Master’s Programme in Innovation and Global Sustainable Development

# Is the Climate Changing for the Climate-Smart?

## A study on Climate-Smart Agriculture (CSA), Resilience and Hunger

by

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## Abstract

Could the use of CSA practices stabilize the hunger crisis? Despite the general understanding that CSA practices increase farmers' food security, its resilience to climatic shocks is much less understood. To address this gap, this study analyzes the effect of three CSA practices: inorganic fertilization, intercropping and improved seeding on maize productivity in Ethiopia, Tanzania, and Uganda. By using plot-level panel data collected within the three countries between 2010-2012, the analysis suggests that inorganic fertilization and intercropping are positively associated with increased productivity (kg/acre), increasing maize yields by 32 and 63 percent, respectively. Climatic shocks, while decreasing maize productivity across all plots, were less severe in plots where inorganic fertilization and intercropping occurred. Aside from the plot-level analysis, this study also adds a new layer of granularity to the literature, namely the analysis on the agroecological zone level, allowing the conclusions to extend beyond national borders and thus contributing to the generalization of the findings.

*Keywords:* Maize Productivity, Hunger, Resilience, Climate-Smart Agriculture, Climatic Shocks, Eastern Africa, Tanzania, Ethiopia, Uganda

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# 1 Introduction

Presently, out of the 7.7 billion global population, around 821 million people, including 45 million children, go to bed hungry every single day (FAO, 2020; UN, 2017; WFP, 2021). While the global population is expected to increase by 10.6 billion people (UN, 2020), the business as usual scenario predicts that another 2 billion people will face severe malnutrition by 2050 (Mottaled, Fatah, Kruseman & Erenstein, 2021). Therefore, to ensure basic food security, eliminating hunger by 2030 in line with the Sustainable Development Goal 2 (SDG2), it is essential to increase our supply of basic food items (Below, Artner, Siebert & Sieber, 2010; Dell, Jones & Olken, 2012; Smil, 2016; IPCC, 2018; Nyasimi, Amwata, Hove, Kinyangi & Wamukoya, 2014; Rogelj, Meinshausen, & Knutti, 2012) without compromising the ability of future generation to do the same (WCED, 1987). Yet, current climate change projections harm the visions of reaching zero hunger. Weather changes primarily affect over 22 percent of cultivated food crops as crop yields[1] need to increase productivity by 70 percent to reach adequate food supplies (World Bank, 2016; FAO, 2016).

Maize, also known as corn, is a crop significantly impacted by these trends. It has become one of the most important food crops, accounting for over 30 percent of the calorie intake of 5 billion people in the most vulnerable nations (Shiferaw, Prasanna, Hellin & Bänziger, 2011). By 2030, a study by NASA (2021) projects that the maize yield will decrease by 24 percent due to prolonged droughts and temperature increases. In Eastern Africa (EA), a region highly impacted by extreme hunger and climatic changes, projections show that the region will lose 56 percent of its maize yield output, above the global average (Shiferaw et al. 2011; Jonathon, 2019). Simultaneously, maize represents a food staple alone in EA, providing nutritional intake for over 75 percent of the poorest population living in rural areas with agriculture as their primary source of income. Thus, increasing maize yield productivity while minimizing costs through increased resource-use efficiency is vital in attaining agricultural output (World Bank, 2016; FAO, 2014).

To meet these requirements, scholars have stressed the need for resilient[2] agricultural techniques to meet climate shocks[3] affecting the maize yield (Adams, Rosenzweig, Peart, McCarl, Glyer, Curry, James, Jones, Kenneth, Boote & Hartwell, 1990; Mendelsohn, Dinar & Sanghi, 2001; Schlenker & Roberts, 2006; Deschenes & Greenstone, 2007). In particular, the land management approach launched by the Food Agriculture Organization (FAO) in 2009 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,

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[1] The term crop "yield" represents a standard measurement of agricultural production harvested and is often expressed in tons, bushels, kilograms or pounds per unit of land area (FAO, 2018b, p.2).

[2] "Resilience" can be defined as the process of "equipping farmers to absorb and recover from shocks and stresses to their agricultural production and livelihoods" (Farming First, 2014).

[3] The term "climate shocks" defines short-term peakes in averages of precipitation or temperatures, which offer results in droughts or floods (FAO, 2019; Rioux et al. 2017). Since this thesis focuses on a short time period of two years (2010-2012) this expression is suitable and will be used throughout the paper.

Ramankutty,Herreo & West, 2016; Thornton, Rosenstock, Förch, Lamanna, Bell, Henderson & Herreo, 2018; Engel & Muller, 2016).

However, what is CSA, and why do we need it? FAO (2013) defines CSA as "agriculture that sustainably increases *productivity*, enhances resilience (*adaptation*), reduces/removes GHGs (*mitigation*) where possible, and enhances achievement of national food security and development goals" (FAO, 2013, p.2). It is an agricultural land management approach where the pillar, *productivity,* is central in intensifying food supplies while ensuring resilience (FAO, 2013). It contains several practices for climate-smart crop cultivation to increase crop yield output without compromising ecosystem functioning (FAO, 2013). Regardless of economic entity or unit, like agricultural holdings, the term *productivity* 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). In this term, inputs represent factors of production such as labor, seeds use, fertilizers, or agrochemicals, while the output is kilograms produced per unit of land. An increase in this ratio is associated with improved agricultural output and thus an increase in food supplies (FAO, 2018b). Within this context, this study is set to investigate the efficiency of CSA in explaining productivity variations, increasing the maize yields, and, therefore, ensuring stabilized food supplies in the EA region.

## 1.1 Research Problem

While CSA might be an environmentally friendly approach to farming, its definition is vague, and its requirements are limited by its demand for extensive institutional and capacity coordination (CIAT & World Bank, 2017). Although the central purpose of the CSA implementation is to take the local conditions into account, farmers are often left out of the agenda while context-specific challenges related to agro-practices are ignored (Rioux, Laval, Karttunen, Lwakatare, Natai, Majule, Massoy, Malozo & Bernoux, 2017; Arslan et al. 2012). In the EA region, CSA has been widely introduced. However, institutional coordination and scale down to the micro-level are lacking, leading to weak absorption of innovations and low adaptive capacity to CSA policies (FAO, 2016).

Although EA countries have seen a growth in the agricultural sectors over the past decade, where maize production stands as the main pillar of cultivation, accounting for over 50 percent of the grain supply, the region faces challenges in maintaining the productivity of the maize yield. This is primarily due to sensitivity to temperature rises, unproductive agricultural techniques, and socioeconomic factors such as conflicts (Rioux et al. 2017; Arslan et al. 2012). As a result, the region faces a low level of commercialization of the maize industry while increased prices worsen the situation of the poorest people, an issue which has come to classify the region as the poorest region on the globe (UN, 2020; FAO, 2016; FAO, IFAD, & WFP, 2015; FAO, 2020). In 2021, Ethiopia, Tanzania, and Uganda were the biggest suppliers of maize within the region, accounting for approximately 43-56 percent of total exports. Nevertheless, due to climate shocks affecting the drought-sensitive maize plant, the three countries lie 40 percent below their national averages in 2021/2022, increasing severe hunger across the region (FEWS NET, 2021; FAO, IFAD, & WFP, 2015; Yalew, 2016).

To change the current trend, these countries are now trying to accelerate the implementation of CSA policies to coordinate farmers, scaling down innovative agricultural techniques to boost resilience and maize production in the EA region. However, investments fail to support the implementation of innovative technologies, while CSA is context-specific and cannot be generalized, leading to difficulties in coordination and collaboration across country borders. Limited knowledge about CSA techniques leads to an inadequate understanding of its impact on productivity and the scale down to local levels, therefore, becomes defective. Further, due to climate variations and agroecological conditions, certain CSA techniques function differently within given countries (Arslan et al. 2012; Rioux et al. 2017; FAO, IFAD, & WFP, 2015; CIAT & World Bank, 2017). To understand this in greater detail, a micro-level examination of the EA region is of utmost importance.

For a proper CSA implementation, studies need to capture challenges faced by the farmer on a local level, and each CSA method should be studied concerning its contextual capacity. Thus, this research highlights the micro-perspective by analyzing the plot level by looking at three major maize suppliers in the EA region. In turn, findings enable policymakers to create guidelines and tools for operationalizing the CSA framework concerning the need of Ethiopian, Tanzanian and Ugandan farmers.

## 1.2 Aim, Scope, and Research Question

This research examines the maize yield productivity in the EA region when a set of CSA practices are implemented. Using micro-level data collected on a plot level between 2010 and 2012, this study seeks to quantify the effect of three CSA practices; *inorganic fertilization, intercropping and improved seeding,* and their efficiency in maintaining a stabilized output under temperature rises. These practices are frequently used on the maize plant and recommended by FAO as efficient practices during droughts or floods (Arslan et al. 2012; Rioux et al. 2017; FAO, IFAD, & WFP, 2015).

Three countries are put in focus: Ethiopia, Tanzania, and Uganda, as these are major maize producers within the EA region and, therefore, important suppliers of a vital food crop. Furthermore, maize is grown within similar agro-ecological contexts within these countries, making a regional analysis possible to interpret. Thus, ignoring country borders, the site-specific variations in climate are captured by dividing the EA region into agro-ecological zones (AEZ). These zones, *tropic-cool/subhumid, tropic-warm/subhumid, tropic-cool/humid,* and *tropic-warm/humid,* account for altitude, terrain roughness, soil, and temperature, precipitation and enable a horizontal investigation of the CSA contribution.

Regional trends can be understood from a micro-level by examining the plot level. This paper, therefore, produces conclusions that are useful for policymakers aiming to design efficient methods to increase the maize output within the EA region, which is facing the growing issues of extreme hunger. To approach the research problem, the following research question has been formulated: *Can differences in maize yields be understood by the use of CSA practices, especially when controlling for climate shocks?*

To investigate the research question, three hypotheses have been addressed:

**H1** *Agricultural productivity of the maize yield increases across countries when CSA is applied*

**H2** *Agricultural productivity of the maize yield varies when controlling for both traditional and CSA techniques*

**H3** *CSA practices contribute horizontally across* ***countries*** *and* ***AEZ*** *under climate shocks*
- *a: Intercropping*
- *b: Improved seeding*
- *c: Inorganic fertilization,*

where hypothesis 1 (H1) tests the general impact of CSA and determinants of agricultural productivity, analyzing various factors such as the *socioeconomic, economic, production-specific, infrastructural,* and *climatological/agro-ecological* aspects. Hypothesis (H2) tests traditional methods such as *pure stand, traditional seeding,* and *organic fertilization* which are the corresponding methods used instead of given CSA practices. Lastly, hypothesis (H3) accounts for the variation between countries, and in a second step, the agro-ecological context is emphasized, and country borders are ignored.

## 1.3 Contribution

This paper adds three contributions. Firstly, previous research has mainly captured the household level when examining the impact of CSA practices (Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998; Arslan et al. 2015; Mugabe, 2015). However, this research uses a new level of granularity by investigating the CSA effects on a plot level. Secondly, as previous scholars have analyzed CSA through case studies or CSA projects (Branca et al. 2011; Pretty et al. 2006), this study uses data where farmers did not engage in certain CSA evaluations. Thus, by testing various techniques, both traditional and CSA, various methods are emphasized, which reduces the level of unobservable bias. Lastly, most studies in the research field have taken societal development into account when examining various countries (Arslan et al. 2015; Mugabe, 2015; Kassie et al. 2010; Kato et al. 2011). This study adds a new layer of granularity to the literature, namely the analysis on the agroecological zone level, allowing the conclusions to extend beyond national borders and thus contributing to the generalization of the findings.

## 1.4 Limitations

This research inevitably faces a few limitations. Firstly, variables included in the estimations of productivity were chosen after availability, meaning that they do not capture a perfect understanding of the local context. Several other factors affecting the maize yield were not included in this study. Fixed effects were applied to the models to face the issue of unobservable factors and endogeneity of estimations, reducing time-invariant factors. In addition, since the data was collected as a household survey, not as a natural experiment, applying propensity score matching enabled an “experiment-like” situation. This reduces the chance of self-selection bias and reverse causality. Lastly, estimations had to be approached with caution due to a high level of missing data. By examining agroecological variations, weather projections, and maps, estimated results could be supported by previous studies and secondary sources. To fill the gaps mentioned, future research should include improved micro-level data to reduce potential unobservable factors that might impact the maize yield.

## 1.5 Outline of the Thesis

This paper is structured along with seven main chapters. In chapter 2, the contextual framework sets the scene of the paper by providing an analysis of maize in the EA region, emphasizing agro-ecological characteristics, climate change, and CSA practices. In chapter 3, previous research is examined, and the contribution of this study is outlined. In chapter 4, the data is described, and limitations are addressed in greater detail. In chapter 5, the empirical strategy is presented through the variables used and the construction of the baseline model. In chapter 6, findings are presented, and the three hypotheses are tested. In chapter 7, empirical results are analyzed through the lens of previous studies. In chapter 8, conclusions are made followed by recommendations for future research.

# 2 Contextual Framework

## 2.1 Maize, Climate Change and Zero Hunger

Maize, also known as corn, has become the most important food crop of our time by providing over 30 percent of the food calories to 5 billion people across developing nations (Shiferaw et al. 2011). Thus, the total production of maize, surpassing that of rice and wheat, represents a food staple alone, especially in Africa, meaning that the crop is consumed in such quantities that it constitutes a major part of the human standard diet (Jonathon, 2019). Maize is further utilized in industrial products, counting the production of biofuels, and it is a key component of animal feed. Additionally, maize is cultivated in most areas of the world, and with a greater amount cultivated each year, 1.04 billion tonnes in 2014 and 1.15 billion tonnes in 2018, it produces more than any other grain (IGC, 2013).

Nevertheless, production shortfalls and increasing demand for maize over the past decade have contributed to a surge in maize prices and led to market volatility, making the role of maize as an important food staple highly threatened (Shiferaw et al. 2011). As visualized in *Appendix B.1*, showing consumer prices for maize over time (2009-2021) there has been a steady increase in international maize prices since 2009 (blue line), leading to a heavy increase, especially in the EA region. This trend had various implications for people living in the countries of interest, namely, Ethiopia, Tanzania, and Uganda. While small-scale farmers would benefit from selling their maize crop at a greater price, consumers dependent on low food prices suffered from severe starvation (Shiferaw et al. 2011; Meijerink & Berkum, 2009).

As a result of these past trends, many studies reveal that these countries may struggle with achieving the United Nations Sustainable Development Goal 2 (SDG2) of zero hunger by 2030. According to a recent study published by NASA (2021), the project that in 2030, climate change will considerably affect the maize yield in the tropics. Specifically, while wheat is projected to grow approximately 17 percent, the maize crop yield is expected to decline by 24 percent (NASA, 2021). By utilizing advanced agricultural and climate models, scholars have proven that maize is a crop highly dependent on water availability and thus sensitive to increasing temperature and climate variability. Wheat, on the other hand, becomes more productive under higher temperatures and is expected to be produced in higher quantities, especially in the tropics (Ranum, Peña-Rosas & Garcia-Casal, 2014; Shiferaw et al. 2011).

Therefore, changes in rainfall patterns, increases in temperatures, and concentrated carbon dioxide from greenhouse gases have a strong negative correlation with changes in maize yields (NASA, 2021). The study by NASA concludes that regions close to the equator, such as Tanzania, Ethiopia, and Uganda, are countries where an increase in temperature will be most dramatic. As seen in Figure C.1 in *Appendix C*, droughts are the main cause of a disrupted food supply, especially in Ethiopia, Tanzania, and Uganda.

Simultaneously, it is within these countries where the maize is produced in greater quantities meaning that, in the upcoming years, the so-called ‘breadbasket regions’ or regions producing the majority of our global food supply will face severe stress on their maize plants (NASA, 2021). In the short run, this will mean poor soil quality, harvest loss, and low productivity of the maize plant, while the long-run projections reveal that a decline in the maize crop yield will have severe impacts on the provision of adequate global food supply. Not just within the Global South, where the maize crop is an essential source of calorie intake, but also within developed countries where maize has become a cornerstone of the modern food system (UN, 2017; UN, 2019; UN 2020).

According to the World Health Organization (WHO), a food crop is considered an important food source if consumption is above 50 grams per person a day. The African continent consumes up to 328 grams per person whereas the consumption in South America is 267 grams per person (Ranum, Peña-Rosas & Garcia-Casal, 2014). Nevertheless, these levels of intake are expected to decrease following the projections highlighted by NASA (2021) above, meaning that people will have a calorie intake lower than 1, 800 calories per day (Action Against Hunger, 2021; Ranum, Peña-Rosas & Garcia-Casal, 2014). Concerning the targets within SDG 2 about tackling zero hunger, the intakes of maize need to be maintained, or else, 250 million maize consumers in Africa will face severe malnutrition by 2030 if they go below this minimum level of calorie intake (UN, 2019; UN, 2017).

## 2.2 The Role of the Maize Industry in Eastern Africa

In the EA region, agriculture represents the backbone of national economies, whereas the maize industry constitutes a major source of the domestic product (GDP). In Tanzania and Uganda, the maize crop stands for approximately 50 percent (see *Appendix B.2*) of the national grain supply. These two countries are also considered the major surplus-producing countries within the region (FEWS NET, 2021; FAO, 2016). In Ethiopia, the production is slightly less, although the maize grain is still one of the major food sources, accounting for above 30 percent of the national food supply (see *Appendix B.2*). Further, the three countries are the top actors in trading within the region (FEWS NET, 2021). Due to their geographical location (see Figure 2), they are connected to various markets and trading routes linked to the import-dependent countries such as Kenya, South Sudan, and Somalia (FEWS NET, 2021; FAO, 2016).

Figure 1. The geographical location of Ethiopia, Tanzania, and Uganda
Source: Modified by author, Google Maps (2022)

A report by Famine Early Warning System Network, FEWS NET, (2021) shows that in the third quarter of 2021 (July to September), around 273, 000 MT of maize grain was traded within the region. Among all EA countries, Tanzania and Uganda accounted for 56 and 43 percent of total exports, respectively (FEWS NET, 2021), whereas Ethiopia is third on this list (see Figure 2). The report by FEWS NET (2021) further shows that the production of maize between 2016 and 2022 remained stable for most countries in the region, although Ethiopia and import-dependent countries such as Kenya, Somalia, and South Sudan were lower than average levels due to prolonged droughts. This resulted in a decrease in productivity and had major effects on the maize yield (FEWS NET, 2021).

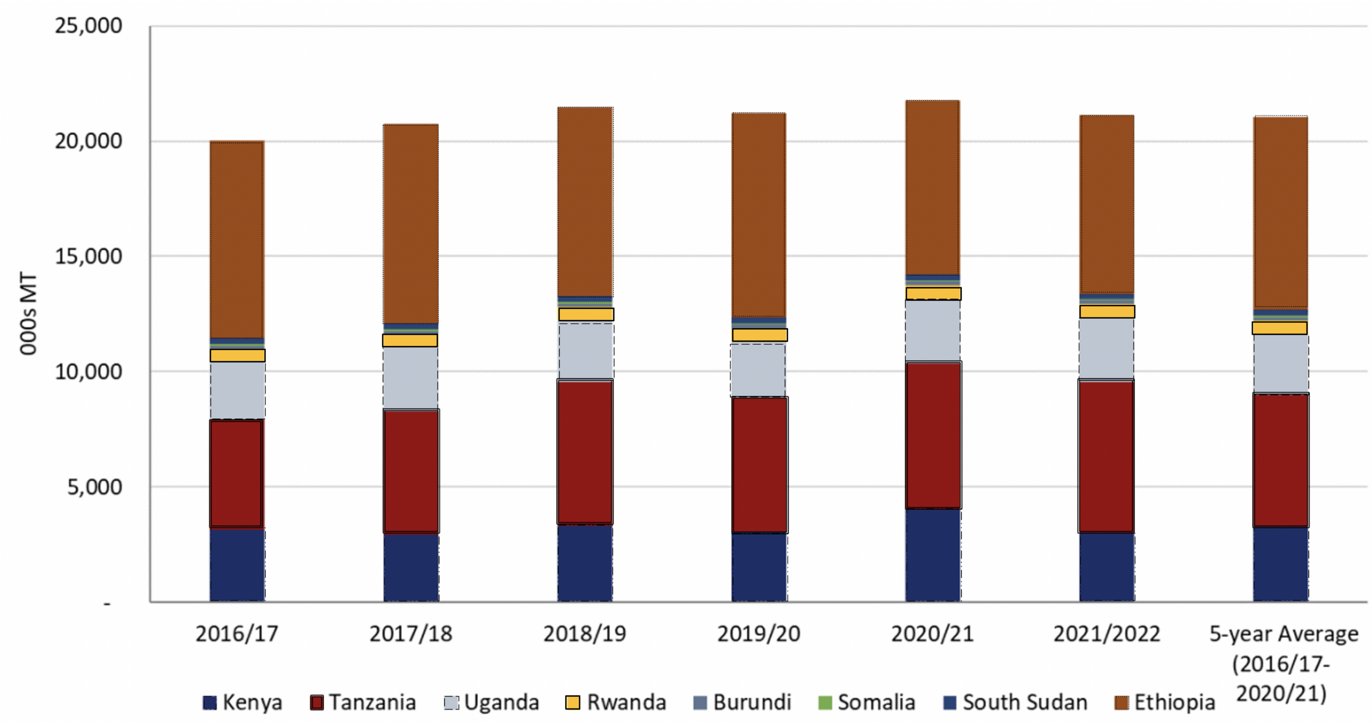

Figure 2. Estimates of Regional Maize Production
Source: FEWS NET (2021)

Although importing maize from international markets is rare within EA, it takes place especially during the period of droughts (since the maize crop is negatively affected by increased temperatures) or when production is below average in surplus producer countries like Tanzania and Uganda (FEWS NET, 202; FAO, 2016). As shown in Figure 3, only Tanzania is estimated to maintain an exportable maize surplus above average, while Ethiopia and Uganda lie below average in 2021/2022. This estimation means that the aggregate regional exportable surpluses will be below average at almost 40 percent. This result will not only have a tremendous impact on food supplies within the EA region, but also on individual farmers and their ability to invest in resilient and climate-smart agricultural techniques (FEWS NET, 2021).

