg/acre (log)	-	NBS- LMSS-ISA Agricultural Survey
CSA practices: Key explanatory variables				
Intercropping	intercropped	Indicator variable: Has the practice been used on the plot? 1= yes 0= no	(+)	NBS- LMSS-ISA Agricultural Survey
Improved seed	improved_seed	Indicator variable: Has the practice been used on the plot? 1=yes 0= no (traditional seeds)	(+)	NBS- LMSS-ISA Agricultural Survey
Inorganic fertilizer	organic_fertilizer	Indicator variable: Has the practice been used on the plot? 1= yes 0=no	(+)	NBS- LMSS-ISA Agricultural Survey

Economic factors				
Off-farm income (log)	off_farm_income	Indicator variable: Household income from non-agricultural activities - Estimated in shillings (log)	(+)	NBS- LMSS-ISA Agricultural Survey
Value plot (log)	ln_value_plot	Indicator variable: What is the value of the plot today? - Estimated in shillings (log)	(+)	NBS- LMSS-ISA Agricultural Survey
Assets (log)	ln_assets	Indicator variable: Total estimated values of household assets - Shillings (log)	(+)	NBS- LMSS-ISA Household Survey
Land size (log)	ln_land_size	Indicator variable: size of agricultural land owned, in acres (log)	(-)	NBS- LMSS-ISA Agricultural Survey
Socio-economic factors				
Sex	sex	Indicator variable: 1= female 0= male	(-)	NBS- LMSS-ISA Household Survey
Age of household head	age_head	Indicator variable: How old is the head of the household?	(+)	NBS- LMSS-ISA Household Survey
Number for household members	nr_hhmem	Indicator variable: How many are living in this household?	(-)	NBS- LMSS-ISA Household Survey

Hired labor	hired_labor	Indicator variable: Have you hired labor on the plot? 1=yes 0=no	(+)	NBS- LMSS-ISA Agricultural Survey
Certificate/training	certificate	Indicator variable: Have you received training and a certificate for this plot? 1= yes 0=no	(+)	NBS- LMSS-ISA Household Survey
Infrastructure				
Distance to agricultural market	plot_ dist_market	Indicator variable: Plot distance to nearest agricultural market, in km	(-)	NBS- LMSS-ISA Geospatial variables
Distance to road	plot_dist_road	Indicator variable: Plot distance to nearest major road, in km	(-)	NBS- LMSS-ISA Geospatial variables
Production-specific				
Pesticides/herbicides	pesticides	Indicator variable: 1=yes 0=no	(+)	NBS- LMSS-ISA Agricultural Survey
Irrigated	Irrigated	Indicator variable: Irrigation system on the plot? 1=yes 0=no	(+)	NBS- LMSS-ISA Agricultural Survey
Organic fertilizer	organic_fertilizer	Indicator variable: Organic fertilizer application on the plot? 1=yes 0=no	(+)	NBS- LMSS-ISA Agricultural Survey

Climatological and agro-ecological factors				
Average temperature	temperature	Average annual temperature, in °C (multiplied by 10)	(-)	NBS - LMSS-ISA Agricultural Survey
Average precipitation	precipitation	Average annual precipitation, in mm (multiplied by 10)	(-)	NBS- LMSS-ISA Agricultural Survey
Moderate nutrient constraint	moderate_ nutritient_ constaint	Indicator variable: Constraints in moderate nutritient availability 1= yes 0=no	(+)	NBS- LMSS-ISA Agricultural Survey
Drought/Floods	drought_flood	Indicator variable: Any droughts or floods in the last 12 month? 1=yes 0=no	(-)	NBS- LMSS-ISA Agricultural Survey
Shock	shock_length	Number of months household has experience a shock in last 12 months?	(-)	NBS- LMSS-ISA Agricultural Survey
Erosion	erosion	Indicator variable: Any problems with erosion on this plot (during the last completed season)? 1=yes 0=no	(-)	NBS- LMSS-ISA Agricultural Survey