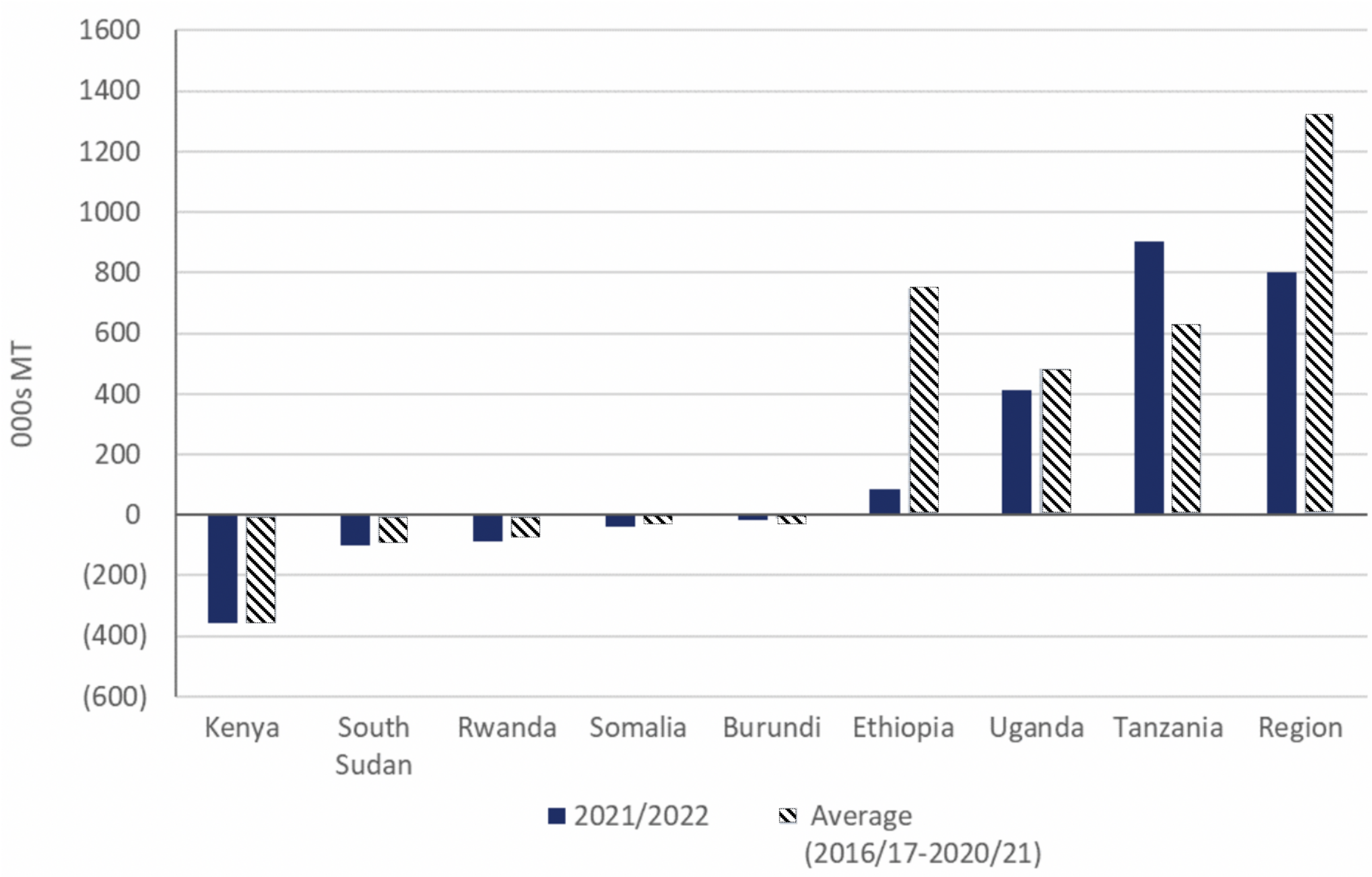

Figure 3. Maize Balance in Eastern Africa (000s MT)
Source: FEWS NET (2021)

According to FEWS NET (2021) and FAO (2016), a major explanation for this trend is low productivity and increasing maize prices. This is mainly due to rising temperatures affecting the maize yield combined with high inflation and conflict-related trade sabotage. Therefore, it is essential to consider these factors when examining agricultural productivity for a specific country or region. As shown in *Appendix B.1*, consumer prices have steadily increased for the EA region, where Ethiopia, Uganda, and Tanzania lie above the global average. This trend might affect domestic production and hunger levels in these countries. On the contrary, while it becomes expensive for consumers, the situation becomes beneficial for farmers. Scholars argue that farmers may be more likely to produce maize if the international market pays more for it (Scherr & Hazell, 1994; Clay et al. 1998).

Thus, when looking at producer prices, it seems clear that the data used in this study follows the same pattern as the trend represented by FAO in *Appendix B.1*, namely that prices increase over time. As seen in Figure 4, producer prices increased steadily between 2010 and 2012 and continued to rise between 2012 and 2015 with more than 10 percent (in 2015, PPI is above 110 for all countries). Among the three EA countries, Ethiopia had the highest maize prices in 2015, which further explains the peak of Ethiopian consumer prices in *Appendix B.1*.

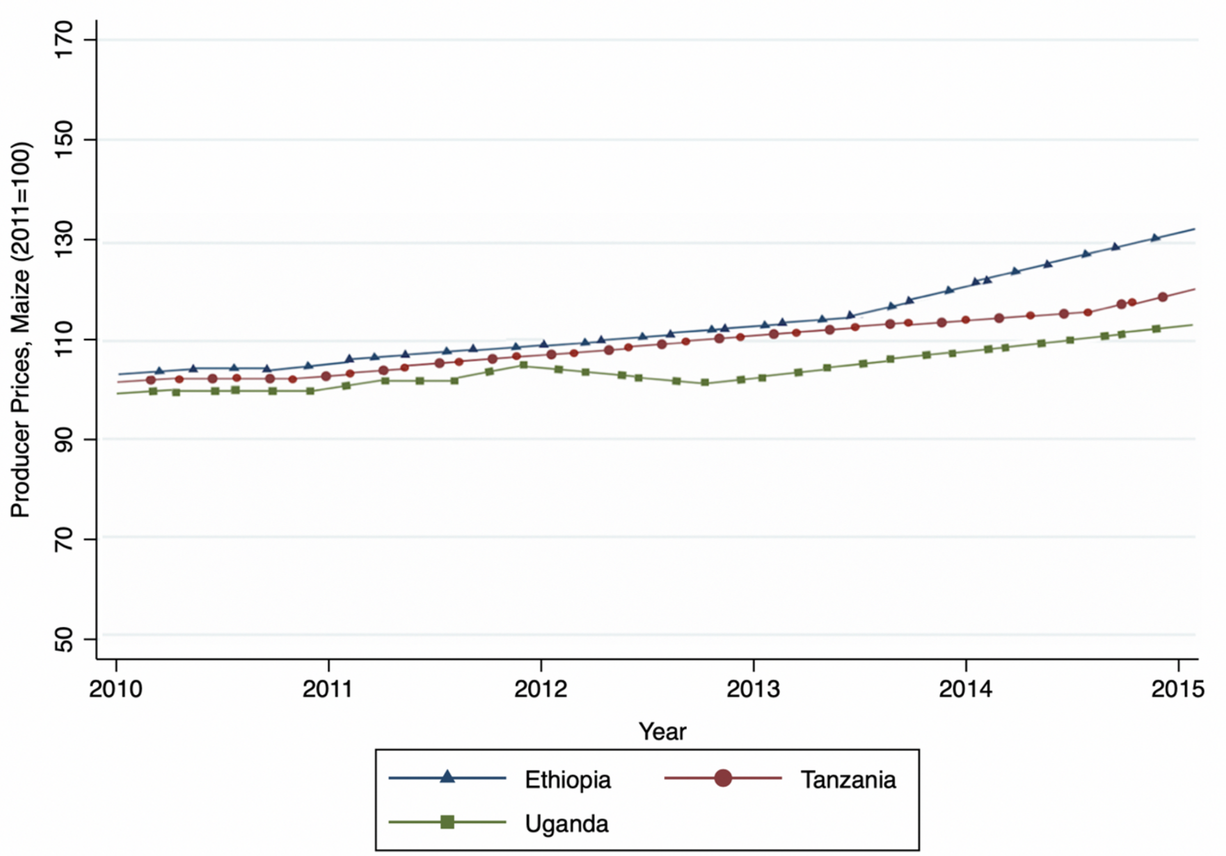

Figure 4. Producer prices by country (PPI)
Source: Estimated by author, data from CSA (2011), NBS (2011), and UBS (2011)

How does this trend affect agricultural productivity in the region? Scherr and Hazell (1994) argue that agricultural productivity tends to increase when the farmer can sell the maize grain at a greater price. They suggest that farmers can invest their increasing revenue into agricultural practices while also boosting the life situation of the household (*e.g.* increasing the number of meals eaten or hiring labor on their plot). Clay et al (1998) further highlight that selling the maize harvest to external actors (on the local, regional and global maize market) is important for a farmer's income. Thus, the availability of food markets and trade between countries are factors that influence the domestic production of maize and boost productivity (Clay et al. 1998). Based on these conclusions, it appears that maize prices influence choices, strategic planning, and the ability to improve practices used on the plot. Yet, beyond the inflation of the maize prices on the producer and consumer side, it seems that climatic changes stand as the main impactor of these market trends. Therefore, to understand this in greater detail, the climatological aspects will be discussed in the next section.

## 2.3 Agro-climatological context

The maize crop is a water-intensive crop sensible for climate variabilities such as prolonged droughts and soil infertility. Nevertheless, the agro-climatological context in the EA region has seen a tremendous variation over the past decade. According to FEWS NET (2021), Ethiopia, Uganda and Tanzania experienced major rainfall changes between 2010 and 2020 with rainfall seasons starting either earlier or later than usual. As seen in Figure 5 below, localized deficits are currently present in much of Uganda, central Ethiopia, and various spots of Tanzania. Projections indicate that average rainfall will stay below the average for 2022 and onwards, causing severe droughts and crop yields below average (FEWS NET, 2021).

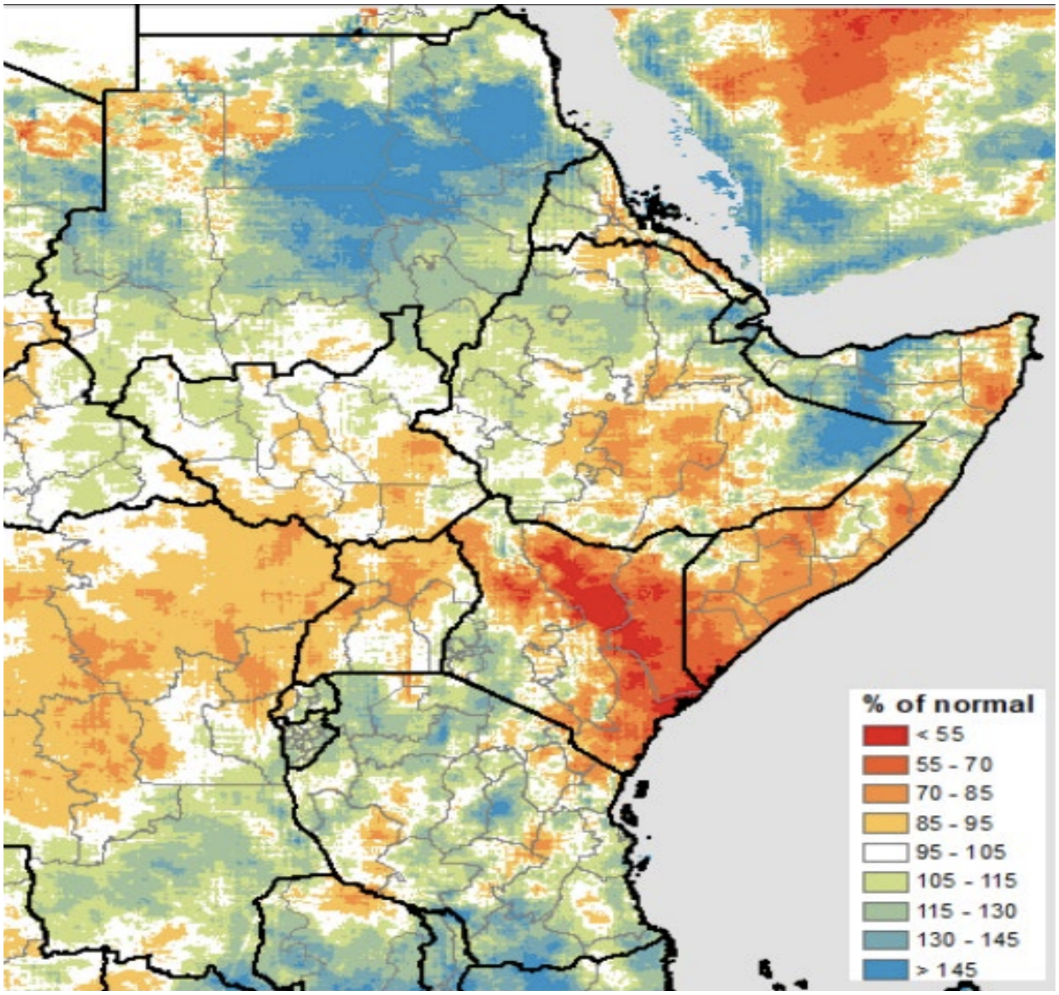

Figure 5. Seasonal rainfall accumulation in 2021 compared to the average of 1981-2010.
Source*:* Estimates based on CHIRPS data (FEWS NET, 2021)

Further, a study published by the Climate Prediction Center, CPC, (2021) estimates that in the upcoming years, the climatological situation for the EA region is going to be drier than usual. These estimations are called "La Niña impacts" (CPC, 2021) and are presented in *Appendix C.1.* La Niña comes from Spanish “the girl” and is an oceanic phenomenon of changes in sea surface temperature around the equatorial band. The atmospheric phenomenon has major effects on the weather across the globe, especially in regions situated close to the equator, such as Ethiopia, Tanzania, and Uganda (CPC, 2021; NOAA, 2021).

As seen in *Appendix C.1*, the EA region is projected to face drier periods between October to March from 2022 and onwards, causing a major impact on the growth of maize. Along similar lines, FAO (n.d) mentions Ethiopia, Tanzania, and Uganda as countries where droughts are the major cause of food emergencies. By looking at the figure in *Appendix C.2,* which represents a set of EA countries, Ethiopia, Tanzania, and Uganda are among the countries facing difficulties with food supply as a cause of increased droughts. Hence, as La Niña continuously affects the regional climate in EA, unpredictable weather shocks vary heavily on a micro-level (CPC, 2021).

To approach this variation, scholars usually divide the micro-level according to agro-ecological zones (AEZ). An AEZ is characterized by a set of climatic conditions such as rainfall patterns, altitude, soil water capacity, growing seasons, and physiographic features (De Pauw 1984; IIASA & FAO, 2012). Based on these conditions, IIASA and FAO (2012) have designed global edaphic[4] requirements for each AEZ stating how specific crops should be grown and managed to achieve desirable output (Ulery & Goss, 2013; IIASA & FAO, 2012).

Looking at the FAO’s map of the EA countries (see Figure 6), one can see that the region is covered by various AEZ, where Ethiopia, Tanzania, and Uganda are mainly *subhumid* (light green color) and *humid* (dark green color) AEZ. Although Ethiopia’s eastern regions are warmer with less rainfall, causing an *arid* climate zone (red color), most of the zones are *subhumid.* These zones have a climate with a stable temperature variability with rich vegetation of prairie grassland. The *humid* zones, on the other hand, have a more fluctuating climate with scorching summers and mild winters, meaning that farmers living in these zones face sudden weather changes more frequently (De Pauw 1984;  Ardö &Yengoh, 2020; Arslan et al. 2015; AMS, 2012; Shiferaw, Negassa, Koo & Sonder, 2013).

When studying the three countries' agro-climate in detail (*see Appendix C.3-C.5*), these two main zones (*subhumid* and *humid*) can further be divided into five subcategories to make interpretation easier, These zones are; *tropic-warm/humid, tropic-warm/subhumid, tropic-cool/humid* and *tropic-cool/subhumid* (De Pauw 1984; Ardö & Yengoh, 2020) where *tropic-cool* and *tropic-warm* represents two main divisions of temperature variation (below and above the AEZ-average). Whilst the *tropic-warm* zone is characterized by drier lands with high variability in rainfall patterns (the rainfall period begins before or after the AEZ-average). The *tropic-cool* zones, in contrast, are cooler due to lower fluctuation in temperatures which often appear in zones with higher altitudes (Arslan et al. 2015; IIASA & FAO, 2012).

The maize crop, itself, is grown in all of these five AEZ. As seen on the map in *Appendix C.6* which shows major crops grown in the EA region, the maize crop is mainly grown in central Ethiopia and the southwestern and northeastern parts of Uganda and Tanzania. The most suitable conditions for the growing of maize are when temperatures lay between 25 ℃ and 27 ℃ during daylight, whereas during nighttime, optimal temperatures range between 17 ℃ and 23 ℃.  When high-temperature stress occurs and there is a

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[4] The term “edaphic” refers to drainage texture and soil conditions and thus explains the agro-climate in more detail, something which is of advantage for the farmer (Ulery & Goss, 2013).

swing from optimal conditions, it decreases the grain yield and growth rate of the production through a disturbance of various physiological processes (Ahmed Wagas et al. 2021; FAO, 2016; Arslan et al. 2015).

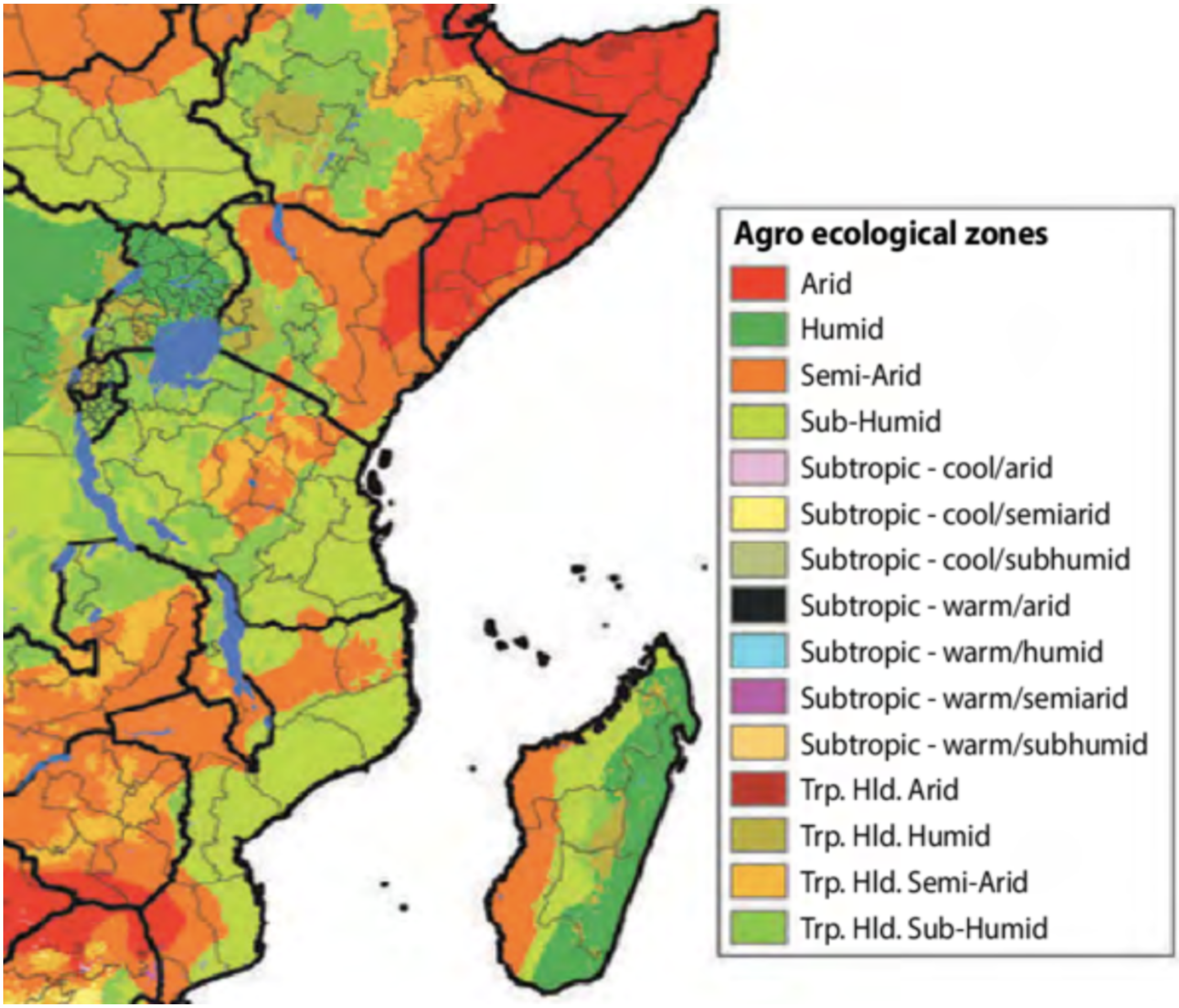

Figure 6. Map of agro-ecological zones (AEZ) in the East African Region
Source*:* Shiferaw, Negassa, Koo & Sonder (2013)
Note: Country-specific maps of AEZ can be found in Appendix C.3-C.5

By 2050, approximately 45 percent of the global maize area is expected to face more than five days in a row every year when maximum temperatures lie above 35 °C (Ahmed Wagas, Syed, Mehmood, Hafiz, Muhammed & Muhammad, 2021). Within this area, a major part of the production is placed in the EA region, where the economic yield of the maize crop is projected to decrease by 3-13 percent as temperatures rise by a mere 1 °C (Ahmed Wagas et al. 2021; FAO, 2016; Arslan et al. 2015).

Furthermore, the five AEZ included in this study are characterized by different weather conditions, impacting the cultivation of maize. When comparing *Appendix C.6* with Figure 6, it seems clear that the maize crop is mainly grown in *subhumid* and *humid* AEZ whereas *arid* and *semi-arid* zones (red and orange color) contain less maize production due to higher temperatures. In these areas, temperatures can exceed 35 °C during a growing season, weakening the maize crop's development stages (Ahmed Wagas et al. 2021; Rioux et al. 2017). Yet, it is not fully clear how the annual output of maize changes when testing for certain AEZ and CSA techniques. To fully understand the weather conditions of the zones and how temperatures affect the maize crop, climatological information is summarized in Table 1 below.

Table 1. Climatological conditions under normal conditions and climatic shock

| A: *AEZs* (specific) | **Humid** | | **Subhumid** | |
|---|---|---|---|---|
| | *Tropic warm* | *Tropic cool* | *Tropic warm* | *Tropic cool* |
| Rainfall distribution (mm/year) | 200-800 | 1200-1800 | 800-1200 | 200-600 |
| Average temperature (range) | 29°C (7,7) | 22°C (6,4) | 27°C (2,8) | 17°C (2,4) |

*B: Climatic shock* (general)

| **Scenarios** | **Temperatures classifications** | **Symptoms of the maize grain** | **Yield Reduction** | **References** |
|---|---|---|---|---|
| (1) | 6°C above mean temperature for more than 3 days | Growth rate severely decreased | 13% | Siebers et al. (2017) |
| (2) | 35°C | Abnormal tassel growth | 31% | Yang et al. (2017) |
| | 33 to 36°C | Pollination failure | 10-45% | Neiff et al. (2016) |
| (3) | 30-38°C for 15 days | Low crop performance | 14-17% | Hussain et al. (2019) |
| (4) | 28-32°C | Substantial decrease in growth rate | 10% | Thompson (1975) |
| (5) | Each degree above 30°C | Pollination failure | 1-1.7% | Lobell, Bänziger and Magorokosho (2011) |

Source: Shiferaw, Negassa, Koo & Sonder (2013)

Note: The numbers in A represent the average number of the EA region (the numbers in parentheses is the standard deviation). Table A and B are not linked but summarized together to allow for comparison.
Table B is general and affects all AEZ. Scenario (1) and (4) are tested in the result section.

## 2.4 What is Climate-Smart Agriculture (CSA)?

CSA is a land management approach developed by the FAO in 2009 and contains various agricultural practices and guidelines to increase farmers' resilience to climate change (Lipper et al. 2014). It contains three pillars, namely, *productivity, mitigation,* and *adaptation* which all aim at decreasing carbon emissions from the agricultural sector while increasing the level of food supply (Ahmed Wagas et al. 2021; FAO, 2016). According to the United Nations World Food Programme (2021), CSA is considered an important step toward the realization of the second goal of the 2030 Agenda (SDG2) about reaching zero hunger for all. Nevertheless, despite its interlinked and horizontal approach to farming which connects various sub-sectors, the operationalization is vague and difficult to grasp. Therefore, it is necessary to break down the pieces and look at their meaning in a stepwise manner (WFP, 2021).

Beginning with its sub-sectors, CSA is divided into 1) aquaculture and fishing enterprises, 2) crop practices and technologies, 3) livestock farming, and 4) other practices and technologies. The practices that are central to this research, *improved seeding, intercropping* and *inorganic fertilization,* all belong to the second subsector. This subsector is further divided into three different subcategories, namely 1) crop management (improved seeding), 2) conversation agriculture (intercropping), and 3) soil fertility management (inorganic fertilization) (Lipper et al. 2014). All categories contribute differently to productivity but do have a joint goal of maximizing the crop yield while increasing the level of resilience during periods of droughts or severe flooding. As seen in Table 2 below, the three countries have a slightly different use of the different practices. Although the majority of the farmers still use traditional methods, it seems clear that more than 12 percent applied one of the three CSA techniques.

Table 2. CSA practices implemented in 2010-2012 by country, in percent (%)

| | (1) Improved Seeding (Traditional/Improved) | (2) Intercropping (Pure Stand/Intercropped) | (3) Inorganic Fertilization (No Application/Application) |
|---|---|---|---|
| Ethiopia | 70/30 | 65/35 | 71/29 |
| Tanzania | 52/48 | 70/30 | 75/25 |
| Uganda | 88/12 | 55/45 | 81/19 |

Source*:* Estimated by author, data from CSA (2011), NBS (2011) and UBS (2011)

Let us look into the different techniques and why they are used. *Improved seeding* is a technique that uses stabilized and strong crop varieties. By doing so, the research has focused on developing the quality of the seed so that it needs less water and thus grows even under periods of prolonged droughts (Basnyat, 2017; Rioux et al. 2017). On the contrary to traditional seeding which is applied under longer periods on low yields, the *improved seeding* is used under shorter periods on higher yields. It is still uncertain which seeds are the most suitable for improving productivity. Yet, research has shown that *improved seeding* has reached a higher level of maturity and is thus less dependent on irrigation, fertilizers, and pesticides. Something which allows the farmer to maximize the planting of various seeds, maximizing the planting on the plot (CIAT & World Bank, 2017).

Further, *intercropping* is a practice that has become highly relevant for the growing of maize since this is a crop sensitive to severe sunlight. The farmer plants various crops together, which means that shallow-rooted crops are protected when the average temperature peaks (Zaefarian & Rezvani., 2016). Lastly, *inorganic fertilization* is a method used to improve soil fertility by spreading synthetic chemicals on the soil. This is supposed to maximize the growth of the plant since synthetic material increases the respiration of oxygen during higher temperatures  (Basnyat, 2017; Rioux et al. 2017; Akinnfesi, 2018).

The method has led to a long debate around controversies about its effect on soil and biodiversity. While one camp emphasizes its efficiency in maximizing the growth of the crop, opponents argue that spreading synthetic chemicals has negative effects on human health and manipulates the crops' dependency on pollination. On the contrary, scholars have proven that farmers using this method specialize in a few crops, which allows them to abandon labor-intensive farming. Thus, *inorganic fertilization* intensifies the production, which in the long term improves the harvest and nutrition intake among farmers' households (Akinnfesi, 2018; FAO, 2018b).

Let us now look into the policy measures undertaken in the three countries (Ethiopia, Tanzania, and Uganda). Each country has adopted the CSA framework although they are in different stages of the implementation process. Even though the CSA approach was designed recently, various policy measures within the EA region have been taken to boost agricultural productivity. Currently, the shared challenge in EA countries is finding a joint action between stakeholders and designing a context-specific use of CSA, taking local climatological conditions into account (Rioux et al. 2017; Yalew, 2016; Hisali, Birungi, Buyunza, 2011; CIAT & World Bank, 2017).

Still,  the CSA framework is mainly adopted at a national level, leading to ignorance of climatological variations across AEZ. Further, the scale-up of CSA demands wide cooperation between NGOs, researchers, governments, private sectors, and farmers. NGOs play a role in promoting indigenous CSA techniques and provide farmers with technical assistance; researchers engage in collective learning and conduct participatory research. The private sector, on the other hand, engages in farmers' communities and identifies risk management strategies while farmers engage with all stakeholders through farmer field schools (FFS). Lastly, the government, which is the main contributor to the implementation of CSA, strengthens awareness among stakeholders, formulates strategies, and fosters capacity building (CIAT & Worlds Bank, 2017; Rioux et al. 2017; URT, 2009; TaCCIRe, 2012).

Within each of the EA countries examined in this study, CSA policies are formulated by the Ministry of Agriculture.  In Ethiopia, the government implemented various programs. The main program is called the "Sustainable Land Management Programme (SLMP)" (FAO, 2016). SLMP covers six regions  to streamline CSA projects and address resilient techniques to face climate change variability and improve land productivity among Ethiopian farmers. Within the SMLP, CSA refers mainly to proven practical techniques such as agroforestry, improved water management, mulching, *intercropping*, *improved seeding,* and *inorganic fertilization* (FAO, 2016).

Similarly, the Tanzanian government (the Ministry of Agriculture) has adopted a program to promote CSA and scaled up actions. Through the "Tanzanian Climate-Smart Agriculture Alliance (TCSAA)"(TaCCIRe, 2012), information sharing, dialogue between stakeholders, and coordination strategies are put in focus.

The program promotes research on CSA techniques and  allows the private sector to invest in certain projects to reduce climate change's impact on Tanzanian farmers (TaCCIRe, 2012; URT, 2013).

Lastly, the Ministry of Agriculture in Uganda has, in collaboration with the Ministry of Water and Environment (EWA) and other international organizations, undertaken several CSA projects across the country, with the main focus on reducing climatic shocks on food crops such as the maize grain. For instance, a program called “Enhancing Adoption to Climate-Smart Agriculture Practices in the Farming System of Uganda" (FAO, 2016) is of major importance since it invests in weather forecasting, farmers' schools, and platforms for dialogue between farmers across the country (FAO, 2016).

Yet, countries lack administrative, technical, and financial support for the scale down of CSA to local communities, making the adoption among farmers extremely poor. Further, since there is no CSA coordination across the region, knowledge-sharing and cooperation across borders are still relatively low, although farmers live in similar AEZs. To scale up the use of CSA, CIAT and World Bank (2017) and Rioux et al. (2017) emphasize designed policies that consider the site-specific variability in climatological conditions. Studies examining the local context are, therefore, of major importance since it contributes to such policies and gives farmers a joint agenda on productive and sustainable farming. To fully understand this matter and the complexity of downscaling CSA, an in-depth analysis of current literature is provided in the next chapter.

# 3 Literature Review

This section will discuss the main findings from the literature. The CSA approach has been widely discussed within the EA context but has been a relatively new research body since it was introduced in 2009. The literature stressing CSA has been divided into three angles, whereas the last research angle *increasing productivity and crop yields* (section 3.3.3) is the focus of this paper.

## 3.1 Maize production and Climate Change

Climate change is the effect of increasing anthropogenic greenhouse gas emissions since the pre-industrial era. Scholars have proven that this trend has mainly been driven by population and economic growth, resulting in greenhouse gas emissions which are now more prominent than ever before (IPCC, 2014; Kotir, 2011). According to Besada and Sewankambo (2009), the IPCC's 4th Assessment Report ignores increasing concerns about climate change within the African continent. They argue that the discussion of climatic changes should focus on the links between climate change and recent disaster events such as coastal storms, floods, droughts, and desertification rather than forecasts on carbon emissions and future environmental damages. They further claim that these climate disasters endanger lives and livelihoods and obstruct Africa's economic and social progress. Besada and Sewankambo (2009) look into these climatic trends more broadly, nevertheless, to understand the effect on the maize crop it is of relevance to discuss the literature that emphasizes the maize industry within the African region.

Maize is a crop that originated in Mesoamerica and is now produced across the globe (Shiferaw et al. 2011). It is best grown at moderate latitudes close to the equator where the temperature is stable all year round (Leff, Ramanknutty, & Foley, 2004). In Africa, the crop accounts for 30 percent of the total cultivated land area, and it provides over 30 percent of the calories and proteins consumed (Cairns et al. 2013). Low and lower-middle-income nations produce 67 percent of total maize production in the developing world, demonstrating that maize has an imperative role in the livelihoods of many poor farmers (Shiferaw et al. 2011).

Despite its importance, papers by Cairns et al. (2013) and Adhikari, Nejadhashemi and Woznicki (2015) emphasize that the maize productivity has remained relatively low in Sub Saharan Africa (SSA) with a slight increase from 0.9 to 1.5 tons/ha, with high variations in yield output. They further state that this is mainly due to uncertain climatic conditions and dependency on rainfall (Cairns et al. 2013; Adhikari et al. 2015). This finding adds to the IPCC report (2014), highlighting that the maize yield has been significantly impacted by climate change due to rainfall dependency in numerous places. As a result, maize yields in SSA have stagnated and remained below two tons per hectare even when including the top five maize-producing countries in the world (Cairns et al. 2013).

According to Ng'ombe, Kalinda, and Tembo (2017) and Hamududu and Ngoma (2019), the leading cause for the disparity in maize yields between EA and other regions is the limited adaptive capacity of smallholder farmers when facing the impacts of climate change. Ng'ombe, Kalinda, and Tembo (2017), who examined the linkages between conservation farming and increased crop revenue, argue that the negative consequences of climate change, such as soil erosion, droughts, or floods, are impeding the success of agriculture in EA. To add to this finding, Hamududu and Ngoma (2019) quantified the impacts of climate change on water resources in Zambia suggesting that the rain-fed-farming systems (which are common in EA) are often coupled with a limited adaptive capacity. Therefore, having a proper irrigation system decreases a farmer's vulnerability to climatic impacts. This result corroborates with Smale, Byerlee, and Jayne (2011), who conducted policy research on the maize revolution in SSA for the World Bank. Their paper claims that when considering rain-fed areas, the yield gap between EA and other regions with identical production conditions, the maize yield remains lower in EA. These results indicated that farms with low maize yields are primarily attributed to drought stress than other factors such as weeds, soil fertility, low input availability, inappropriate seeds, pests, or poor irrigation schemes (Hamududu and Ngoma, 2019; Masasi and Ng'ombe, 2019).

While the effects of climate change on maize production appear to be consistent across SSA, trends in maize production in some SSA nations, such as Zambia and Zimbabwe, have shifted due to efficient agricultural policies. In recent years, Zambia has seen a boom in its maize production, mainly due to the availability of subsidized farm inputs, which has improved the technical efficiency of maize production in most provinces across the country (Ng'ombe, 2017). As indicated by Smale, Byerlee, and Jayne (2011), the situation in Mozambique, Angola, and Ethiopia, on the other hand, is different since wars and prolonged civil strife have depressed productivity trends and maize production. Nevertheless, except for the significant impact of wars, the evidence put forward by Amondo and Simtowe (2018) indicates that droughts or floods account for 70-80 percent of maize losses in SSA. As previously mentioned, maize is a highly susceptible crop to increasing temperatures and droughts, leading to a situation where farmers may abandon their plot after planting depending on weather circumstances (Mulungu & Tembo, 2018).

Nelson et al. (2009), who researched for the International Food Policy Research Institute (IFPRI), revealed that the negative impacts of climate change on crop production are especially evident in SSA compared to other agrarian countries across the world. Floodings, droughts, and the loss of arable land, all of which contribute to lower agricultural yields through pathways like loss of livestock and crop failure. As a result, prior years in SSA have been characterized by a 10 percent decrease in maize yield. Current yield projections show that yields from rain-fed agriculture in many SSA countries, including Tanzania, Ethiopia, and Uganda, could be reduced by up to 50 percent in a few years, posing a significant threat to food security (IPCC, 2014; FAO, 2016; UN, 2019). Furthermore, Mulungu, Tembo and Ngoma (2019) predict a worst-case scenario for these countries by arguing that maize yields will decrease by 25 percent, with temperature rises negating the advantages of rain seasons. Along similar lines, Hamududu and Ngoma (2019) suggest that climatic changes will reduce water availability by 13 percent within the region by the end of this century, putting water-intensive crops like maize at great risk.

## 3.2 Adapting maize production to weather changes

Regarding climate change adaptation in vulnerable areas, research on maize production has played a crucial role (Shiferaw et al. 2011). Because of weak institutional, technological and financial capacity, Africa has for long been projected as the most vulnerable region to climate change, meaning that adapting the agricultural sector to these trends will be challenging and complex. Thus, many of these negative consequences are expected to be mitigated through research and plant breeding, a scientific method that produces desired plant characteristics by challenging its traits. Adjusting agricultural rotations, shifting planting dates, or adopting pre-existing crop types are autonomous responses that will help counter some of the detrimental effects of climate change (Knox, Hess and Deccache, 2012).

Yet, scholars such as Tesfaye et al. (2015) emphasize that adapting agricultural systems is crucial to ensuring food security for an increasingly growing population in SSA. Thus, designing relevant measures to target hotspots of climate change and understand its socioeconomic implications at various scales. For instance, Smale, Byerlee, and Jayne (2011) argue that regular investments in maize productivity and the adoption and development of fertilizers and improved maize seeds are crucial for food security and the growth of the agricultural sector. Thanks to investments in efficient agricultural techniques in Ethiopia, the maize area covered by improved seeds increased from 14 to 40 percent between 2004 and 2013 (Abate et al. 2015). Still, the country needs continuous investment in new techniques that could develop a new generation of climate-resilient farming such as *improved seeding* that is resistant to pests, nutrition-efficient, and, most importantly, tolerant to drought and increasing temperatures (Smale, Byerlee and Jayne, 2011).

Therefore, if adequate measures to adapt to the negative impacts of climate change are not taken, the risk of food insecurity is likely to rise tremendously (Khanal, Wilson, Lee, and Hoang, 2018). As indicated in the literature, there is a need for policies supporting investments and implementations of farming techniques such as fertilizer, soil conservation, or maize varieties; all practices that have proven to be tolerant to waterlogging, drought, heat, and insects (Shiferaw et al. 2011). Amos et al. (2015) highlight that governments in Uganda, Ethiopia, and Tanzania have adopted various strategies to increase farmer resilience, such as weather stations aiming to warn and prepare farmers for extreme weather. By giving farmers weather projections about soil quality, water availability, and drought, they will be able to design their agricultural practices for a given period. Further, governments within the three case studies support the education of farmers, research, and capacity building to accelerate long-term solutions for innovative technologies and resilient land management (Amos et al. 2015).

Moreover, scholars have touched upon crucial strategies for creating a more sustainable approach to land management. Hisali et al. (2011) emphasize the importance of reducing the consumption of agricultural products, improving labor supply, and increasing financial savings while also accelerating the research on innovative agricultural technologies. The CSA approach is described as an impactful agricultural approach since it addresses innovative techniques while acting as a platform for increased dialogue (Hisali et al, 2011). Through CSA policies, farmers can reach out for finance,  and education and be a part of a farmers network that collaborates with stakeholders within the SSA and EA region, on both a national and international level. While national NGOs primarily support CSA through raising climate awareness, international institutions such as AGRA, IFAD, and IEDS[5] allocate approximately 35 percent of the budget to adaptation strategies within EA countries (CIAT & World Bank, 2017).

Directly or indirectly, each stakeholder fosters investments through mandated targets towards one or all three of the CSA pillars (productivity, mitigation, adaptation). This network leads the adaptation of the maize industry in SSA by investing in techniques and promoting farmers' communities (CCAFS & UNFAO, 2014; FAO, 2018a). To address policy measures toward efficient agricultural techniques, the next section will discuss the literature that has examined the CSA approach within SSA.

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

## 3.3 Climate-Smart Agriculture (CSA)

Throughout this subsection, three main research angels on CSA will be examined, and important debates about its efficiency will be highlighted. To get a clear understanding of these angles, each angle will be discussed separately. Finally, the contribution of this paper will be discussed in section 3.3.3.

### 3.3.1 Economic impacts and trade-offs

Various papers have examined the wider impact of climate change on agricultural production by looking at CSA with a cross-sectional focus (Mwongera et al. 2017; Gallup et al. 1999; Sachs and Warner 1997; Nordhaus, 2006). Scholars such as Mwongera et al. (2017) discuss the notion of 'trade-offs'[6] as a result of disciplinary thinking when implementing sustainable land management practices. As explained previously, the CSA approach requires a collaborative approach between farmers, the private sector, and governments. Suppose stakeholders work with their specific mandate without regard to other targets. In that case, a trade-off usually appears since one goal within CSA (adaptation, mitigation, productivity) is being fulfilled at the expense of another. To prevent trade-offs in the implementation process, Mwongera et al. (2017) therefore argue that having an integrated or an economywide approach when implementing land management policies is of utmost importance.

An example of such a trade-off was examined by Robinson et al. (2012) in Ethiopia. They looked at the inconsistencies between developing rural road networks while also protecting land from these constructions due to the extension of irrigation systems. While improved rural roads allow them to easily connect with other stakeholders and sell their agricultural products at the local market, building roads decreases the land area and thus limits plot sizes and yield outputs. Other paper looking at this topic is Yalew (2016), Komarek et al. (2019), Gebreegziabher et al. (2016), and Robinson and Willenbockel (2011), nevertheless, they do not emphasize the issues with silo-thinking and trade-offs, but rather on the inconsistencies between economic efficiency and investments packages.

Shilomboleni et al. (2020), on the other hand, take a new angle when looking at economywide effects by focusing on the impact of CSA on the social economy. Specifically, the concept can be understood 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). Through this definition, Shilomboleni et al. (2020) suggest that joint solutions are needed to capture this definition and operationalize it into reality. Accordingly, their paper suggests that public-private partnerships (PPP), investing strategies, and platforms for shared policy dialogue are required for CSA to be fulfilled.

Similarly, Newell et al. (2019) argue that CSA approaches need to be more than just a solution to sustainable land management locally. It needs to be seen as the concrete implementation of the UN sustainable goals SDG2 and SDG12 about no hunger and sustainable production. By creating platforms for incentives, multi-stakeholder collaboration, and peer learning through the lens of SDG2 and SDG12, CSA will also become a political pressure on African governments. Newell et al. (2019) suggest that establishing a national

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[6] A balance of factors which are not possible to fulfill at the same time. When disciplinary 'thinking' takes place, actors works in silos separately from one another. This creates a dilemma where one goal is fulfilled at the expense of another (Cambridge, n.d).

narrative around these goals will enable the African governments to steer their development and become a part of global achievements.

## 3.3.2 The impact on food security and income

This research angle focuses on the many forms of CSA and its impact on poverty levels and food security within farmers' households. Generally, two primary approaches within the literature can be outlined. While some scholars emphasize the role of government interventions in increasing food security (Samberg et al. 2016; Di Faco & Veroness, 2013; Hoegh-Guldberg et al. 2018), others argue that farmers individually play a crucial role in combining proper CSA techniques when maintaining stable food supply (Abdulai, 2016; Cholo et al. 2019).

Cholo et al. (2019) examined the combination of sustainable land management and land fragmentation and how the interlinkages increase food supply compared to households that did not combine these techniques. Their findings showed that households using new practices for farming, such as *improved seeding, intercropping* or *inorganic fertilization,* also reached out to farmers' networks to a greater extent. Through increased dialogue, these households could exchange ideas and improve their implementation of agricultural approaches such as CSA.

Along similar lines, Abdulai (2016) studied conservation agriculture (CA)[7] within Zambian households and concluded that exchanging ideas gave more opportunities for collaboration and stable income. Their study provides us with micro-level evidence of the linkages between stable incomes and food security. Through farmers' collaboration in combining efficient farming practices, farmers were able to increase their financial liquidity and re-invest in proper CA practices. Even though Samberg et al. (2016) add to these arguments, their paper takes another approach by focusing on the public sector as the main driver of improved food security. By studying farmers' vulnerability to weather changes, beyond their choice of implementing agricultural methods, governments can absorb the farmers' perspective and design efficient policy solutions. Therefore, their study emphasized the link between food supply and climate change, adding to the debate by increasing our knowledge of the indirect and direct impact of agricultural policies (Samberg et al. 2016). Thus, in contrast to Cholo et al. (2019) and Abdulai (2016), Samberg et al. (2016) emphasize the role of the state rather than the ability of the farmer to choose the most efficient combination of agricultural practices.

Additionally, papers by Hoegh-Guldberg et al. (2018) and Di Faco and Veroness (2013) take a similar approach but use a broader angle by looking at public services in combination with the private sector and farmers' organizations. They provide us with a long-term perspective on sustainable farming by arguing that farmers who collaborated with various stakeholders and were positive in developing their farming practices were more confident when preparing for future crises. Therefore, increased support and guidance from both the public and private sectors improved their ability to absorb innovative techniques for farming.

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[7] This agricultural technique is a leg within CSA and contains methods such as intercropping. CA focuses on minimizing soil disturbance by improving soil protection and species diversification from organic material (FAO, n.d).

The papers discussed used different approaches when discussing the impact of CSA on poverty, food security, and income. However, they all came to a joint conclusion that the link between human wellbeing, climate change, and policymaking is crucial and that the CSA approach brings farmers together into shared visions that can improve the quality of life.

### 3.3.3 Increasing productivity and crop yields

Moving to the third research angle and also the focus of this study, it can be concluded that various scholars have taken a micro-level perspective to receive evidence of the determinants of CSA and its productivity implications (Kassie et al. 2010; Arslan et al. 2015; Shiferaw & Holden, 1998; Kato et al. 2011). To do so, case studies have been used to look at a specific country or a geographical area of interest. In general, most of these studies agree upon the productivity implications of CSA and argue that it is a land management approach that creates resilience for the farmers, something which tends to increase productivity levels of the plot. Additionally, scholars such as Dell, Jones, and Olken (2012) suggest that this applies especially to countries situated close to the equator due to the tropical climate and high climate variability.

Nevertheless, even though there seems to be a general understanding of CSA as a resilient method that stabilizes the variation of the yield, there is an ongoing debate under which conditions this implies. A paper by Lal (2009) examined *mulching*[8] which is used to improve the quality of the soil and the investigation concluded that farmers who applied *mulching* on their plots increased their productivity. However, Lal (2009) makes an interesting finding by concluding that it is not the practice alone that increases the productivity of the plot but the use of lower labor inputs. Since mulching demands a low input of labor due to its time efficiency it gives the farm a more effective allocation of labor. In turn, greater means can be invested into weather alarming systems or other agricultural practices that potentially increase agricultural output.

To investigate this further, Branca et al. (2011) conducted a meta-study covering 217 CSA projects across SSA. The study focused especially on the practices of improved varieties, crop rotations, and mulching, and like Lal (2009), they concluded that CSA practices increase agricultural productivity by 116 percent on average. Along similar lines, a paper by Pretty et al. (2006) looked at various CSA projects across SSA and quantitatively examined productivity levels where certain practices were used. Their findings suggest that CSA, on average, stabilized the agricultural output and that this result was not due to lower labor inputs as Lal (2009) argued, but because the practices themselves prevent variation of the yield.

Worth noticing is that the studies mentioned above were all conducted on the selection of established CSA projects. Farmers included in their studies were familiar with the techniques and complexities around the implementation prices. Thus, this gives them an advantage in comparison to farmers that are unfamiliar with CSA and it is, therefore, possible to argue that the studies by Branca et al. (2011) and Pretty et al. (2006) used ‘success’ projects leading to a risk of selection bias. What about the farmers that did not use similar techniques? Would their findings still reveal a positive image of CSA if these farmers were to be included in the sample?

---

[8] Mulching is a farming technique where the farmer uses plant material such as leaves, straw, green manure crops, stones, crop residues, or plastic planes to protect the soil from erosion. Mulching provides nutrients to the crop and provides the soil with organic matter (Infonet, n.d).

To avoid selection bias, a paper by Arslan et al. (2015) included a diverse sample by including farmers who had both used CSA or continued with traditional techniques. By using Zambia as a case study they were able to divide the country into various agro-ecological zones (AEZ) and, therefore, take the site-specific weather condition into account. They concluded that practices such as *inorganic fertilization* and *improved seeding* positively affect agricultural output while *intercropping*, mulching, and minimum soil disturbance were not statistically significant. Nevertheless, all practices proved to have a stabilizing effect on crop yield output, especially regarding maize.

Similar to Arslan et al. (2015) this paper avoids selection bias by using a sample of farmers who used different techniques, labor inputs, and other pre-harvest strategies. Most of the studies mentioned above have used case studies looking into certain countries or CSA projects focusing on a set of different crops. To add to current literature, this paper provides a new level of granularity by looking into the plot level giving an in-depth understanding of a specific crop. Further, many scholars have proven that integrated collaboration is crucial for the implementation of CSA. This applies to actors across borders since they face similar challenges. Therefore, in contrast to previous studies, this analysis provides important evidence about the determinants of maize production across the EA region.

# 4 Data

This part focuses on the data used in this study. First, the data characteristics will be described, followed by a discussion of data limitations. Further, the chapter covers descriptive statistics and visualizes main trends within the data.

## 4.1 Living Standard Measurement Study (LSMS ISA)

The panel data used in this study was collected by the World Bank as a part of their Living Standard Measurement Study (LSMS ISA). The project covered SSA and was implemented in eight countries (Uganda, Tanzania, Nigeria, Niger, Mali, Malawi, Ethiopia, Burkina Faso) with a primary focus on increasing agricultural content and the comparability between these areas. The data was collected on a micro-level (household, plot, and crop level) within each country, mainly by national statistical agencies, all of which were part of the regional LSMS ISA project.