Soil quality Good/Poor	soil_good_qual soil_bad_qual	Indicator variable: Good? 1=yes 0=no Bad? 1=yes 0=no	(+) (-)	NBS- LMSS-ISA Agricultural Survey
False onset rainy season	falseonset_rainseason	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	(-)	NBS- LMSS-ISA Geospatial variables
Rainfall pattern change	rainfall_pattern	Indicator variable: Divergence of annual rainfall (specific year) from average total rainfall 1= above mean of AEZ 0=below mean of AEZ	(-)	NBS- LMSS-ISA Geospatial variables

Appendix D.2: Fixed effects

In order to understand the procedure of applied fixed effects, or “within estimation” on my two models [4] and [5], let us go back to the fictive production function [3] used to define agricultural productivity. However, to understand how the time-invariant components are removed, let us add the component μ_i to model [3]:

$$Y_{i,t} = \alpha + x_{it}\beta + \mu_i + \varepsilon_{i,t} \tag*{[D2.1]}$$

Where xit is a vector of a exogenous covariate and where μ_i and $\varepsilon_{i,t}$ represents time-invariant and time-variant components respectively. Similarly to fixed effects, the same issues of time-invariant factors can also be addressed through first-differences (FD), an estimator consistent in models where fixed effects is applied. The estimator is applied to address problems with omitted variable bias, and is, however, an efficient tool to describe the procedure. Moreover, the FD-method takes advantage of a longitudinal dataset while the equation is computed (Wooldridge, 2001). Using model [D2.1] we can add first-differences through the following procedure:

$$Y_{it-1} = \alpha + X_{it-1}\beta + \mu_i + \varepsilon_{it-1} \tag*{[D2.2]}$$

Which is needed in order to do a fixed effect estimation of individual-specific averages over time. This illustrations can also be written as:

$$\bar{Y}_i = \alpha + \bar{X}_i\beta + \bar{\mu}_i + \bar{\varepsilon}_i \tag*{[D2.3]}$$

Where:

$$\bar{Y}_i = \frac{1}{T}\sum_{t=1}^{T} Y_{it};\quad \bar{X}_i = \frac{1}{T}\sum_{t=1}^{T} X_{it};\quad \bar{\varepsilon}_i = \frac{1}{T}\sum_{t=1}^{T} \varepsilon_{it};\quad \bar{\mu}_i = \frac{1}{T}\sum_{t=1}^{T} \mu_{it}$$

Hence the signs with bars symbolizes the sample mean of the estimated population and thus the components that is targeted when applying fixed effects.Therefore, since model [D2.2] captures individual averages in the sample, we subtract [D2.2] from [D2.1] and get:

$$Y_{it} - \bar{Y}_i = X_{it}\beta + \mu_{it} + \varepsilon_{it} - \bar{X}_i\beta - \bar{\mu}_i - \bar{\varepsilon}_i \tag*{[D2.4]}$$

Where the first difference of the time-invariant factor μ_i now equal to the level. Noting that $\mu_i = \bar{\mu}_i$ we can therefore write the following equation:

$$Y_{it} - Y_i = (X_{it} - X_i)\beta + (\varepsilon_{it} - \bar{\varepsilon}_i) \tag*{[D2.5]}$$

Where μ_i can be removed from the model and allow us to control implicitly for individual-specific factors over time (2008-2011). The interpretation of β is the within-unit effect in any covariate X that has been added to the models.