As seen in Table 3 below, the data on Ethiopia, Tanzania, and Uganda covers the period 2010 to 2012 and includes a total of 10 609 small-scale farmers who live in rural areas across various domains. Most of the farmers own multiple plots distributed in various AEZs. For each country, farmers were visited during two "waves," which symbolize one specific year. In other words, wave one covered the period 2010 to 2011, and farmers were later re-visited for wave two during 2011 and 2012. The waves contained similar information and were combined separately before merging the three countries into one data file.

Table 3. Country-specific datasets 2010-2012

| | (1) Ethiopia | (2) Tanzania | (3) Uganda |
|---|---|---|---|
| **Sample size:** | 3,969 | 3,924 | 2,716 |
| **Coverage:** | All rural and small-town areas | National | National |
| **Domains:** | Amhara, Oromiya, Tigray, SNNP and other regions | Dar es Salaam, Zanzibar, and rural mainland | Kampala and rural mainland |
| **Executing Agency:** | Central Statistical Agency (CSA) | National Bureau of Statistics (NBS) | Uganda Bureau of Statistics (UBS) |
| **Panel data:** | Yes | Yes | Yes |

Source: Based on data from CSA (2011), NBS (2011) and UBS (2011)

Note*:* For a geographical overview of the *domains* please see Figure C.3-C.5 in Appendix C.

The data covers fishery, crop production, and livestock in three different surveys, namely, geospatial, household, and agricultural surveys. While the geospatial survey covers geographical information (e.g., latitude, longitude, regions, AEZ, distances), the household survey includes data on linkages between socioeconomic and economic factors, focusing on agricultural production and food consumption (e.g., meals eaten per day). Lastly, the agricultural survey focuses mainly on production processes, including climatic conditions, agricultural methods, and harvest issues.

Since each country (each statistical agency) was a part of the LSMS ISA project, similar questions were asked to farmers' households. The data thus have similarities, making it possible to combine them. Further, the data is linked to the plot level due to farmers owning multiple plots. This strengthens the research as it adds more granularity than most of the research produced in the field. Since plots, even when owned by the same household, may be located in different AEZ, this study account for that.

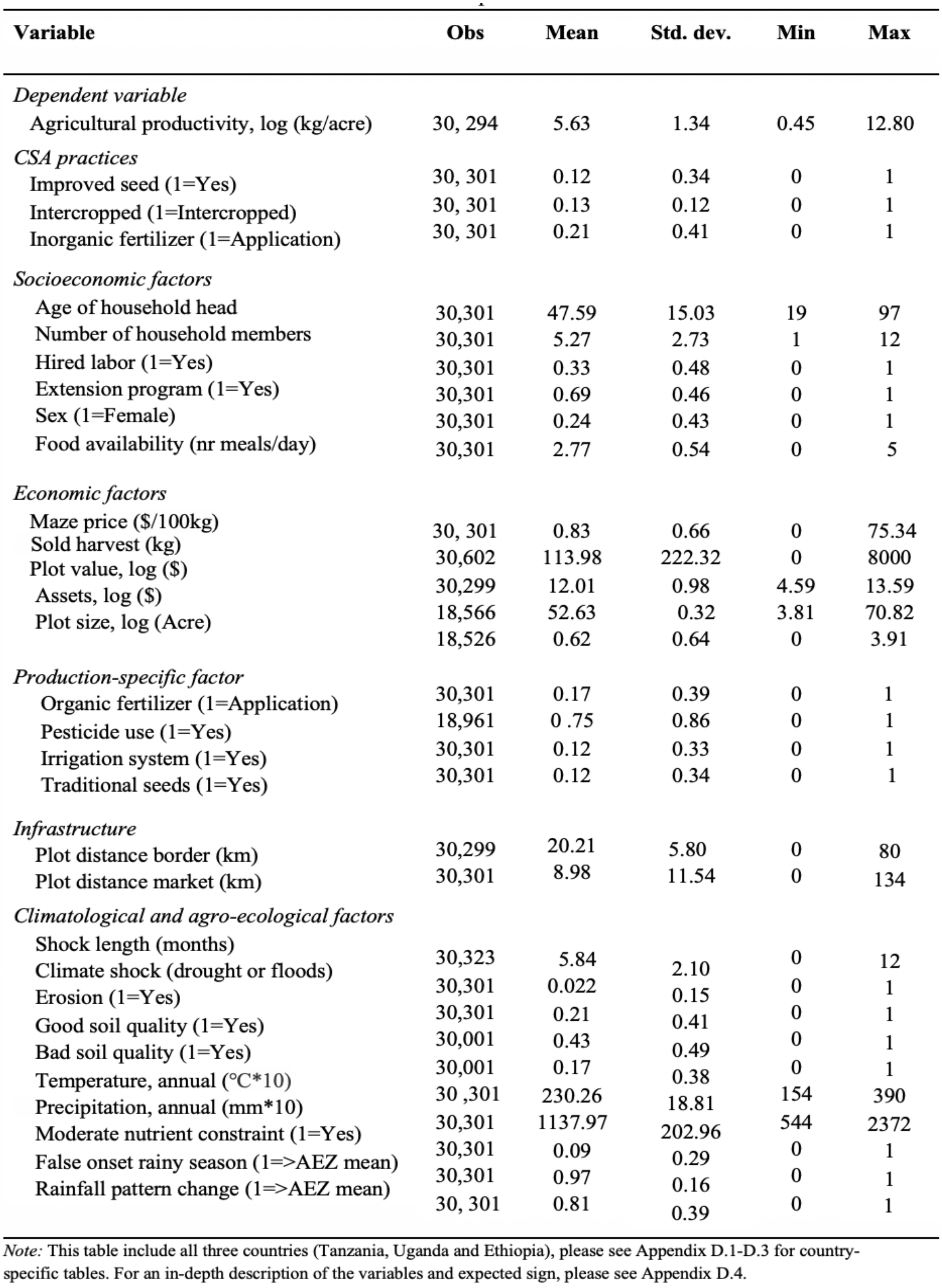
However, there are a few limitations with the data which needs to be taken into account. Although the LSMS data collection is portrayed as reliable due to the wide scope and the local dimension, there is no warranty regarding adequacy, legality, or reliability. Firstly, the data contains many missing values, and in some cases, the information between waves and the country data differs. Farmers that were included in the projects had a close collaboration with the LSMS team and felt trust in answering the survey. To avoid misunderstanding and biased results, the LSMS-visits were well-documented. For instance, when a different answer was given between the two years, follow-up questions were always included in the survey *(e.g How much did you harvest since our last visit? How has your consumption changed since last year?)*

On the other hand, it would be unreliable if the information about obstacles and faced climate conditions were repeated over the different sample periods. The life situation of these respondents changed between wave one and wave two, which is also a trend fully portrayed in the data (Arslan et al. 2015; Bell, Jones & Olken, 2012). Further, including many factors in the models also decreases the chance of omitted variable bias. The reader of this paper has to bear in mind that various factors affect the level of productivity, factors that were not included in this research. By executing robustness checks and including relevant variables that are likely influencers of productivity, the reliability of the estimations could be improved.

Regarding the data accuracy, it is highly relevant to answer the research question of this study. The LSMS project covers farmers who implemented both CSA and traditional practices, meaning that they can compare the most effective method. Using data that do not specifically target CSA users gives a more objective picture of its efficiency. The LSMSA team also argues that this approach avoids the issue of self-selection bias. The data includes information beyond the production-specific and considers livelihoods and food consumption trends across various geographical domains, making it possible to map, analyze and generalize the use of CSA properly.

## 4.2 Descriptive statistics

Table 4. Descriptive statistics



| Variable | Obs | Mean | Std. dev. | Min | Max |
|---|---|---|---|---|---|
| *Dependent variable* | | | | | |
| Agricultural productivity, log (kg/acre) | 30, 294 | 5.63 | 1.34 | 0.45 | 12.80 |
| *CSA practices* | | | | | |
| Improved seed (1=Yes) | 30, 301 | 0.12 | 0.34 | 0 | 1 |
| Intercropped (1=Intercropped) | 30, 301 | 0.13 | 0.12 | 0 | 1 |
| Inorganic fertilizer (1=Application) | 30, 301 | 0.21 | 0.41 | 0 | 1 |
| *Socioeconomic factors* | | | | | |
| Age of household head | 30,301 | 47.59 | 15.03 | 19 | 97 |
| Number of household members | 30,301 | 5.27 | 2.73 | 1 | 12 |
| Hired labor (1=Yes) | 30,301 | 0.33 | 0.48 | 0 | 1 |
| Extension program (1=Yes) | 30,301 | 0.69 | 0.46 | 0 | 1 |
| Sex (1=Female) | 30,301 | 0.24 | 0.43 | 0 | 1 |
| Food availability (nr meals/day) | 30,301 | 2.77 | 0.54 | 0 | 5 |
| *Economic factors* | | | | | |
| Maze price ($/100kg) | 30, 301 | 0.83 | 0.66 | 0 | 75.34 |
| Sold harvest (kg) | 30,602 | 113.98 | 222.32 | 0 | 8000 |
| Plot value, log ($) | 30,299 | 12.01 | 0.98 | 4.59 | 13.59 |
| Assets, log ($) | 18,566 | 52.63 | 0.32 | 3.81 | 70.82 |
| Plot size, log (Acre) | 18,526 | 0.62 | 0.64 | 0 | 3.91 |
| *Production-specific factor* | | | | | |
| Organic fertilizer (1=Application) | 30,301 | 0.17 | 0.39 | 0 | 1 |
| Pesticide use (1=Yes) | 18,961 | 0 .75 | 0.86 | 0 | 1 |
| Irrigation system (1=Yes) | 30,301 | 0.12 | 0.33 | 0 | 1 |
| Traditional seeds (1=Yes) | 30,301 | 0.12 | 0.34 | 0 | 1 |
| *Infrastructure* | | | | | |
| Plot distance border (km) | 30,299 | 20.21 | 5.80 | 0 | 80 |
| Plot distance market (km) | 30,301 | 8.98 | 11.54 | 0 | 134 |
| *Climatological and agro-ecological factors* | | | | | |
| Shock length (months) | 30,323 | 5.84 | 2.10 | 0 | 12 |
| Climate shock (drought or floods) | 30,301 | 0.022 | 0.15 | 0 | 1 |
| Erosion (1=Yes) | 30,301 | 0.21 | 0.41 | 0 | 1 |
| Good soil quality (1=Yes) | 30,001 | 0.43 | 0.49 | 0 | 1 |
| Bad soil quality (1=Yes) | 30,001 | 0.17 | 0.38 | 0 | 1 |
| Temperature, annual (°C*10) | 30 ,301 | 230.26 | 18.81 | 154 | 390 |
| Precipitation, annual (mm*10) | 30,301 | 1137.97 | 202.96 | 544 | 2372 |
| Moderate nutrient constraint (1=Yes) | 30,301 | 0.09 | 0.29 | 0 | 1 |
| False onset rainy season (1=>AEZ mean) | 30,301 | 0.97 | 0.16 | 0 | 1 |
| Rainfall pattern change (1=>AEZ mean) | 30, 301 | 0.81 | 0.39 | 0 | 1 |

*Note:* This table include all three countries (Tanzania, Uganda and Ethiopia), please see Appendix D.1-D.3 for country-specific tables. For an in-depth description of the variables and expected sign, please see Appendix D.4.

As seen in Table 4 showing the panel data, it consists of 10 609 small-scale farmers and includes information ranging from *socioeconomic, economic, production-specific, infrastructural,* and *climatological/agro-ecological* factors. The data are merged on the plot level since farmers own multiple plots distributed in various domains and AEZ (*see Appendix D.1-D-3* for country-specific tables). Agricultural productivity, which is the dependent variable, is a logarithmic variable consisting of 30, 294 observations ranging from 0.45 and 12.80. To illustrate productivity levels across various AEZ, a boxplot was created (*see Appendix B.3*) which shows that productivity levels are similar across AEZ, although plots located in *tropic-cool/subhumid* zones seem to reach a slightly higher productivity level. However, it is difficult to visualize a difference. Furthermore, when looking at the distribution of plots where CSA practices were used, Figure 7 shows that 62 and 35 percent of the plots were located in a tropic-warm/subhumid and tropic-cool/subhumid climate, respectively.

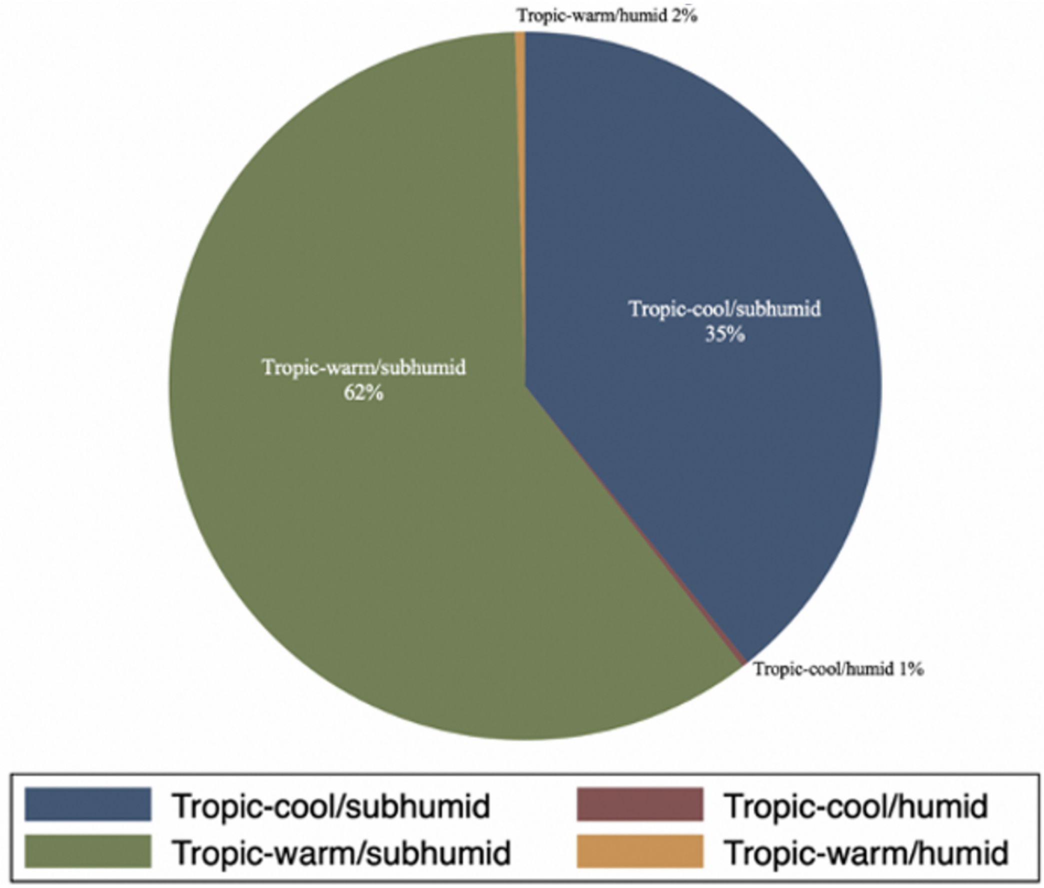


Figure 7. Distribution of plots by AEZ
Source*:* Based on data from CSA (2011), NBS (2011) and UBS (2011)

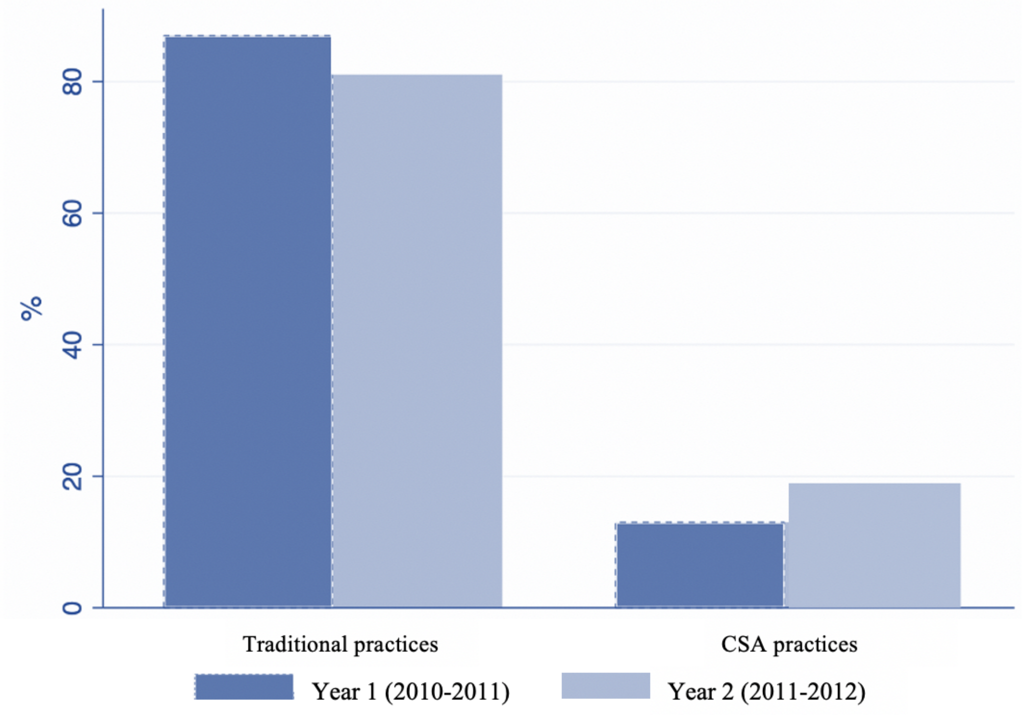


Figure 8. The use of traditional and CSA practices (2010-2012)
Source: Based on data from CSA (2011), NBS (2011) and UBS (2011)
Note: For country specific figures, please see Appendix B.4-B.6

As seen in Figure 8, it is clear that traditional methods (such as organic fertilization, traditional seeding, and pure stand) were the main approach used between 2010 and 2012. Small-scale farmers are used to these techniques throughout generations and might not be open-minded toward new land management approaches. Yet, while traditional practices decreased from 85 to 81 percent between year 1 and 2, CSA practices seem to increase among farmers. CSA was only used by 15 percent of the farmers during the first year while 19 percent became CSA users during the second year.

When zooming into the country-specific CSA usage (*see Appendix B.4-B.6*) it seems that the practices gained momentum, especially in Ethiopia. During the first year, only 2 percent of Ethiopian farmers applied CSA compared to 21 and 15 percent in Tanzania and Uganda. However, this percentage increased to 15-20 percent for all three countries during year 2. A result that reveals a positive image of the CSA impact.

When comparing the practices presented in Figure 9, it seems that the mean lies above 5 percent for all three although the boxplot for *intercropping* proves to be slightly higher than the other two. The outliers for *improved seeding* range between 1 and 12 yields in kg per acre indicating that its efficiency might vary within countries. Overall, Figure 9 proves that the impact of the techniques is slightly different, making an in-depth review relevant.

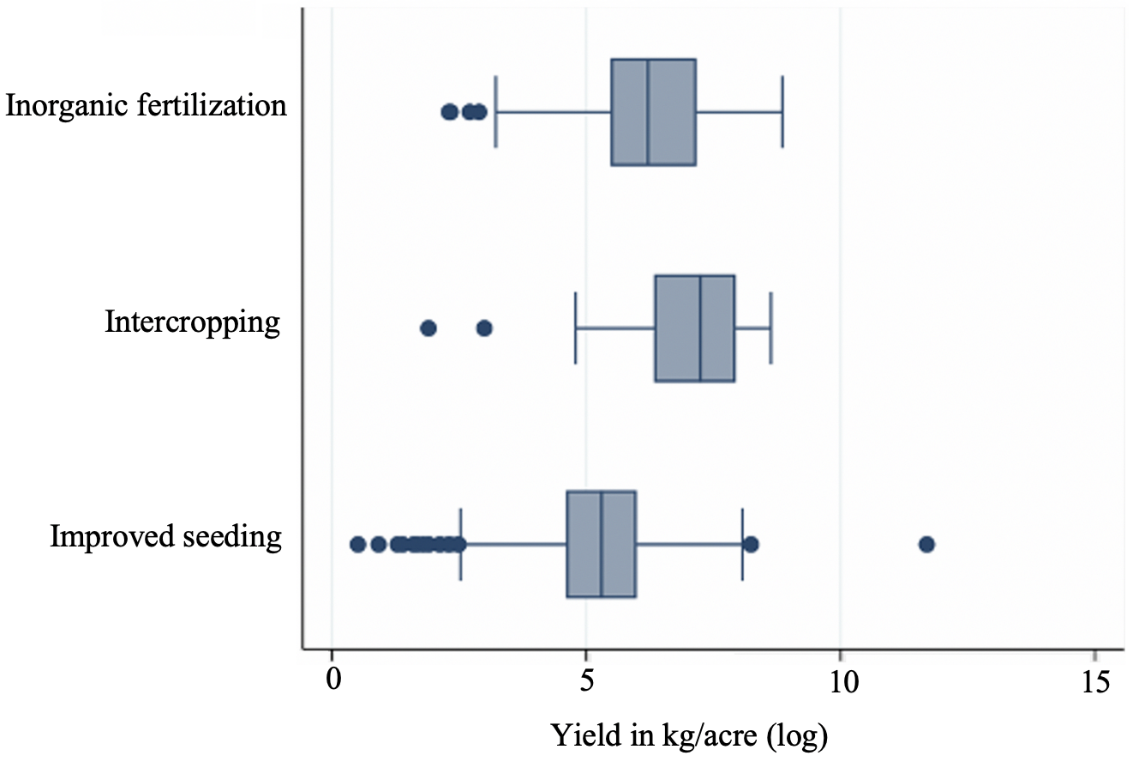


Figure 9. The productivity of the three CSA practices in the EA region (2010-2012)
Source: Based on data from CSA (2011), NBS (2011) and UBS (2011)

Further, studies have stressed the importance of human capital and the quality of life when examining agricultural productivity (Asadullah & Rahman, 2009; Feder et al. 1985; Nelson & Phelps, 1966). For instance, *food availability* determines whether the farmer can work effectively on their farm. Maize is an important crop for nutritional intake, and a lack of basic needs impairs a farmer's health and prosperity. In addition, studies have proven that the *number of household members* is relevant when analyzing food availability (Asadullah & Rahman, 2009). As seen in Table 4, a farmer's household eats between 0-5 meals a day. When testing the relationships between maize prices and temperatures, Figure 10 indicates that food availability (meals/day) is positively correlated with the maize price but negatively correlated to increased temperatures.

A possible explanation for these trends is that increased maize prices allow farmers to sell their harvest at the greatest prices, boosting their production and strengthening their financial stability. On the other hand, increased temperatures have proven to negatively affect the maize crop (see Table 1) through pollination failure and decreased growth rates in yields, leading to a poor nutritional intake in the household (Siebers et al. 2017; Yang et al. 2017; Neiff et al. 2016; Hussain et al. 2019; Thompson, 1975; Lobell, Bänziger & Magorokosho, 2011).

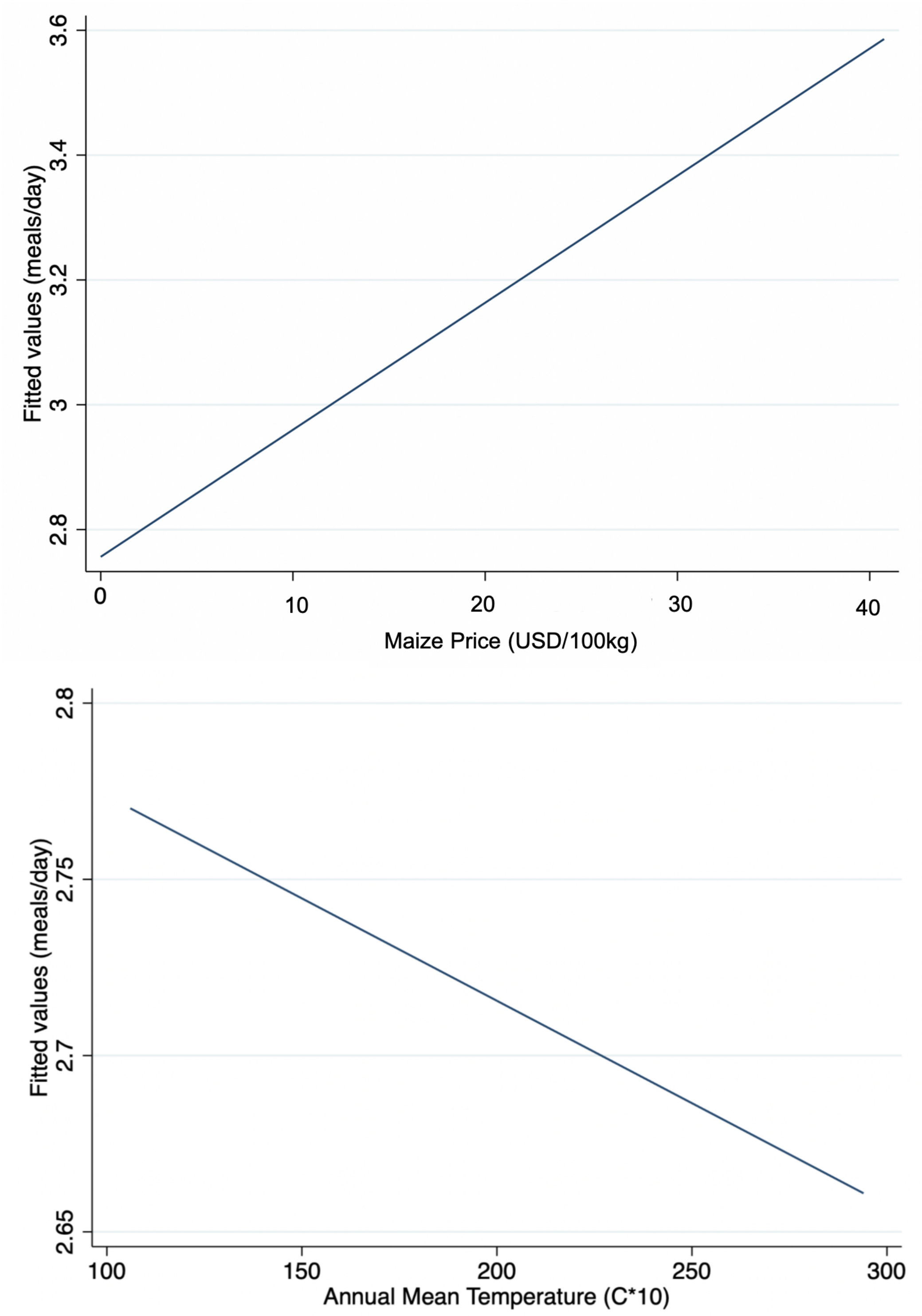


Figure 10. Maize price and temperature impact on nutritional intake in the EA region (2010-2012)
Source*:* Based on data from CSA (2011), NBS (2011) and UBS (2011)

# 5 Empirical Strategy

This chapter focuses on the empirical strategy and outlines the basic functional form to estimate agricultural productivity. An overview is given about the construction and assumptions around the used model followed by a final justification of the baseline model.

## 5.1 Estimation method

When operationalizing *agricultural productivity*, this research relies on the definition constructed by the FAO which defines it 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). In mathematical terms, it can also be defined as;

$$Prodt = Ot / Xt, \tag{1}$$

where *Prodt* is the productivity growth which is equal to the difference between the output and the input growth, respectively, at period *t:*

$$Prodt \cong Ot - Xt, \tag{2}$$

Solow (1962) also explains productivity growth as the growth in outputs which is not being defined by the growth of either inputs or residuals. In this study, the performance of the maize yield is quantified by using a *stochastic production frontier* approach. The production function method simply quantifies the given output produced, also expressed as *Yi,t* in model 3 below. Further, the method includes a set of inputs, usually expressed as *Xi,t* which in this study refers to the production-specific factors - such as the use of CSA methods. By using the stochastic production function, the following relationship can be outlined:

$$Yit = \beta x_{it} + \varepsilon_{it,} \tag{3}$$

where *i* symbolizes a plot and *t* denotes the period (FAO, 2018b). Nonetheless, to proxy *agricultural productivity* this research follows an approach outlined by Fermont and Benson (2011) which estimates the yields in kilograms per acre. This approach is further structured by Reynolds et al. (2015) who divided the weight of a harvested crop (in kg) with the land area of a given plot or farm (kg/acre). By using this approach, this analysis includes situations where farmers experience harvest losses between planting and harvest periods. After constructing the dependent variable in line with Fermont and Benson (2011) and Reynolds et al. (2015), I began with the assumption that agricultural output (y) of a farmer's plot (*i*) in a given year (*t*) is given by the amount of capital (K) and labor employed (L) plus an error term μ, written as:

$$y_{it} = f_{\mathrm{it}} (\mathrm{K}_{\mathrm{it}}, \mathrm{L}_{\mathrm{it}}) + \mu_{\mathrm{it}} \tag{4}$$

Further, I divide the farmers into two different groups, those who use CSA practices and those who use traditional techniques. Mathematically, this process is represented by the dummy variable, $C_t$, which interacts with the climatological situation of the farmer ($A_{it}$). Therefore, let us consider a function *g* denoted by:

$$y_{it} = g_{it}\,(K_{it},\ L_{it}, C_t,\ A_{it.}) + \mu_{it} \qquad [5]$$

where *g* can be expressed as:

$$git = K_{it} + L_{it} + C_t A_{it.} + \mu_{it} \qquad [6]$$

From equation 6, I can now expand production where K and L includes economic ($E_{it}$), socioeconomic ($S_{it}$), infrastructural ($I_{it}$) and production ($P_{it}$) specific factors:

$$git = S_{it} + E_{it} + I_{it} + P_{it} + C_t A_{it.} + \mu_{it} \qquad [7]$$

Ultimately, the basic functional form can be written as:

$$Y_{mpait} = \beta_1 S_{it} + \beta_2 E_{it} + \beta_3\, I_{it} + \beta_4 P_{it} + \beta_5\, C_t A_{it.} + \mu_{it} \qquad [8]$$

where $Y_{mpait}$ accounts for agricultural productivity proxied by the yield of the maize crop *m* measured in kilograms per acre of land (kg/acre) on plot *p* at household *i* at time *t.* Socioeconomic factors ($S_{it}$) contains information about *age of household head, number of household members, labor availability, extension program (farmer school), sex and food availability.* Further, economic factors ($E_{it}$), considers the *maize price, sold harvest, plot value*, farmer *assets* and *plot size* whereas the infrastructural factors ($I_{it}$) includes information on the plot distance to the national *border* and agricultural *market*. The production specific factor ($P_{it}$) captures dummy variables on the use of *organic fertilizer, pesticides use, irrigation system* and *traditional seeds*. The vector CSA ($C_t$) includes the three CSA practices that are of interest in this study, namely *improved seeding, intercropping* and *inorganic fertilization.* Lastly, climatological conditions ($A_{it}$) covers *climate shock* (droughts or floods), *erosion, soil quality, temperature, precipitation, moderate nutrient* and *rainfall patterns.*

# 6 Results

This chapter focuses on the estimated results and discusses the robustness of the findings. By following the methodological framework, using the basic functional equation [8] presented in the previous chapter, the *three* hypotheses are tested to answer the following research question: *Can regional differences in agricultural productivity be understood through the use of CSA, especially when controlling for the effects of climate shocks?* The section is divided into three subsections (6.1, 6.2, 6.3) to test the hypotheses.

## 6.1 Determinants of maize productivity across countries

*H1: Agricultural productivity of the maize yield increases across countries when CSA is applied*

This hypothesis was tested in two steps. While the first step, presented in Table 5, focuses on a stepwise analysis of the EA region, the second step, presented in Table 6, provides country-specific results. Based on Table 5 and 6, results indicate that CSA practices are positively associated with agricultural productivity of the maize yield across countries, even when adding the covariates. Thus, a result that supports the confirmation of H1, namely that *agricultural productivity of the maize yield increases across countries when CSA is applied.*

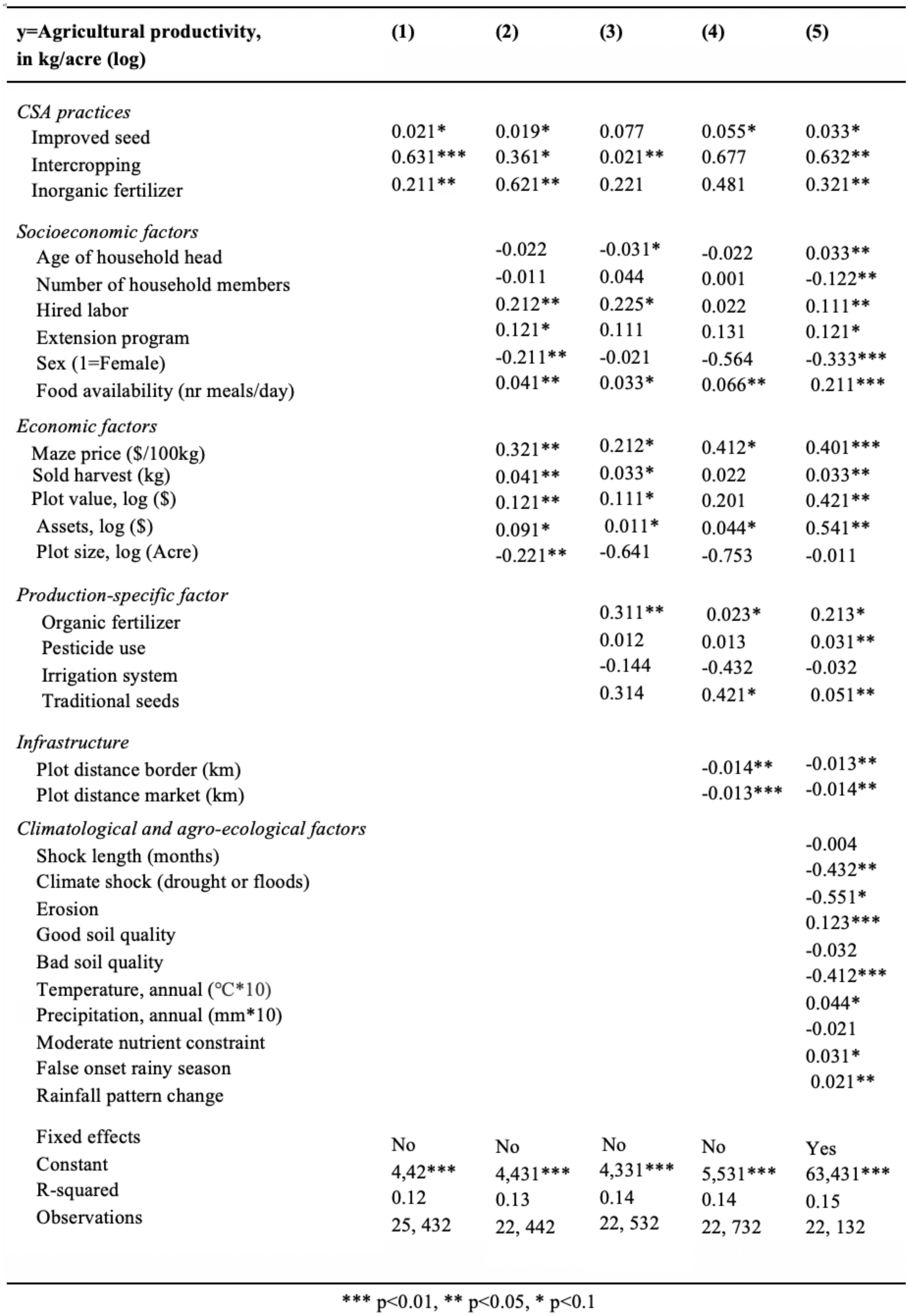
Beginning with the first step in the examination of H1, Table 5 was created through a stepwise procedure, adding the covariates (*socioeconomic, economic, production-specific, infrastructural,* and *climatological factors*) one by one. The baseline model is presented in column (5) with all variables included and fixed effects applied. The results show that *improved seeding* is lower in magnitude than the other two (0.033) and remains statistically significant only on a 10 percent significance level. Although the effect seems less significant, *improved seeding* is still positively associated with productivity, increasing the maize yield by 3.3 percent on average compared to farmers not using this technique, holding all other variables constant. Further, the coefficient between column (1) and (5) increase in magnitude, indicating that the efficiency of the practice increases when *climatological and agro-ecological factors* are taken into account in column (5).

On the contrary, *intercropping* show a much stronger effect on productivity in column (5). Intercropped maize plants are associated with an average increase of 63.2 percent compared to plots not subjected to this method. Still, its strong significance only applies to columns (1) and (5), which suggest that intercropped maize plants have a significant effect on productivity when controlling for *climatological and agro-ecological factors* (column 5). What could be the explanation behind this strong significant effect? Controlling for temperature and climatic shocks reveals the efficiency of the *intercropping* method as suggested by various scholars (Rioux et al. 2017; Zaefarian & Rezvani., 2016). Planting the maize plant close to other crops such as banana or sorghum provides the maize plant with shadow and protects it from the most severe sunlight (Rioux et al. 2017). *Intercropping* require little specific knowledge or extra labor since it is significant simpler when compared to other CSA techniques (Zaefarian & Rezvani., 2016).

When adding *infrastructural factors* in column (4), *intercropping* as well as *inorganic fertilization* becomes statistically insignificant. However, looking at column (5) the CSA variables becomes statistically significant again, proving that plot distances to borders and markets explain some of the variations, but this is only valid up to the point when fixed effects are added.

Furthermore, both *intercropping* and *inorganic fertilization* increase in magnitudes between column (1) and (5) and remain positive and statistically significant at a five percent significance level. Their determination to maize productivity is, therefore, possible to interpret. Furthermore, *inorganic fertilization* is associated with a slightly weaker significant effect on productivity compared to *intercropping*, improving the maize yield by 32.1 percent on average compared to farmers not using this technique. In contrast to the other two practices, *inorganic fertilization* is, however, associated with a stronger significant effect when adding *socioeconomic* and *economic factors* in column (2), increasing maize yield from 21.2 to 62.1 percent on average between columns (1) and (2), holding all other variables constant. In contrary, the other two become weaker in magnitude.

Table 5. Determinants of agricultural productivity, EA region



| y=Agricultural productivity, in kg/acre (log) | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| *CSA practices* | | | | | |
| Improved seed | 0.021* | 0.019* | 0.077 | 0.055* | 0.033* |
| Intercropping | 0.631*** | 0.361* | 0.021** | 0.677 | 0.632** |
| Inorganic fertilizer | 0.211** | 0.621** | 0.221 | 0.481 | 0.321** |
| *Socioeconomic factors* | | | | | |
| Age of household head | | -0.022 | -0.031* | -0.022 | 0.033** |
| Number of household members | | -0.011 | 0.044 | 0.001 | -0.122** |
| Hired labor | | 0.212** | 0.225* | 0.022 | 0.111** |
| Extension program | | 0.121* | 0.111 | 0.131 | 0.121* |
| Sex (1=Female) | | -0.211** | -0.021 | -0.564 | -0.333*** |
| Food availability (nr meals/day) | | 0.041** | 0.033* | 0.066** | 0.211*** |
| *Economic factors* | | | | | |
| Maze price ($/100kg) | | 0.321** | 0.212* | 0.412* | 0.401*** |
| Sold harvest (kg) | | 0.041** | 0.033* | 0.022 | 0.033** |
| Plot value, log ($) | | 0.121** | 0.111* | 0.201 | 0.421** |
| Assets, log ($) | | 0.091* | 0.011* | 0.044* | 0.541** |
| Plot size, log (Acre) | | -0.221** | -0.641 | -0.753 | -0.011 |
| *Production-specific factor* | | | | | |
| Organic fertilizer | | | 0.311** | 0.023* | 0.213* |
| Pesticide use | | | 0.012 | 0.013 | 0.031** |
| Irrigation system | | | -0.144 | -0.432 | -0.032 |
| Traditional seeds | | | 0.314 | 0.421* | 0.051** |
| *Infrastructure* | | | | | |
| Plot distance border (km) | | | | -0.014** | -0.013** |
| Plot distance market (km) | | | | -0.013*** | -0.014** |
| *Climatological and agro-ecological factors* | | | | | |
| Shock length (months) | | | | | -0.004 |
| Climate shock (drought or floods) | | | | | -0.432** |
| Erosion | | | | | -0.551* |
| Good soil quality | | | | | 0.123*** |
| Bad soil quality | | | | | -0.032 |
| Temperature, annual (°C*10) | | | | | -0.412*** |
| Precipitation, annual (mm*10) | | | | | 0.044* |
| Moderate nutrient constraint | | | | | -0.021 |
| False onset rainy season | | | | | 0.031* |
| Rainfall pattern change | | | | | 0.021** |
| Fixed effects | No | No | No | No | Yes |
| Constant | 4,42*** | 4,431*** | 4,331*** | 5,531*** | 63,431*** |
| R-squared | 0.12 | 0.13 | 0.14 | 0.14 | 0.15 |
| Observations | 25, 432 | 22, 442 | 22, 532 | 22, 732 | 22, 132 |

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

Source*:* Based on data from CSA (2011), NBS (2011) and UBS (2011)

Note*:* A table with standard errors can be found in Appendix D.5

Interestingly, when *production-specific* factors are added in column (3), both *inorganic fertilization* and *improved seeding* lose their significant effect while *intercropping* becomes very weak in magnitude (0.021). To understand this in greater detail, H2 was formulated which emphasizes the variations in productivity between CSA and traditional methods such as *organic fertilization, pesticide use* or *traditional seeds.* These results will be further investigated under section 6.2.

The result implies that considerable differences between estimated coefficients prove the importance of applying fixed effects. Excluding time-invariant factors in the baseline model (5), controlling for unobserved heterogeneity, resulted in a slight increase in R-square and stronger magnitude for all three CSA practices. When considering the estimated results for the covariates, column (5) with fixed effects is, therefore, put in focus when interpreting the results of the covariates.

In general, all covariates follow a priori expectations as expected and along similar lines with previous research *(see Appendix D.4).* For instance, *food availability* and *maize price* are both positively correlated with productivity as discussed throughout the paper. These variables are associated with an average increase in maize yields by 21.1 and 40.1 percent, respectively, suggesting that farmers might be able to increase their sold harvest and their living standards, as productivity increases.

The variable *temperature,* on the other hand, is negatively associated with productivity. In fact, one unit increase in temperatures is associated with an average decrease in maize yields by 41.2 percent, holding all other variables constant. Scholars presented in Table 1*,* suggest that different temperature increase scenarios harm the maize grain through abnormal tassel growth, and pollination failure, which causes low crop performance. Based on the results in Table 5, it seems that this study can confirm this hypothesis. The maize crop is sensitive to droughts, and increases in temperatures lead to droughts, harming primarily food availability and farmers' households highly dependent on the maize grain (see Figure 10). Thus, as shown through the temperature coefficient, food production can be severely disrupted if the temperature rises, on average, by one degree.

Table 6. Determinants of agricultural productivity, by country

| **y=Agricultural productivity, in kg/acre (log)** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| *By EA country* | | | | | |
| Ethiopia | (ref) | (ref) | (ref) | (ref) | (ref) |
| Tanzania | 0.021*** | 0.031* | 0.123 | 0.222* | 0.341** |
| | (0.034) | (0.011) | (0.043) | (0.021) | (0.044) |
| Uganda | 0.011** | -0.012 | -0.022* | 0.034* | 0.121** |
| | (0.021) | (0.033) | (0.091) | (0.001) | (0.026) |
| CSA controls | Yes | Yes | Yes | Yes | Yes |
| SOC controls | No | Yes | Yes | Yes | Yes |
| EC controls | No | Yes | Yes | Yes | Yes |
| PROD controls | No | No | Yes | Yes | Yes |
| INFR controls | No | No | No | Yes | Yes |
| CLIMA controls | No | No | No | No | Yes |
| Observations | 22, 234 | 19, 191 | 18, 256 | 15, 796 | 15, 222 |
| Fixed effects | No | No | No | No | Yes |
| $R^2$ | 0.2175 | 0.2169 | 0.2014 | 0.2212 | 0.2214 |

Robust standard errors in parentheses

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

Source*:* Based on data from CSA (2011), NBS (2011) and UBS (2011)

Does the result in Table 5 differ from Table 6, when controlling for country-specific productivity? The answer is no, at least when adding *production-specific factors* (see column 3)*.* This leads us to the second step of testing H1. Table 6 was created, and like Table 5, the results for each country become statistically insignificant in column 3 (when production-specific factors are added) and R-squared becomes weaker. Similar to Table 5, magnitudes increase between columns (1) and (5), suggesting that applying fixed effects to the model seems to exclude time-invariant factors, stabilizing the variations of coefficients.

Ethiopia was used as a reference since the country had comparatively fewer applications of CSA between 2010 and 2012, as shown in *Appendix B.4*. Although the use of CSA increased between years 1 and 2, using it as the reference reveals the actual CSA effect. As seen in Table 6, Tanzania, the country with the greatest share of CSA implementations between 2010 and 2012 (see *Appendix B.5)* is performing better than Ethiopia in terms of productivity. In column (5), Tanzania is associated with 34.1 percent higher maize yields on average, compared to Ethiopia, holding all other variables constant.

Along similar lines, Uganda, which had the second-highest implementation of CSA (*see Appendix B.6*) has stronger productivity of maize yields than Ethiopia in column (5) and an increase in magnitude between columns (1) and (5) when *climatological factors* are added*.* However, in columns (2) and (3), the coefficients become negative when *economic* and *production-specific* factors are applied. Possible explanations for this effect are due to the rise in prices in Ethiopia, as presented in Figure 4 (blue line). Between 2010 and 2012, Ethiopia exceeded the other two countries in terms of maize prices, meaning that Ethiopian farmers could sell their maize harvest at a greater price, a factor which has proven to positively impact productivity, as shown in Table 5. Further, high maize prices (see Figure 4 and *Appendix B.1*) and a dependency on traditional methods *(Appendix B.4-B.6)* might also explain the control for *production-specific factors*. Nevertheless, as already mentioned, H2 was formulated and examined in the next section to control variations between practices in detail. What can be concluded for this section is that the results in Tables 5 and 6 prove H1, namely that *agricultural productivity of the maize yield increases across countries when CSA is applied.*

## 6.2 Variations between traditional and CSA practices

> *H2: Agricultural productivity of the maize yield varies when controlling for both traditional and CSA techniques*

The previous section proved that CSA has a positive effect on maize productivity, confirming H1. However, this effect seems to vary, in EA and across countries, when adding *production-specific factors* that mainly emphasize traditional agricultural methods. Hence, H2 was formulated to test these variations further, adding more substance and insights to this study.  To do so, Table 7 was created, and these results were further robust tested in Table 8, by applying Propensity Score Matching (PSM).

The results in Tables 7 and 8 indicate a substantial variation between techniques, except for seeding types (improved or traditional seeding) which showed an insignificant impact. Therefore, H2 can only be confirmed for the utilization of fertilizers (organic vs inorganic) and planting systems (intercropped or pure stands). Hence, while the traditional use of fertilizers (organic) proved to be more efficient under normal conditions, the CSA technique of *intercropping* proved to be more effective both under normal conditions and when controlling for *climatological factors* (such as increased temperatures or prolonged droughts).

As seen in Table 7, *climatological factors* were excluded in order to test the practicality of these methods under normal conditions. The results imply that traditional methods such as *organic fertilization* are more efficient under normal conditions than *inorganic fertilization,* while *intercropped* maize plants seem to perform better than plots with *pure stands* (see panel A) The seeds use, traditional or improved, does not significantly impact productivity, suggesting that only *organic fertilization* seems to be more efficient under normal conditions, when climatological aspects are not taken into account.

When comparing the coefficients of the *intercropping* and *pure stand*, the magnitude for all countries increases between A and B. For instance, in Ethiopia, farmers using an intercropped planting system on their plots are associated with an average increase of 12.1 percent than farmers not using this technique, holding all other variables constant (see panel B). The same significant effect can be observed in Tanzania and Uganda, indicated by coefficients increasing by 0.201 to 0.225 and 0.116 to 0.132, respectively, between A and B (see column 2 and 3).