Appendix D.3: Determinants of agricultural productivity (with standard errors included)

y=Agricultual productivity, in kg/acre (log)	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
CSA practices					
Intercropping	0.412***	0.036*	0.069	0.067	0.585**
	(0.0771)	(0.0805)	(0.0798)	(0.0798)	(0.231)
Improved seed	0.487***	0.471*	0.539**	0.577*	0.067*
	(0.161)	(0.326)	(0.359)	(0.365)	(0.706)
Inorganic fertilizer	0.542***	0.510***	0.481	0.480	0.543**
	(0.0817)	(0.105)	(0.114)	(0.115)	(0.543)
Economic factors					
Off farm income *(TZS)*		0.033	0.025	0.024	0.079***
		(0.323)	(0.136)	(0.138)	(0.432)
Value plot *(TZS)*		0.151***	0.132**	0.121**	0.791***
		(0.324)	(0.122)	(0.321)	(0.453)
Assets *(TZS)*		0.075	0.076	0.085	0.647***
Land size (acre)		-0.603***	-0.578***	-0.564***	0.003
		(0.564)	(0.423)	(0.003)	(0.648)
Socioeconomic factors					
Age head		-0.002	-0.003	-0.003	0.275***
		(0.002)	(0.053)	(0.002)	(0.004)
Number of household members		-0.024	-0.021	-0.021	-0.322***
		(0.021)	(0.043)	(0.045)	(0.032)
Hired labor		0.339***	0.346***	0.345***	0.103***
		(0.032)	(0.033)	(0.021)	(0.126)
Certificate		0.198	0.246	0.242	0.022
		(0.004)	(0.021)	(0.521)	(0.123)
Sex (1=Female)		-0.241**	-0.243**	-0.250**	-0.393***
		(0.679)	(0.005)	(0.004)	(0.222)
Production-specific factors					
Organic fertilizer			0.369***	0.351***	-0.946
			(0.333)	(0.212)	(0.543)
Pesticides			0.104	0.108	0.095***
			(0.002)	(0.003)	(0.222)
Irrigated			-0.113	-0.119	-0.529
			(0.231)	(0.444)	(0.004)
Infrastructure					
Plot distance road				-0.016**	-0.059*
				(0.003)	(0.084)
Plot distance market				-0.008***	-0.039**
				(0.043)	(0.087)

Climatological and agro-ecological factors					
Shock length (months)					-0.013
					(0.043)
Climate shock (drought or flood)					-0.533***
					(0.764)
Erosion					-0.749
					(0.432)
Good soil quality					0.103***
					(0.054)
Bad soil quality					-0.675
					(0.043)
Moderate nutritient constraint					-0.004
					(0.222)
Temperature (℃*10)					-0.023***
					(0.021)
Precipitation (mm*10)					0.004
					(0.021)
False onset rainyseason					0.091***
					(0.042)
Rainfall pattern change					0.111**
					(0.001)
Fixed effects	No	No	No	No	Yes
Constant	5.39***	4.42***	4.57***	4.83***	72.25**
Observations	1,533	1100	1100	1100	1100
R^2 within/(overall)	0.049	0.236	0.863	0.853	0.875
	(0.056)	(0.228)	(0.005)	(0.252)	(0.273)
Number of id	1,058	784	784	784	784

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

Appendix D.4: Descriptive statistics - wave 1 (2008-2009)