Similarly, this applies to the EA region, farmers using *intercropping* in the EA region, are associated with an average increase of 10.1 percent in maize yields compared to plots not subjected to this method. Whether these are plots subjected to pure stand or not, is impossible to interpret, but it is clear that the significant effect becomes stronger between A and B.

Table 7. Variations in productivity between traditional and CSA methods, by country

| | (1) Ethiopia | (2) Tanzania | (3) Uganda | (4) EA region |
|---|---|---|---|---|
| *A: Traditional practices* | | | | |
| Pure stand | 0.114*** | 0.201** | 0.116** | 0.093** |
| | (0.052) | (0.172) | (0.480) | (0.254) |
| Traditional seeding | 0.072 | 0.028 | 0.446* | 0.022* |
| | (0.021) | (0.177) | (0.257) | (0.021) |
| Organic fertilization | 0.081** | 0.0411** | 0.126** | 0.172** |
| | (0.024) | (0.281) | (0.353) | (0.245) |
| Observations | 22, 101 | 21, 121 | 20, 999 | 20, 441 |
| R² | 0.1444 | 0.1791 | 0.2562 | 0.2231 |
| *B: CSA practices* | | | | |
| Intercropping | 0.121** | 0.225** | 0.132** | 0.101** |
| | (0.061) | (0.048) | (0.131) | (0.121) |
| Improved seeding | -0.062 | 0.029 | 0.449* | 0.021 |
| | (0.003) | (0.214) | (0.313) | (0.213) |
| Inorganic fertilization | 0.051** | 0.390** | 0.114* | 0.171** |
| | (0.110) | (0.298) | (0.034) | (0.042) |
| 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 | No | No | No | No |
| Observations | 19,222 | 18,212 | 15,332 | 14,112 |
| Fixed effects | Yes | Yes | Yes | Yes |
| R² | 0.1325 | 0.1277 | 0.2411 | 0.2564 |

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

Source: Based on data from CSA (2011), NBS (2011) and UBS (2011)

Note: Column 4 includes all three countries

To test the robustness of these findings, Propensity Score Matching (PSM) was performed throughout three steps, this time with *climatological factors* added to the equation. Propensity Score Matching (PSM) is a two-sample test performed to compare the control group with the treatment group, where the '"treated" in this case is farmers utilizing CSA methods. For this test, climatic conditions were taken into account since the PSM results need to be compared to the FE baseline model in Table 5.

Firstly, following the structure of Caliendo and Kopeinig, (2005) a set of covariates was chosen according to two principles: 1) variables cannot be affected or manipulated by the participant and 2) variables influence the outcome variable (agricultural productivity). Considering these criteria, the table in *Appendix A.1* includes the following variables: *plot size, plot value, assets, sex, age of household head, plot distance border,* and *shock (months).* The test suggests that the smaller the p-value, the less unlikely the population mean differs between groups, which is not desirable when estimating population means. As seen in *Appendix A.1, agricultural productivity, plot size,* and *plot distance border* all have a p-value that equals zero, indicating that it is unlikely to find differences between the sample and the population mean.

Secondly, balancing tests called "balancing conditions" were performed (*Appendix A.2-A.4)* for each agricultural practice (traditional vs CSA) where the matching process needs to balance the distribution of variables in the treatment and control group (Caliendo & Kopeinig, 2005). The desired result is when variables lie below a mean bias of 5 percent. This could be confirmed for all of the three CSA practices meaning that a balanced distribution can be confirmed. The overlaps between treated and untreated (farmers using CSA vs farmers using traditional methods) can further be visualized in the figure in *Appendix B.7.*

Lastly, based on the performed steps above, Table 8 could be constructed. As seen in column (1) and (3), the magnitude of *intercropping* in the PSM test is stronger (0.702) than in the FE baselines results in Table 5, while *inorganic fertilization* shows a weaker significant effect (0.301). This confirms H2, that there are variations between the use of techniques. Further, the results support the positive impact of CSA, especially regarding the use of *intercropping* and *inorganic fertilization*, given the significant results. Still, the positive effect can be seen for *improved seeding*, although there is a less significant impact (0.034).

Table 8. Effectiveness of CSA practices - Robustness Checks (Propensity Score Matching)

| | (1) Intercropped (Intercropped vs Pure Stand) | (2) Improved Seeds (Improved vs Traditional) | (3) Inorganic Fertilizer (Application vs No Application) |
|---|---|---|---|
| ATET | 0.702** | 0.034* | 0.301** |
| | (0.111) | (0.181) | (0.112) |
| FE baseline results | 0.632** | 0.033* | 0.321** |
| | (0.099) | (0.069) | (0.129) |
| Observations (PSM) | 22, 401 | 22, 401 | 22, 401 |

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

Source: Based on data from CSA (2011), NBS (2011) and UBS (2011)

Note*:* Please see *Appendix B.7* for a visual presentation. ATET = Average Treatment Effect on the Treated (farmers utilizing CSA methods).

## 6.3 The efficiency of CSA in maintaining agricultural productivity under climate shocks

*H3: CSA practices contribute horizontally across* ***countries*** *and* ***AEZ*** *under climate shocks*
*a: Intercropping*
*b: Improved seeding*
*c: Inorganic fertilization*

In this step, climate shocks are added to the controls to test the robustness of the CSA practices. This has been done throughout *three* steps. Firstly, a country specific result is provided in Table 10, and in a second step, country borders are ignored and AEZ are instead put in focus (Table 11). Lastly, findings are robust tested in Table 12, utilizing Average Marginal Effects (AME) under three scenarios[9]. Based on findings in these steps, following conclusions could be drawn:

Table 9. Summary of findings, Hypothesis 3

| Steps | Table | Explanation | H3a | H3b | H3c |
|---|---|---|---|---|---|
| **1:** *Countries* | 10 | **a:** contributes across all countries<br>**b:** slight significant effect in Uganda, but not within a five percent significance level → rejected<br>**c:** significant impact for all countries, especially in Ethiopia | ✓ | X | ✓ |
| **2:** *AEZ* | 11 | **a:** contributes to *tropic-warm zones* (humid and subhumid) → hypotheses rejected for all other zones<br>**b:** no significant results, missing data → rejected<br>**c:** contributes to *tropic-cool zones* → hypothesis rejected for all other zones. | ✓/X | X | ✓/X |
| **3:** *Robust checks: AME* | 12 | **a:** resilience for all three scenarios<br>**b:** significant effect under normal conditions, not under climate shocks → rejected<br>**c:** minor impacts to resilience → confirmed with limitations, needs to be tested by future research | ✓ | X | ✓/X |

Source: Table constructed by the author

Note: The sign (✓/X) means that the hypothesis is partially accepted

As seen in Table 9 above, results are varying between steps, meaning that the confirmation (✓) or rejection (X) of H3 are differing between CSA practices. In general, *intercropping* shows a strong contribution to productivity and resilience, meaning that hypothesis H3a is confirmed for all three steps, but with a minor note (✓/X) for AEZ. *Intercropping* is associated with contributions to productivity in *tropic-warm zones*

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[9] Scenario 1: Short temperature peak above the mean of AEZ (28-32°C)
Scenario 2: Droughts (6°C above mean temperature, more than 3 days)
Scenario 3: Rainfall pattern change interactions (above or below mean of AEZ)

*(humid and subhumid)* but not for other AEZ meaning that H3a can only be confirmed for the former. Thus, H3a is partially accepted (✓/X).

The same applies to *inorganic fertilization* but the other way around. This practice is associated with contributions to productivity in *tropic-cool zones (humid and subhumid)*. Moreover, it seems that *inorganic fertilization* contributes to resilience in step 3 but with a weak significance. Therefore, H3c for AEZ is partially accepted (✓/X), suggesting that future research should investigate this in greater detail. Findings for *improved seeding* were insignificant in all steps leading to a rejection of H3b across all three scenarios.

Let us now take a closer look at the results, beginning Table 10. Findings indicate that coefficients for *intercropping* are positively associated with maize productivity and significant at a five percent significance level across all columns. These results can be confirmed for both panels A and B whereas the significant effect can be confirmed, especially for Uganda. Ugandan farmers who *intercropped* their maize plants are associated with an average increase in productivity  of 12.6 percent, under normal conditions. Interestingly, this association remains positive when controlling for a climate shock. Thus, farmers utilizing this technique under *climate shocks* are still on average 11.2 percent more productive than farmers not using *intercropping.* The result indicates that these farmers are more resilient to shocks.

Similar results could be found for the use of *inorganic fertilizers,* especially among Ethiopian farmers. As seen in Table 10, the coefficient only decreases slightly between panel A and B. Under normal circumstances, Ethiopian farmers applying *inorganic fertilizers* on their plots are associated with an average increase in maize yields by 29.1 percent compared to plots not employed this method. When testing for climate shocks, their productivity is still positive and associated with an average increase of 28.8 percent compared to Ethiopian farmers not utilizing this method. For *improved seeding,* a minor effect can be seen among plots located in Uganda, nevertheless, the coefficients are only significant on a 10 percent significance level, making results difficult to confirm. Thus, it has to be investigated in greater detail by future scholars.

Moving beyond country borders, similar contributions to resilience could be found for AEZ, although the results differ between CSA methods. As seen in Table 11, no significant impact is found for *improved seeding* and missing data lead to an error in the estimation of *tropic-cool/humid* and *tropic-warm/subhumid* zones (columns 2 and 3). Regarding *intercropping*, the methods seem to contribute horizontally across *tropic-warm* zones given the significant coefficients between panel A and B. For instance, plots subjected to *intercropping* in *tropic-warm/subhumid* and *tropic-warm/humid* zones, under normal circumstances, are associated with an average increase in productivity  of 11.8 and 13.6 percent, respectively. When droughts or floods appear in these zones (panel B), farmers owning these plots are maintaining their positive output. Still, these plots are on average approximately 11 percent more productive than plots not employed by *intercropped* planting systems.

*Inorganic fertilization,* on the other hand, shows a strong contribution to plots situated in *tropic-cool* zones and no significant contribution to plots in *tropic-warm* zones. Under normal circumstances, plots located in *tropic-cool/subhumid* and *tropic-cool/humid* zones and subjected to this method are associated with a 22.5 and 31.8 percent increase in maize yields, respectively, than plots where this fertilizer was not utilized.

When applying climate shocks, the magnitude decreases to 10.6 and 12.5 percent, respectively, but is significantly contributing to a surplus in maize yields.

Hence, findings in Table 10 and 11 indicate a horizontal contribution by *intercropping* and *inorganic fertilization* across countries and AEZ while *improved seeding* shows an insignificant impact. To test this hypothesis in further detail, it is, nevertheless, of importance to robustness check each practice in interactions with specific climate shock scenarios.

Table 10. Efficiency of CSA practices under climate shock, by country

| | (1) Ethiopia | (2) Tanzania | (3) Uganda | (4) EA region |
|---|---|---|---|---|
| *A: normal conditions* | | | | |
| Intercropping | 0.094*** | 0.111** | 0.126** | 0.099** |
| | (0.012) | (0.112) | (0.480) | (0.154) |
| Improved seeding | 0.044 | 0.088 | 0.051* | 0.061* |
| | (0.011) | (0.199) | (0.117) | (0.011) |
| Inorganic fertilization | 0.291** | 0.021* | 0.115* | 0.199** |
| | (0.044) | (0.291) | (0.311) | (0.299) |
| Observations | 22, 601 | 21, 111 | 20, 019 | 20, 444 |
| $R^2$ | 0.2264 | 0.1111 | 0.2572 | 0.2621 |
| *B: with climate shock* | | | | |
| Intercropping | 0.091** | 0.095** | 0.112** | 0.191** |
| | (0.011) | (0.088) | (0.131) | (0.221) |
| Improved seeding | -0.012 | -0.099 | 0.029* | 0.091 |
| | (0.006) | (0.219) | (0.223) | (0.223) |
| Inorganic fertilization | 0.288** | 0.010** | 0.113* | 0.118** |
| | (0.033) | (0.211) | (0.033) | (0.022) |
| 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 | 14,9222 | 19,221 | 18,212 | 15,444 |
| Fixed effects | Yes | Yes | Yes | Yes |
| $R^2$ | 0.1125 | 0.1231 | 0.2044 | 0.2145 |

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

Source: Based on data from CSA (2011), NBS (2011) and UBS (2011)

Table 11. Efficiency of CSA practices under climate shock, by AEZ

| | (1)<br>Tropic-cool/ subhumid | (2)<br>Tropic-cool/ humid | (3)<br>Tropic-warm/ subhumid | (4)<br>Tropic-warm/ humid |
|---|---|---|---|---|
| *A: normal conditions* | | | | |
| Intercropping | 0.111* | 0.324* | 0.118*** | 0.136** |
| | (0.119) | (0.934) | (0.099) | (0.043) |
| Improved seeding | 0.022 | - | - | 0.025 |
| | (0.032) | | | (0.054) |
| Inorganic fertilization | 0.225** | 0.318** | 0.444 | 0.094 |
| | (0.093) | (0.113) | (0.194) | (0.333) |
| Observations | 19, 432 | 11, 022 | 21, 654 | 10, 442 |
| R² between/(overall) | 0.1044 | 0.1065 | 0.1935 | 0.1374 |
| | (0.1261) | (0.1335) | (0.1991) | (0.1345) |
| *B: with climate shock* | | | | |
| Intercropping | 0.106* | 0.215* | 0.116*** | 0.111** |
| | (0.061) | (0.023) | (0.076) | (0.033) |
| Improved seeding | 0.033 | - | - | -0.052 |
| | (0.044) | | | (0.034) |
| Inorganic fertilization | 0.106** | 0.125** | 0.335 | 0.092 |
| | (0.802) | (0.194) | (0.019) | (0.031) |
| 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 | 11, 444 | 9, 442 | 11, 765 | 8, 032 |
| Fixed effects | Yes | Yes | Yes | Yes |
| R² between/(overall) | 0.1249 | 0.1817 | 0.7021 | 0.2325 |
| | (0.1441) | (0.3212) | (0.2111) | (0.2224) |

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

Source: Based on data from CSA (2011), NBS (2011), and UBS (2011)

To test the robustness of the findings, AME controls were performed. AME is applied to understand the variation of the dependent variable (agricultural productivity) when climate controls are added (Caliendo & Kopeinig, 2005). Based on previous studies presented in Table 1, two scenarios were chosen and applied as the AME controls. The first scenario (1), is based on Thompson (1975) which suggests that a temperature peak between 28-32°C would lead to a substantial decrease in growth rates and a maize yield reduction by 10 percent (see Table 1). The second scenario (2), was developed by Siebers et al (2017) which projects a 13 percent decrease in maize yields if temperatures increase 6°C above the mean for more than 3 days. Whilst these two scenarios focus on temperature increase, scenario (3) aims to test a scenario where precipitation is deviating from the mean of the AEZ, leading to either droughts or floods and severe implications on the maize plant.

Table 12. CSA practices in interaction with climatological factors - Average Marginal Effects (AMEs)

| | (1) Short temperature peak above the mean of AEZ (28-32°C) | (2) Droughts (6°C above mean temperature, more than 3 days) | (3) Rainfall pattern change interactions (above or below the mean of AEZ) |
|---|---|---|---|
| *Intercropping* | | | |
| Without shock | 0.222*** | 0.442** | 0.111** |
| With shock | 0.111*** | 0.151*** | 0.091** |
| *Improved seeding* | | | |
| Without shock | 0.132** | 0.091** | 0.221* |
| With shock | 0.021 | -0.023 | 0.011 |
| *Inorganic fertilization* | | | |
| Without shock | 0.221*** | 0.542*** | 0.221*** |
| With shock | 0.019*** | 0.051** | 0.016** |
| Observations | 18, 759 | 16, 119 | 15,999 |

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

Source*:* Based on data from CSA (2011), NBS (2011), and UBS (2011)
Note*:* Column 1 and 2 represents scenario (1) and (4) in Table 1

Findings in Table 12 imply that farmers facing short temperature peaks (1) can maintain their maize yields if they use either *intercropping* or *inorganic fertilizers.* Plots subjected to *intercropping* under such shocks are still 11.1 percent more productive than plots where this technique was not employed. Similarly, farmers using *inorganic fertilizers* on their plots under scenario (1) can still increase their maize yield by 1.9 percent on average compared to farmers not utilizing this technique. The significant effect *without shock* and *shock* becomes weaker when AME is applied, showing the relevance of testing results presented in Tables 10 and 11. Yet, since the magnitude of the coefficients remains positive regardless of the situation, CSA seems to contribute to resilience by keeping the maize yield output above zero.

For scenario (2), the shock is even more pronounced as seen in the heavy decrease in the magnitude of coefficients. For *intercropping,* the coefficient decreased from 0.442 to 0.151, and for *inorganic fertilization* 0.542 to 0.051. As projected by Siebers et al (2017) a peak in the mean temperature for more than three days would lead to a 13 percent decrease in maize yields. This study shows that this decrease can be even greater as Table 12 shows that maize yields are decreasing between 30 to 50 percent. Still, plots employed by *intercropping* and *inorganic fertilization* are associated with an average increase of 15.1 and 5.1 percent in maize yields, respectively, compared to plots where these practices were not implemented. This finding confirms output resilience since farmers can still maintain a maize yield surplus.

Along similar lines, plots subjected to *intercropping* and *inorganic fertilization* under scenario (3) are still associated with an average increase in productivity by 9.1 and 1.6 percent, respectively, compared to plots without this implementation. The resilience can, especially, be found for plots subjected to *intercropping* since the coefficient slightly decreases from 0.111 to 0.091. Hence, farmers utilizing *intercropped* planting systems on their plots under rainfall pattern changes are associated with an average increase in yields by 9.1 percent compared to farmers not using it. Thus, CSA farmers only lose 2 percent of their productivity under a shock, confirming the horizontal contribution of the method.

In conclusion, AME controls prove that CSA practices are less effective than shown in Table 10 and 11, although they still contribute to positive growth in productivity. As shown in Table 9 which summarizes the findings for the testing of H3, *intercropping* and *inorganic fertilization* contribute to resilience since plots remain positively correlated with productivity, even under climate shocks. These findings, however, vary between countries, AEZ, and scenarios leading to a divided confirmation of H3a, H3b, H3c (see Table 9). To investigate the findings and testing of the three hypotheses of this paper, results will be discussed through the lens of previous studies in the next chapter.

# 7 Discussion

This chapter discusses the findings presented in the previous section, targeting the research question: *Can differences in maize yields be understood by the use of CSA practices, especially when controlling for climate shocks?*. To operationalize this question, three hypotheses were formulated. Firstly, the general efficiency of CSA was tested across countries (H1), secondly, variations between traditional and CSA methods were examined (H2). Lastly, country borders were ignored by testing the effect of CSA within a set of AEZ, applying climate shocks as robustness checks (H3).

Given the results, interesting parallels can be drawn between this paper and previous research. First and foremost, this study confirms previous scholars that CSA is positively associated with maize yields (Arslan et al. 2015; Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998). This was seen throughout the three tests of H1, H2, and H3. Although the impact on maize yields varied when controlling for countries, techniques, climate shock, and AEZ, coefficients remained positive and significant. Along with Branca et al. (2011) and Pretty et al. (2006) who evaluated a set of CSA techniques, this study, therefore, confirms the significance of *intercropping* and *inorganic fertilization*.

*Improved seeding,* on the contrary, needs further evaluation due to insignificant results (see Table 9). As seen in this study, the practice showed a slight significant effect on the maize yield under normal conditions but remained statistically insignificant for all AME controls. *Improved seeding* has been mentioned as an efficient method in increasing the resilience of the maize plant (Basnyat, 2017; Rioux et al. 2017; Branca et al., 2011; Pretty et al., 2006). Thus, using strong crop varieties with a high level of drought resistance, these seeds have proven to be less susceptible to temperature fluctuations (Basnyat, 2017; Rioux et al. 2017). Yet, variations in coefficients presented in this study indicate that improved maize seeds are sensitive to such changes. Although there is a positive correlation between the practice and maize yields, the significant impact is very low compared to the other two methods, increasing maize yields by a 3.3 percent on average, compared to plots not employed by this practice (see Table 5). These findings, therefore, contradict both Branca et al. (2011) and Pretty et al. (2006), who confirmed strong significance for *improved seeding.* However, these studies, among others in the field (Basnyat, 2017; Rioux et al. 2017), examined the household level, proving the necessity of analyzing the plot level.

However, should farmers use traditional or CSA methods? Based on findings in this study, the answer depends on the farmers' financial situation and the contextual capacity of each practice. The key to the current debate is to understand whether CSA practices provide farmers with greater resilience than traditional methods. Results imply that CSA is not only associated with an increase in productivity, confirmed by several studies (Arslan et al. 2015; Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998), but also with greater resilience. This finding applies, especially to the use of *intercropping.* While the traditional use of fertilizers and seeding proved to be efficient under normal conditions, *intercropping* stabilized the output of the plot both under normal circumstances and under climate shocks, such as short temperature peaks and prolonged droughts. Therefore, *intercropping* seems to be an efficient choice regardless of climatic shock, contributing to output resilience across the EA region. As stated previously, maize is sensitive to temperature peaks, and by *intercropping* the plot, shallow-rooted plants can be protected by severe sunlight (Rioux et al. 2017). The method is rather simple and does not require technical pre-knowledge. In contrast, the other two practices have a technical complexity and need greater evaluation through the lens of previous studies.

Arslan et al. (2015) suggest that *inorganic fertilizers* and *improved seeding* are methods more sensitive to droughts. Even though they are promoted as drought-resistant, agroecological conditions and the economic situation of the farmers (e.g. ability to invest in the knowledge and technique) are factors playing a key role, proving the necessity of controlling for such factors. While *intercropping* requires less knowledge, the other two practices are technical and require more funding (Arslan et al. 2015).

As shown in this paper, economic factors also proved to highly influence output performance. Assets, plot value, and maize price are all positively associated with productivity since it does not only give the farmer financial stability but also an opportunity to expand maize production, increase sales, and invest in technologies such as the *inorganic fertilizer*. Therefore, the technique itself might still be effective in increasing the resilience of the plot. Still, underlying factors like pre-knowledge and funding are affecting infrastructural capacities and, therefore, a proper implementation.

On the other hand, Miller (2018) suggests that *inorganic fertilizers* are weaker in magnitude since scholars usually examine a short period. Since the practice provides minerals to the crop during longer periods of droughts, its impact is only reflected when studying a longer period. To control for this, prolonged droughts were applied in Table 12. Findings suggest that the practice is associated with output resilience during droughts, increasing maize yields by 5.1 percent on average compared to plots not subjected to the method. When comparing the yield reduction in this step to a short temperature peak (a short period), it is much more severe, confirming Miller's (2018) point.

This study further confirms Siebers et al (2017) and Thompson (1975) who demonstrated that peaks in temperature would cause a substantial (Thompson, 1975) or severe (Siebers et al. 2017) yield reduction between 10-13 percent. In this study, the magnitude was even stronger which again proves the necessity of using a higher granularity by examining the plot level. Maize yields are associated with an average decrease between 12-50 percent when controlling for the three scenarios in Table 12, where *intercropping* once again proved to stabilize plots, regardless of a climate shock.

When analyzing AEZs, *intercropping* showed a strong significant impact in tropic-warm zones while *inorganic fertilization* seems to be more effective when applied in tropic-cool areas. Interestingly parallels can be drawn when comparing these results to the map presented in Figure 6 and *Appendix C.3-C.5*. Warm tropic zones appear mainly in western and northeastern Ethiopia, northeastern Tanzania (around Lake Victoria), and central Uganda, suggesting that plots located in these areas would benefit from the application of *intercropping*. On the other hand, plots located in central Ethiopia, southeastern Tanzania (coastal areas), and southern Uganda are subjected to a cooler climate, making *inorganic fertilization* a more appropriate choice for the farmer. *Improved seeding* showed an insignificant impact for all AEZ, and the lack of micro-data makes the findings inadequate. Future research is, therefore, necessary to prove its significant impact on the maize yield.

This geographical argumentation can further be supported by looking at the map in Figure 5, showing the rainfall patterns across EA. As visualized, seasonal rainfall (in 2021 compared to 1981-2010) has decreased particularly in central Uganda and Ethiopia as well as in centralized spots all over Tanzania. Most of these zones are, in fact, tropic-warm zones when comparing the map to Figure 6 and *Appendix C.3-C.5*. This suggests that a regional strategy for these zones, regarding the use of *intercropping,* would be of advantage since farmers face similar challenges with reduced rainfall and higher temperatures. On the contrary*, inorganic fertilization* which is a soil fertility management method (Lipper et al. 2014) suits best in higher altitudes which oftentimes are tropic cool zones with greater rainfall distribution. Along with Basnyat (2017) and Rioux et al (2017), this study confirms this hypothesis of the fertilizer and provides evidence useful when designing a geographical strategy for the regional implementation of CSA (for *both intercropping* and *inorganic fertilization*).

Yet, can we understand differences in the maize yield by examining CSA? Is it that simple? On one hand, the answer is yes, but on the other hand, no. Firstly, there are various unobservable and exogenous factors influencing the maize yield. Secondly, the three countries are different in terms of economic and social development, making a generalization of CSA difficult. There will always be factors (national policies, funding, infrastructural capacity) that influence the CSA knowledge of the farmer, and choices regarding its implementation (Arslan et al. 2015; Kassie et al. 2010; Kato et al. 2011; Shiferaw & Holden, 1998). To account for this, various factors (socioeconomic, economic, production-specific, infrastructural, and climatological/agro-ecological) were included in the analysis and by looking at AEZ, climatic conditions were put in focus, and differences in national development ignored.

Although the implementation of CSA is influenced by underlying factors as suggested by Arslan et al. (2015), and the studied time period by Miller (2018), studying the plot level enables an analysis of the direct impact of climate change. Therefore, by comparing findings in these papers with maps and previous studies, CSA practices explain differences in maize yields, especially when controlling for climate shocks. Plots subjected to CSA under climate shocks are generally more productive, suggesting that CSA is not only associated with improved productivity, but also with greater output resilience. This impact also seems to vary when considering traditional methods, countries, and AEZ.

Summing up, results indicate that CSA provides farmers with greater output resilience. Nevertheless, it appears that the sensitivity of the maize grain to temperature rises (Table 5 and 12) is significant, and this is where global warming becomes noticeable. Food production can be severely disrupted if the temperature rises, on average, one degree. The effect is comparable to the coefficient estimated for droughts or floods (Table 5), suggesting that a unit increase in temperature is quantitatively the same as a catastrophic event. Therefore, the question remains: would CSA stabilize food supplies of maize in case humankind fails to prevent global warming? This is hopefully a question we never have to provide an answer to. However, finding in this paper suggest that CSA may be a potential mitigation strategy. It seems that practices such as *intercropping* and *inorganic fertilization* stabilizes the yield output. Still, this has to be confirmed by future studies testing a longer period of prolonged temperature rises.

# 8 Concluding remarks

This study includes relevant implications for the implementation of CSA in the context of the maize industry in the EA region. The region is already facing extreme hunger, with millions of children going to bed hungry every single day. As the temperature rises, the food supplies of maize will severely deteriorate. To change this trend, FAO launched the land management approach CSA in 2009 to intensify productivity without compromising ecosystem functioning for future generations (FAO, 2020; UN, 2017; WFP, 2021).

Yet, countries in EA struggle with a proper implementation due to an inadequate scale down to local levels, making it difficult to understand the contextual capacity of CSA techniques. Additionally, years of a change in rainfall patterns and temperatures have led the major regional maize suppliers, Ethiopia, Tanzania, and Uganda, into a trajectory of unproductive maize yields and lower food supplies, making the starvation across the region even more alarming. Within this context, this study was set to test the efficiency of CSA in increasing and maintaining food production under climate shocks.

This research adds to the current literature by providing insights into the plot level, testing both traditional and CSA methods. Under normal conditions, findings suggest that the CSA method of *intercropping* is more effective, across all countries, than applying pure stands, while traditional methods of fertilizers provide greater productivity. When adding climate shocks, both *intercropping* and *inorganic fertilization* are associated with an increase in maize yields by 19.1 and 11.8 percent, respectively (see Table 10 panel B), compared to plots not employed by these methods. *Improved seeding* showed insignificant results, regardless of country, climate shocks, and AEZ controls. Thus, climatic shocks, while decreasing maize productivity across all plots, were less severe in plots where *inorganic fertilization* and *intercropping* occurred.

Aside from the plot-level analysis, this study also adds a new layer of granularity to the literature, namely the analysis on the agroecological zone level, allowing the conclusions to extend beyond national borders and thus contributing to the generalization of the findings. Results imply that *intercropping* is positively associated with maize yields in tropic-warm zones while *inorganic fertilization* suits best when applied in tropic-cool zones. Within these zones, practices did not only contribute to productivity under normal circumstances but also to output resilience when farmers experienced temperature rises or rainfall pattern changes.

In addition, by addressing the farmers' perspective through the inclusion of economic and socioeconomic factors, micro-level challenges were put in focus. This study, therefore, provides vital conclusions about farmers' livelihoods, providing policymakers with insights into local conditions. The examination of specific CSA techniques at the micro-level highlights the necessity of designing policies accounting for differences in plot location, weather changes, soil quality, and physiography.

Alongside these remarks, it is important to account for the limitations of this research. Maize yields are influenced by factors that were not considered, therefore, future research should include improved microlevel data when it is available, filling the gaps in this study. The results provided in this study thus answer the research question, namely that CSA explains differences in maize yields when controlling for various methods, climatic conditions, and AEZ. However, other investigations should emphasize detailed tools on how to operationalize CSA across EA. Lastly, future research should include additional factors such as harvest storage possibilities, improved water systems, weather alarming systems, which are subsidies to a proper CSA implementation, and factors influencing food supplies in EA.

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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* | | | |
| Plot size | 0 | 0 | 0 |
| Plot value | 0 | 0.018 | 0.395 |
| Assets | 0 | 0.2318 | 0.218 |
| *Socioeconomic factors* | | | |
| Sex | 0.3397 | 0.0022 | 0.0001 |
| Age of household head | 0.0503 | 0.1188 | 0.0612 |
| *Infrastructural factors* | | | |
| Plot distance border | 0 | 0 | 0 |
| *Climatological and agro-ecological factors* | | | |
| Shock (months) | 0 | 0.0532 | 0 |

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

| Variables | Treated | Control | %bias | t-test | V(T)/ V(C) |
|---|---|---|---|---|---|
| *Economic factors* | | | | | |
| Plot size | .115 | 0.092 | 3.3 | 0.38 | 0.72* |
| Plot value | .431 | 0.082 | 4.2 | 0.32 | 0.59* |
| Assets | 0.225 | 0.178 | 1.1 | 0.52 | 0.05* |
| *Socioeconomic factors* | | | | | |
| Sex | .113 | .218 | 2.5 | 0.12 | . |
| Age household head | 22.309 | 48.691 | 3.4 | -0.24 | 0.83 |
| *Infrastructural factors* | | | | | |
| Plot distance border | 1.226 | .092 | 4.6 | -0.67 | 2.59* |
| *Climatological and agro-ecological factors* | | | | | |
| Shock (months) | 3.893 | 5.821 | 3.1 | 0.42 | 1.12 |

*if variance ratio outside [0.75;1.33]

| Ps R2 | Mean Bias | MedBias | %Var |
|---|---|---|---|
| 0.006 | 2.4 | 4.1 | 30 |

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

| Variables | Treated | Control | %bias | t-test | V(T)/ V(C) |
|---|---|---|---|---|---|
| *Economic factors* | | | | | |
| Plot size | .119 | .135 | 1.8 | 0.53 | 0.90 |
| Plot value | 0.111 | 0.134 | 4.1 | 0.32 | 0.59* |
| Assets | 0.115 | 0.178 | 1.1 | 0.62 | 1.01 |
| *Socioeconomic factors* | | | | | |
| Sex | .118 | .218 | 2.2 | 0.12 | . |
| Age household head | 39.056 | 49.691 | 4.6 | -0.14 | 0.83 |
| *Infrastructural factors* | | | | | |
| Plot distance border | 1.666 | 2.092 | 1.7 | -0.62 | 2.59* |
| *Climatological and agro-ecological factors* | | | | | |
| Shock (months) | 3.893 | 5.821 | 3.2 | 0.42 | 1.12 |

*if variance ratio outside [0.87;1.15]

| Ps R2 | Mean Bias | MedBias | %Var |
|---|---|---|---|
| 0.001 | 1.4 | 2.6 | 33 |

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

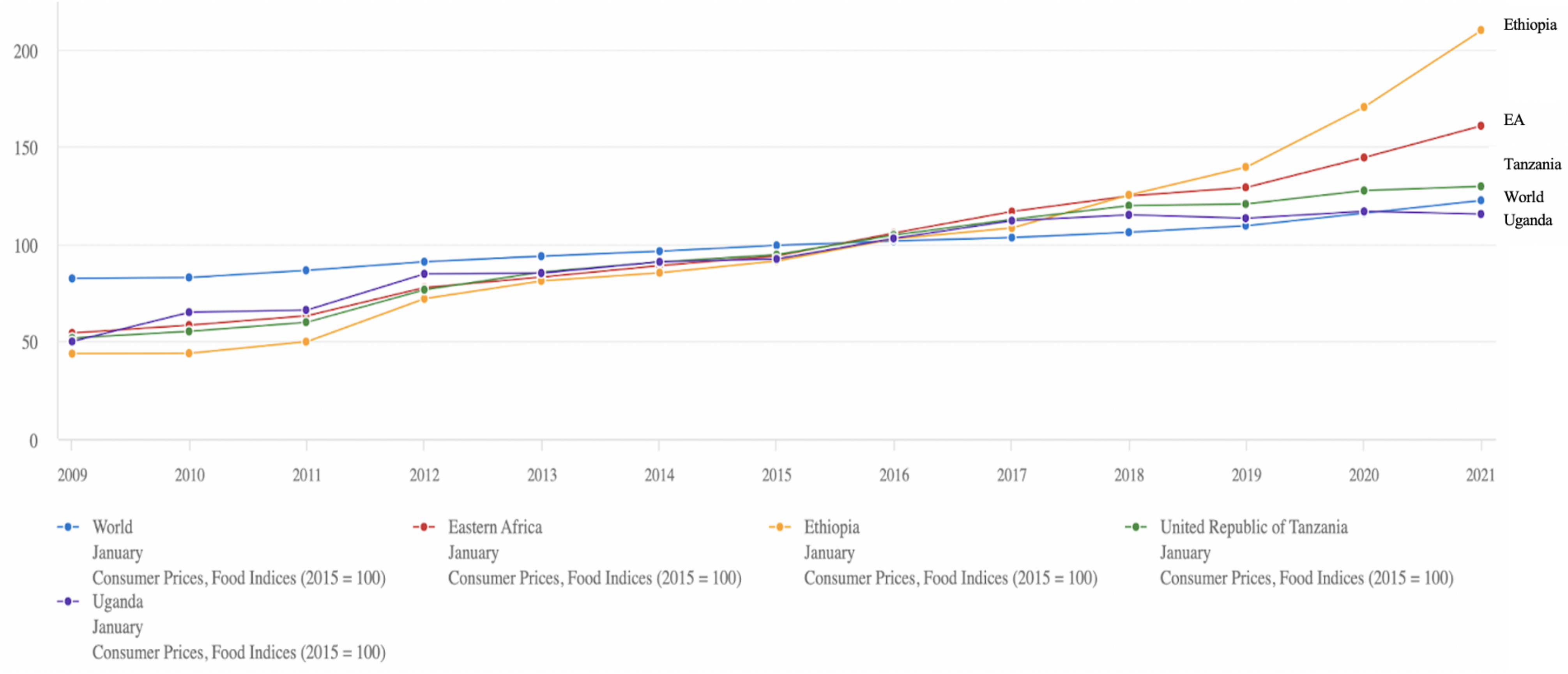
| Variables | Treated | Control | %bias | t-test | V(T)/ V(C) |
|---|---|---|---|---|---|
| *Economic factors* | | | | | |
| Plot size | .229 | .035 | 2.1 | 0.38 | 0.90 |
| Plot value | 0.151 | 0.134 | 1.1 | 0.32 | 0.59* |
| Assets | 0.225 | 0.158 | 4.1 | 0.62 | 1.01 |
| *Socioeconomic factors* | | | | | |
| Sex | .768 | .278 | 1.9 | 0.17 | . |
| Age household head | 66.056 | 49.691 | 2.6 | -0.14 | 0.83 |
| *Infrastructural factors* | | | | | |
| Plot distance border | 1.326 | 2.092 | 1.7 | -0.12 | 1.59* |
| *Climatological and agro-ecological factors* | | | | | |
| Shock (months) | 4.773 | 5.821 | 3.2 | 0.42 | 1.12 |

*if variance ratio outside [0.75;1.33]

| Ps R2 | Mean Bias | MedBias | %Var |
|---|---|---|---|
| 0.006 | 2.6 | 4.1 | 37 |

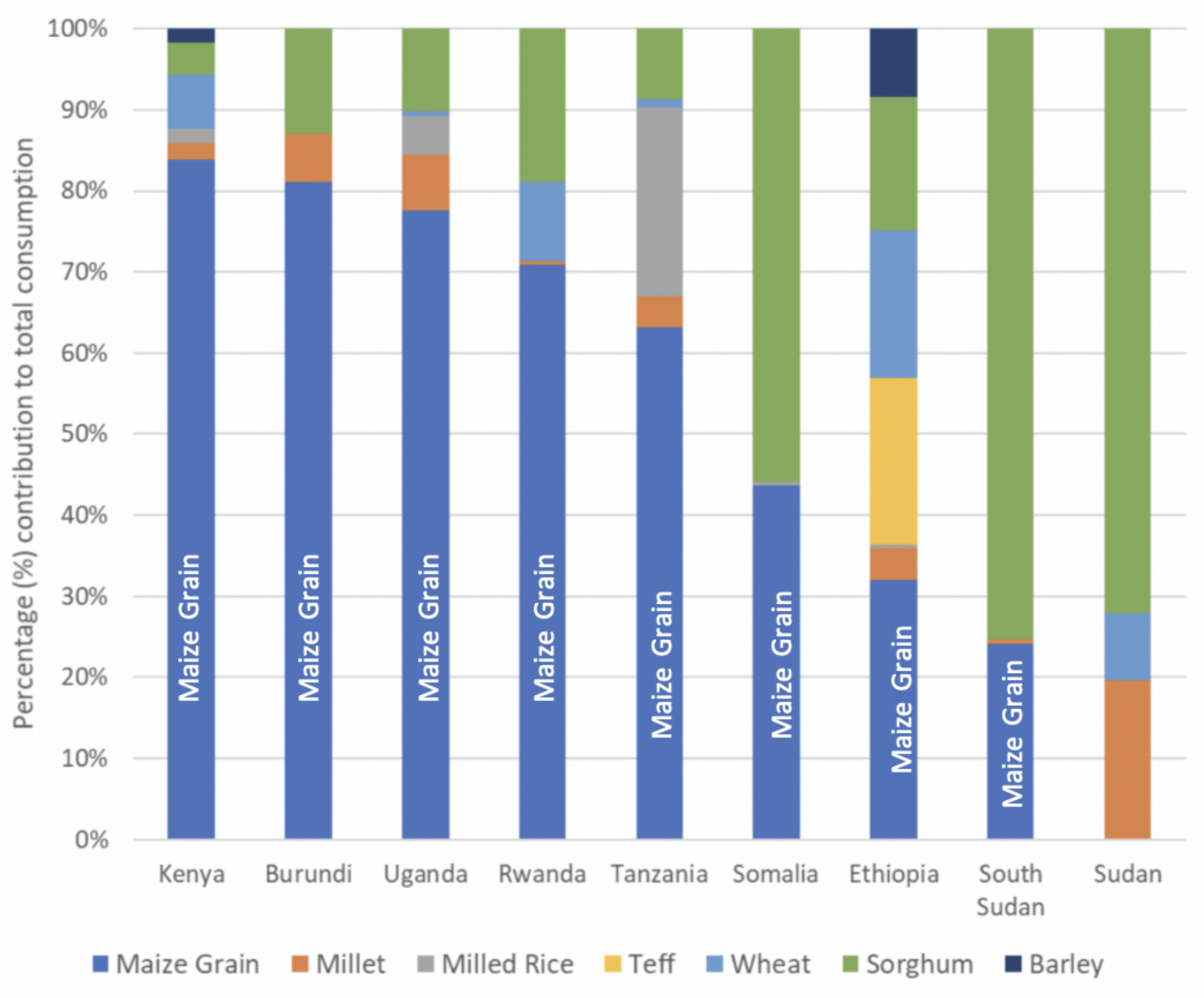
# Appendix B: Figures

*Appendix B.1.* Consumer prices for maize over time 2009-2021

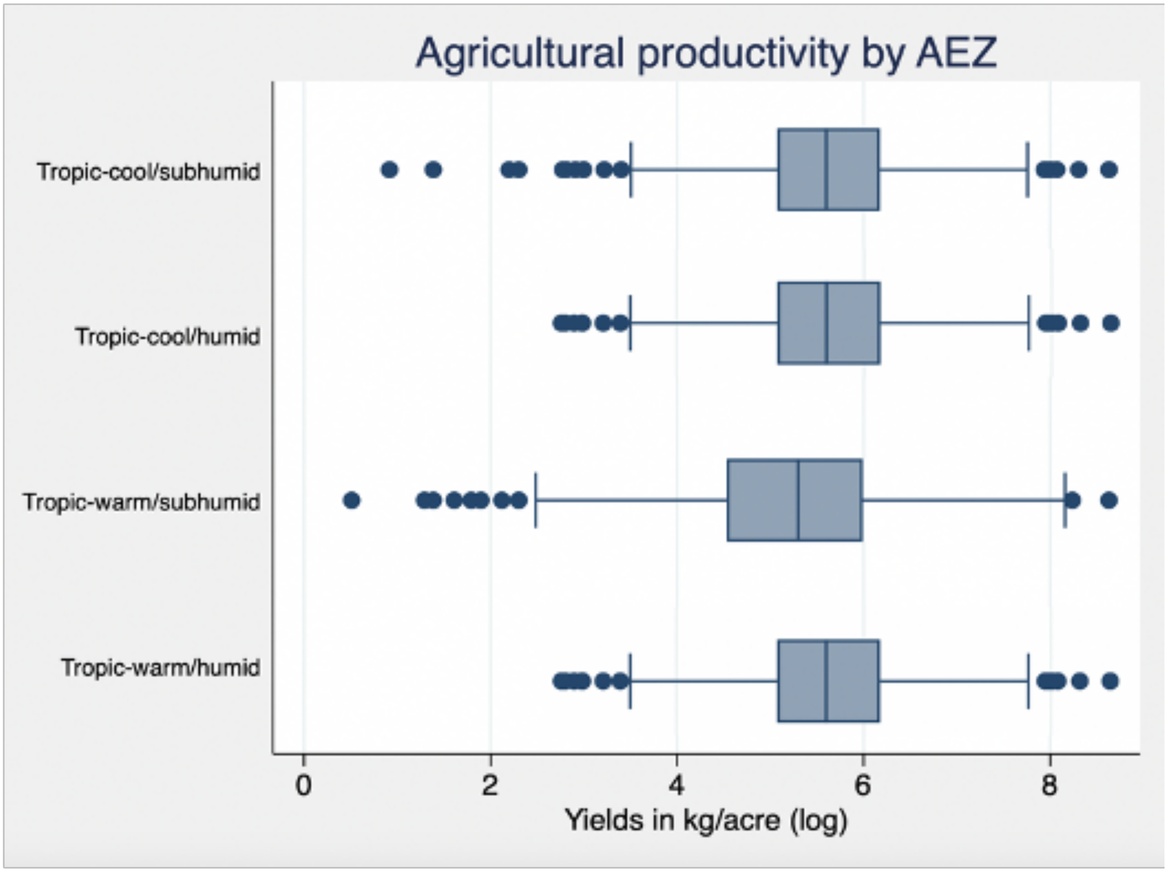


*Source*: Based on data from FAOSTAT (2022)

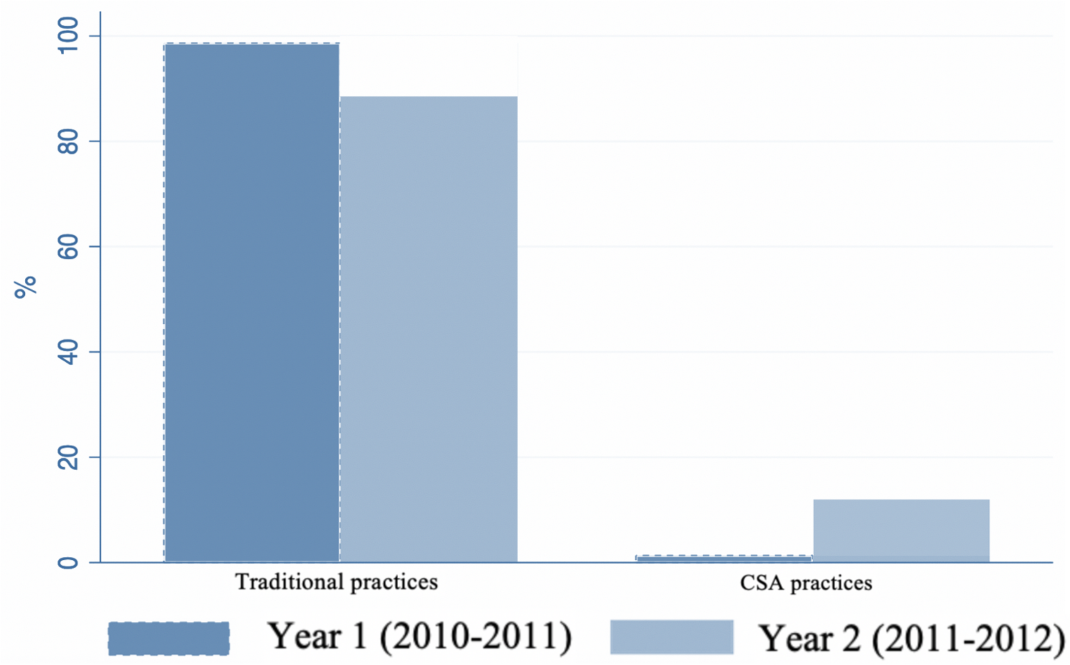
*Appendix B.2. Maize Production to Aggregate Domestic Grain Supply in Eastern Africa*



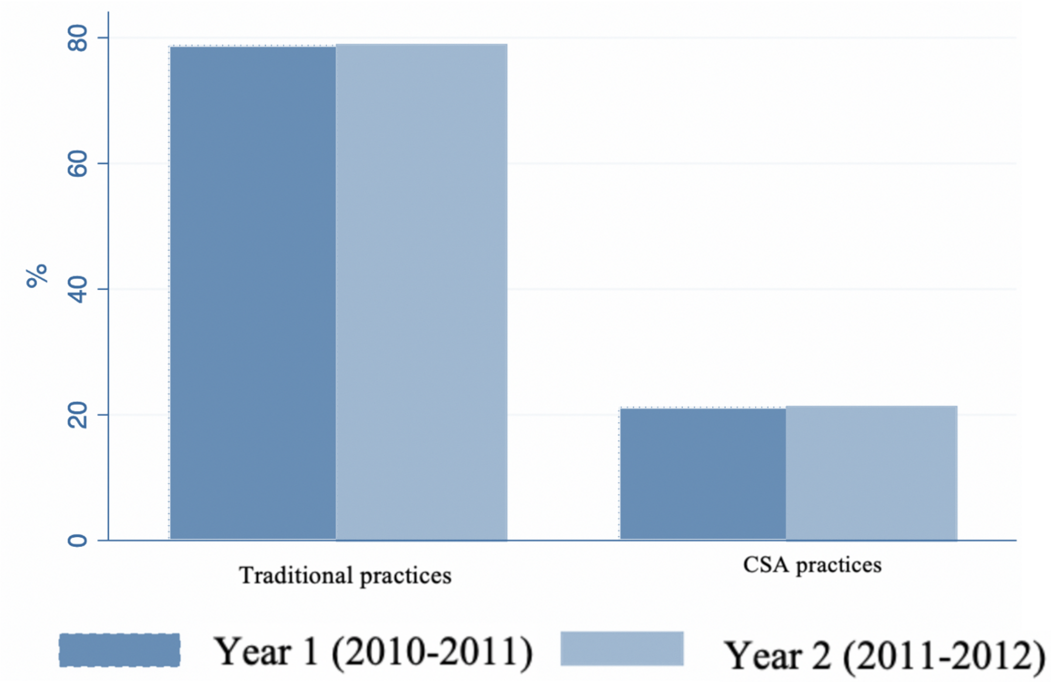
*Appendix B.3.* Boxplot of Agricultural Productivity by AEZ