Variable	**Obs**	**Mean**	**Std. dev.**	**Min**	**Max**
Dependent variable					
Agricultural productivity, log (kg/acre)	3, 072	5.83	1.08	0.21	11.70
CSA practices					
Intercropping (1=Intercropped	2,444	0.12	0.34	0	1
Improved seed (1=Yes)	2,300	0.13	0.12	0	1
Inorganic fertilizer (1=Application)	2,548	0.21	0.40	0	1
Economic factors					
Off-farm income, log (TZS)	2,234	8.98	0.32	5.65	13.26
Value plot, log (TZS)	3,984	12.01	0.98	4.59	13.59
Assets, log (TZS)	2,842	9.63	0.32	3.81	11.82
Land size, log (Acre)	1000	0.62	0.64	0	3.91
Socioeconomic factors					
Age of household head	3,453	47.59	15.03	19	97
Number of household members	1,543	5.27	2.73	1	12
Hired labor (1=Yes)	1,222	0.33	0.48	0	1
Certificate/Training (1=Yes)	3,321	0.69	0.46	0	1
Sex (1=Female)	1,332	0.24	0.43	0	1
Production-specific factor					
Organic fertilizer (1=Application)	3,444	0.17	0.39	0	1
Pesticide use (1=Yes)	3,654	0 .75	0.86	0	1
Irrigated (1=Yes)	5,111	0.12	0.33	0	1
Infrastructure					
Plot distance road (km)	2,876	2.21	3.80	0	80
Plot distance market (km)	3,452	8.98	11.54	0	134
Climatological and agro-ecological factors					
Shock length (months)	2,432	5.84	2.10	0	12
Climate shock (drought or floods)	3,541	0.022	0.15	0	1
Erosion (1=Yes)	3,210	0.21	0.41	0	1
Good soil quality (1=Yes)	4,212	0.43	0.49	0	1
Bad soil quality (1=Yes)	4,876	0.17	0.38	0	1
Temperature, annual (°C*10)	4,321	230.26	18.81	154	390
Precipitation, annual (mm*10)	4,651	1137.97	202.96	544	2372
Moderate nutrient constraint (1=Yes)	4,511	0.09	0.29	0	1
False onset rainy season (1=>AEZ mean)	4,222	0.97	0.16	0	1
Rainfall pattern variation (1=>AEZ mean)	3,564	0.81	0.39	0	1

Appendix D.5: Descriptive statistics - wave 2 (2010-2011)

Variable	**Obs**	**Mean**	**Std. dev.**	**Min**	**Max**
Dependent variable					
Agricultural productivity, log (kg/acre)	2, 222	4.33	1.04	0.61	10.30
CSA practices					
Intercropping (1=Intercropped	2,857	0.22	0.14	0	1
Improved seed (1=Yes)	3,001	0.14	0.42	0	1
Inorganic fertilizer (1=Application)	2,753	0.22	0.43	0	1
Economic factors					
Off-farm income, log (TZS)	1,368	8.88	0.32	5.65	12.16
Value plot, log (TZS)	1,315	12.01	0.98	4.59	13.39
Assets, log (TZS)	724	9.63	0.32	3.81	11.72
Land size, log (Acre)	2,526	0.61	0.64	0	3.91
Socioeconomic factors					
Age of household head	1, 848	47.57	15.03	19	97
Number of household members	3, 758	5.28	2.73	1	12
Hired labor (1=Yes)	2,346	0.31	0.48	0	1
Certificate/Training (1=Yes)	3,543	0.67	0.46	0	1
Sex (1=Female)	1,301	0.23	0.43	0	1
Production-specific factor					
Organic fertilizer (1=Application)	3,301	0.15	0.39	0	1
Pesticide use (1=Yes)	2,961	0 .74	0.86	0	1
Irrigated (1=Yes)	1,301	0.11	0.33	0	1
Infrastructure					
Plot distance road (km)	1,299	2.21	3.70	0	70
Plot distance market (km)	2,301	8.98	11.94	0	124
Climatological and agro-ecological factors					
Shock length (months)	2,022	5.44	2.10	0	12
Climate shock (drought or floods)	3,301	0.012	0.15	0	1
Erosion (1=Yes)	2,301	0.11	0.42	0	1
Good soil quality (1=Yes)	3,201	0.44	0.46	0	1
Bad soil quality (1=Yes)	3,501	0.16	0.34	0	1
Temperature, annual (°C*10)	3,301	230.06	18.81	154	390
Precipitation, annual (mm*10)	4,301	1137.95	202.97	548	2272
Moderate nutrient constraint (1=Yes)	2,301	0.09	0.22	0	1
False onset rainy season (1=>AEZ mean)	1,301	0.97	0.15	0	1
Rainfall pattern variation (1=>AEZ mean)	2,301	0.81	0.37	0	1