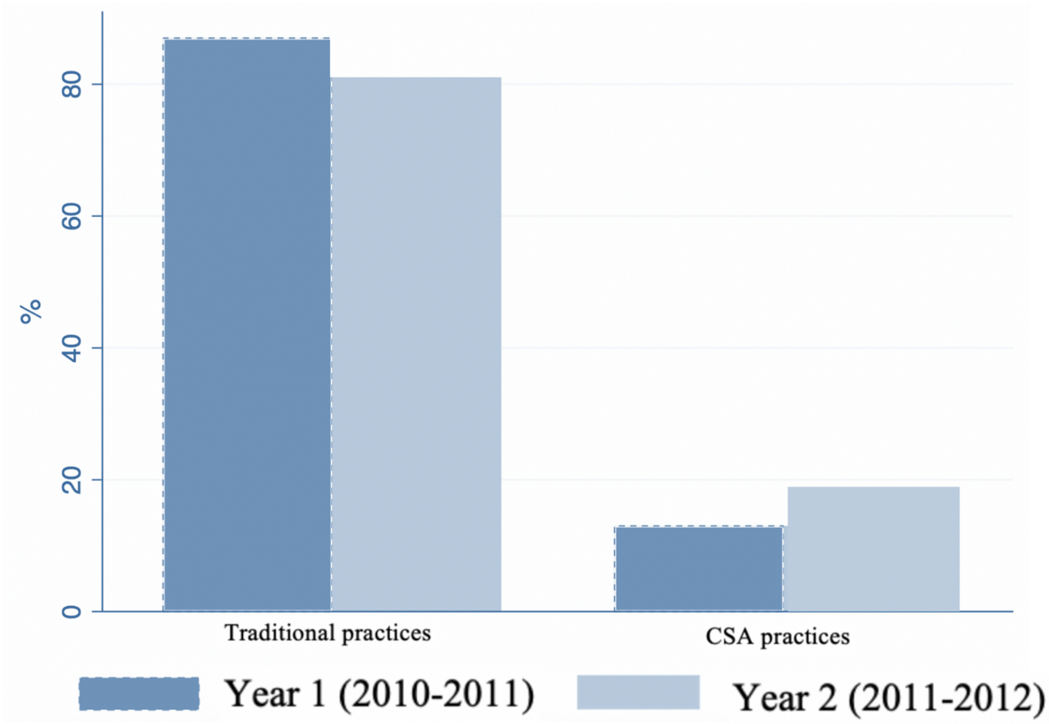
*Appendix B.4.* The use of traditional and CSA practices between 2010-2012, Ethiopia



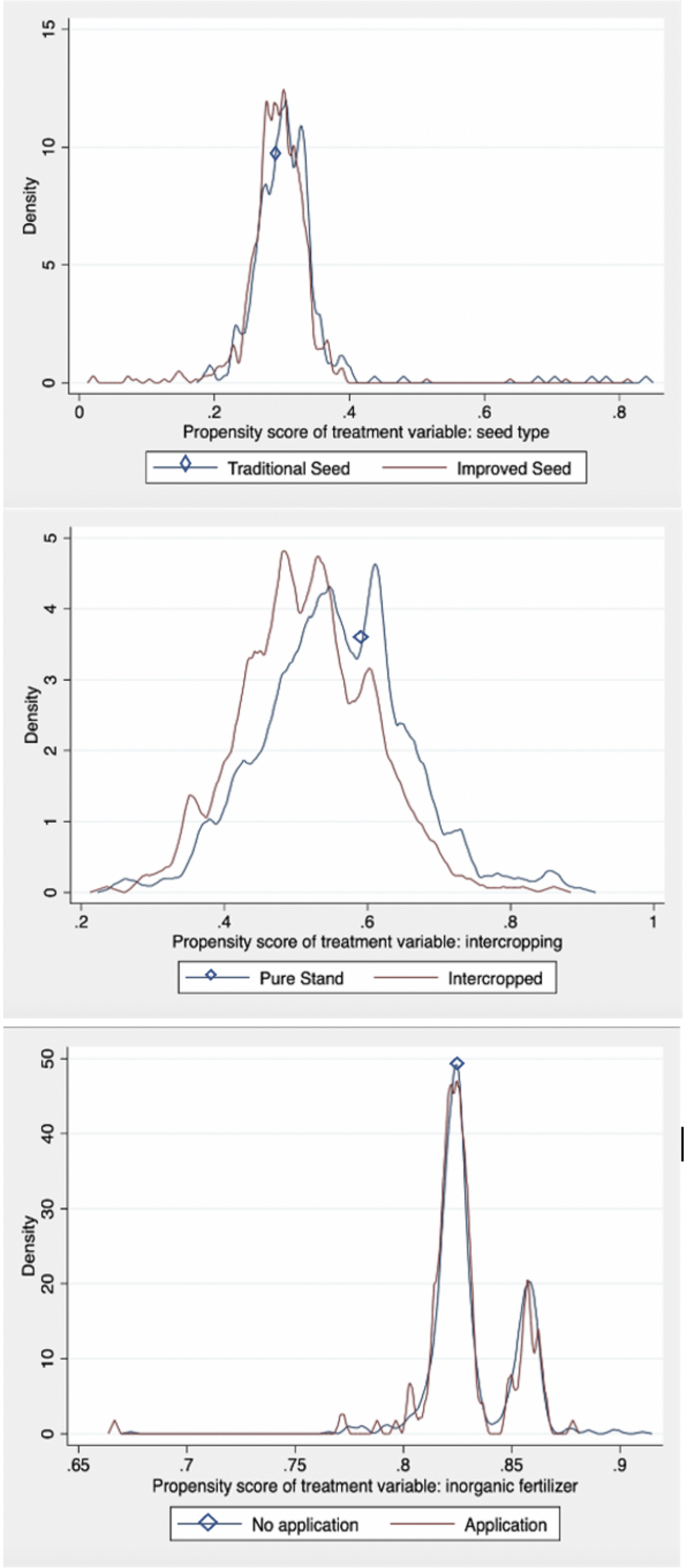
*Appendix B.5.* The use of traditional and CSA practices between 2010-2012, Tanzania



*Appendix B.6.* The use of traditional and CSA practices between 2010-2012, Uganda

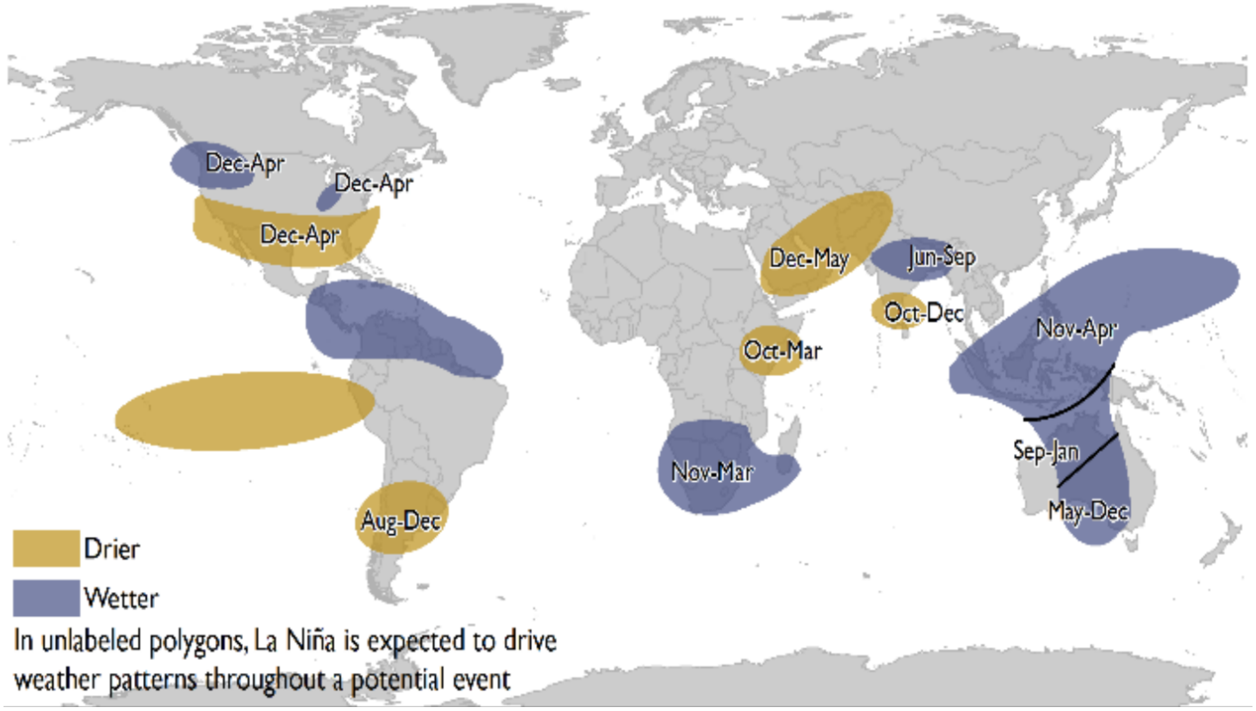


## *Appendix B.7.* Test of Overlap Assumptions



# Appendix C: Maps

*Appendix C.1.* La Niña impacts on climate

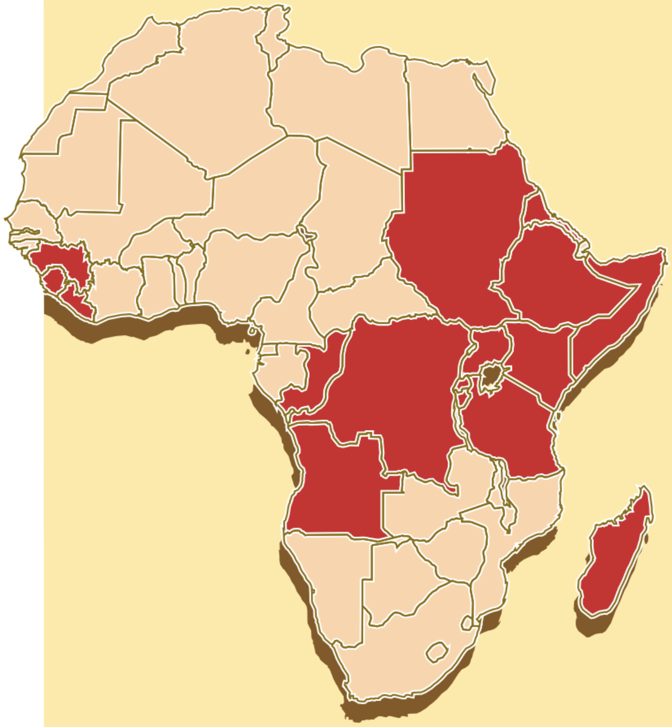


Source: FEWS NET (2021)

*Appendix C.2.* African countries facing exceptional food emergencies

# Africa:
## food emergencies

Civil strife | Weather conditions | Population displacement | Agricultural production | Economic sanctions

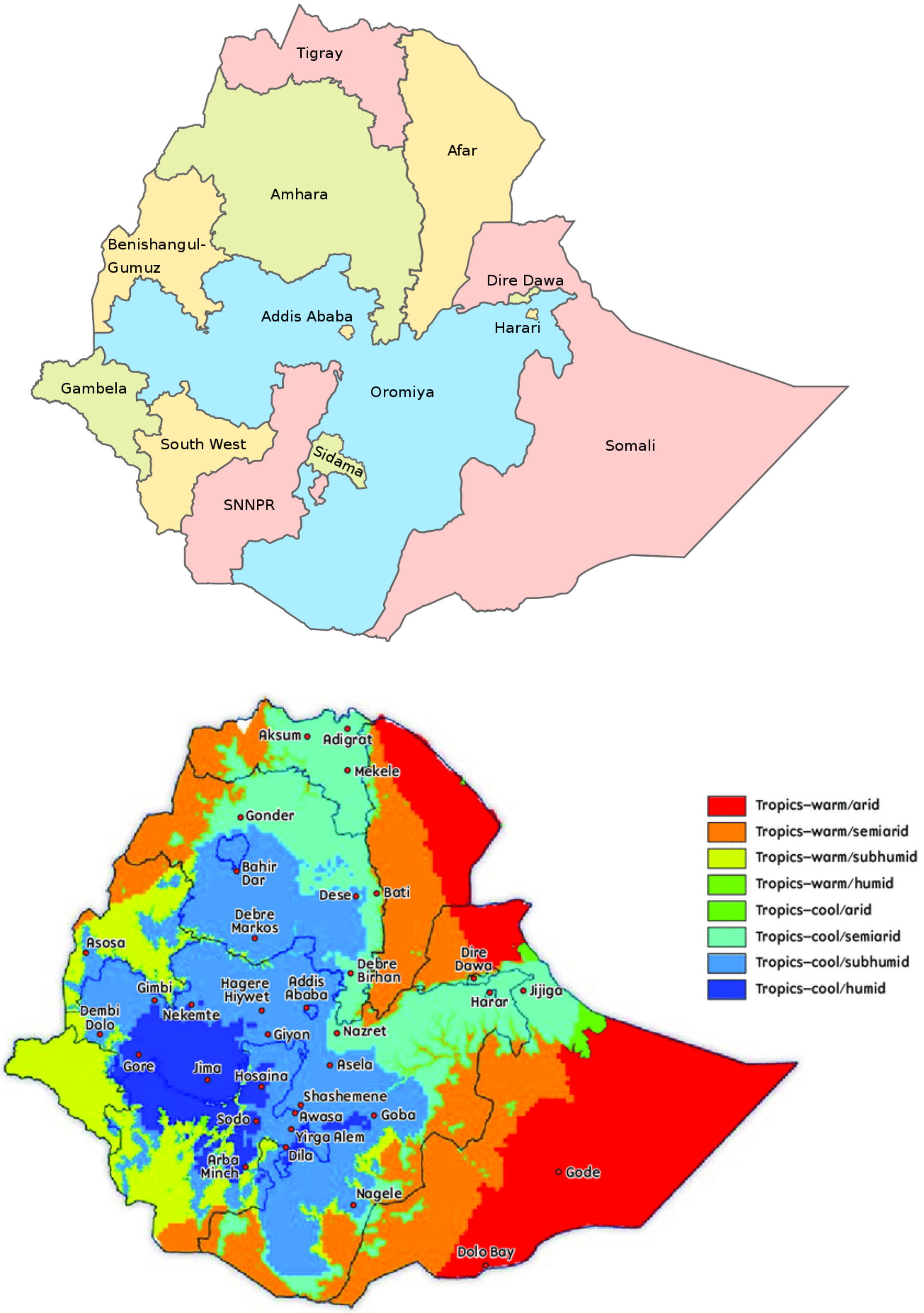


| Civil strife | Weather conditions | Population displacement | Agricultural production | Economic sanctions | Countries facing exceptional food emergencies | |
|---|---|---|---|---|---|---|
| ● | | ● | | | **Angola** | Civil strife and population displacement |
| ● | | ● | | | **Burundi** | Civil strife and population displacement |
| ● | | ● | | | **Congo, Dem. Rep.** | Civil strife and population displacement |
| ● | | | | | **Congo, Rep.** | Impact of past civil strife |
| | ● | ● | | | **Eritrea** | IDPs, returnees and drought |
| | ● | ● | | | **Ethiopia** | Drought, large numbers of vulnerable people and IDPs |
| ● | | ● | | | **Guinea** | Civil strife and population displacement |
| | ● | | | | **Kenya** | Drought |
| ● | | | ● | | **Liberia** | Impact of past civil strife, shortage of farm inputs |
| | ● | | | | **Madagascar** | Drought and cyclones |
| | ● | | | | **Rwanda** | Drought in parts |
| ● | | ● | | | **Sierra Leone** | Civil strife and population displacement |
| ● | ● | | | | **Somalia** | Drought and civil strife |
| ● | ● | | | | **Sudan** | Civil strife in the south, drought |
| | ● | | | | **Tanzania** | Food deficits in several regions due to drought |
| ● | ● | | | | **Uganda** | Civil strife in parts and drought |

**April 2001**

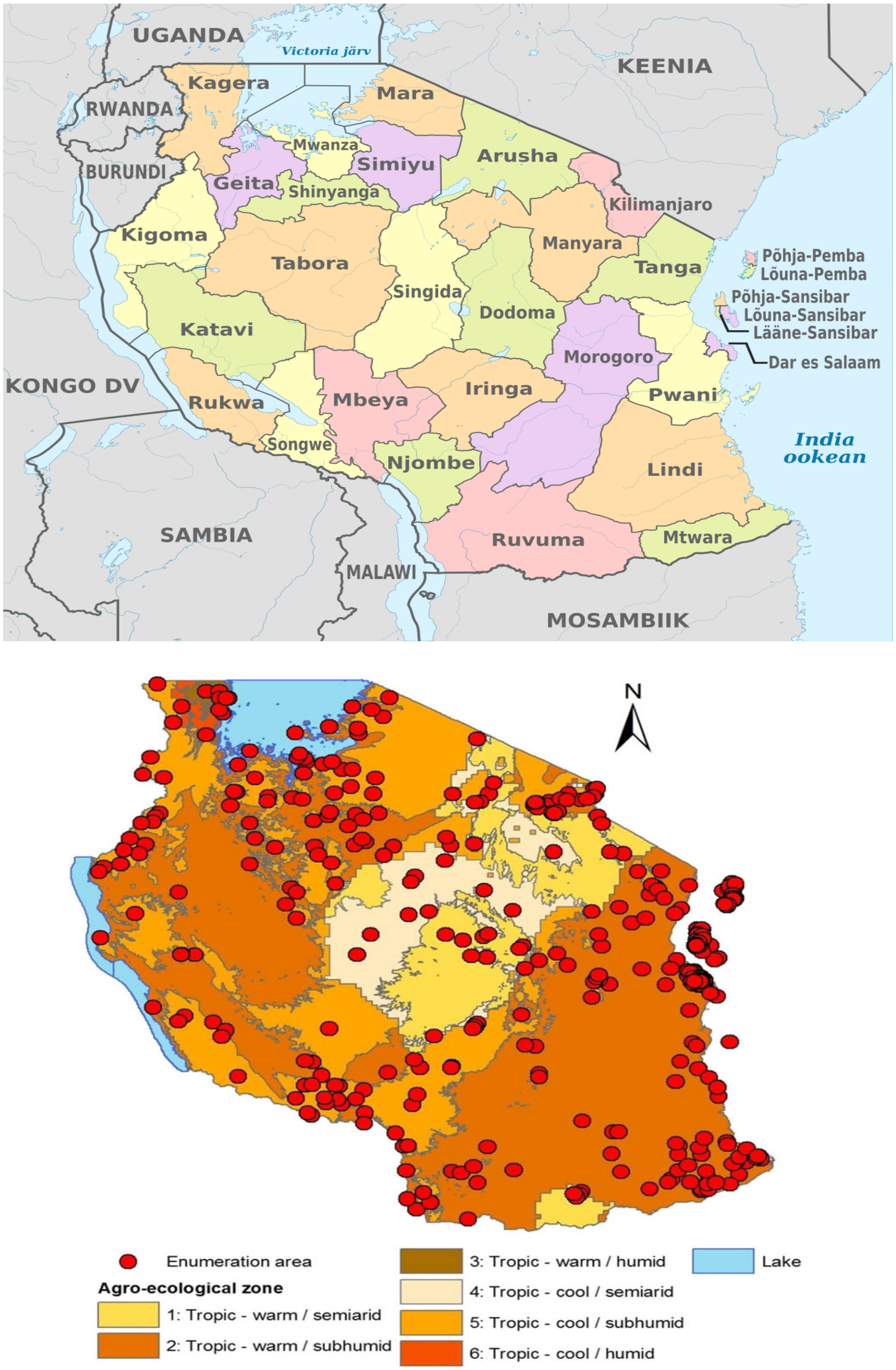
*Source: FAO (n.d)*

*Figure C.3.* Regions and AEZ of Ethiopia



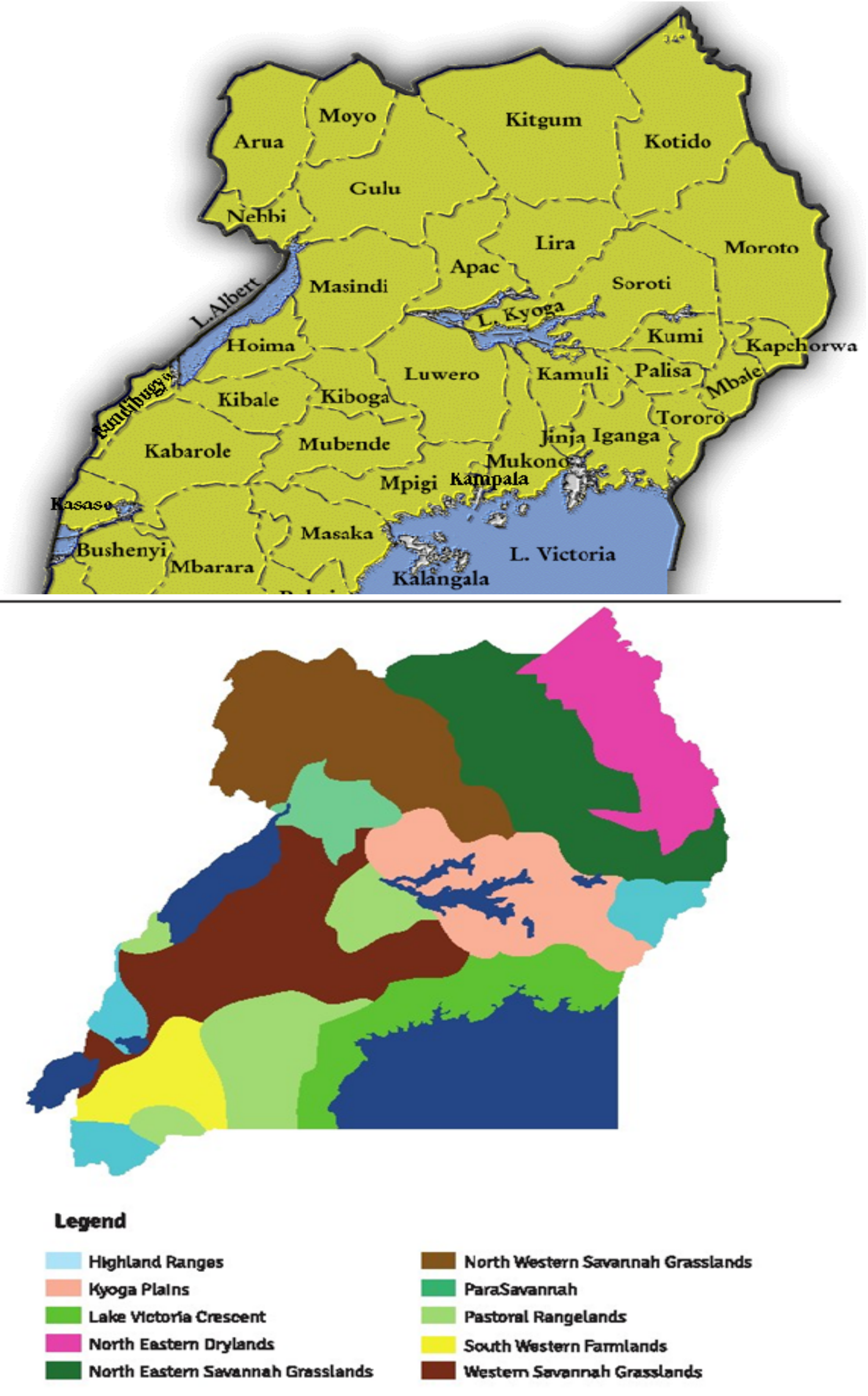
*Source:* UN OCHA (n.d)

*Figure C.4.* Regions and AEZ of Tanzania



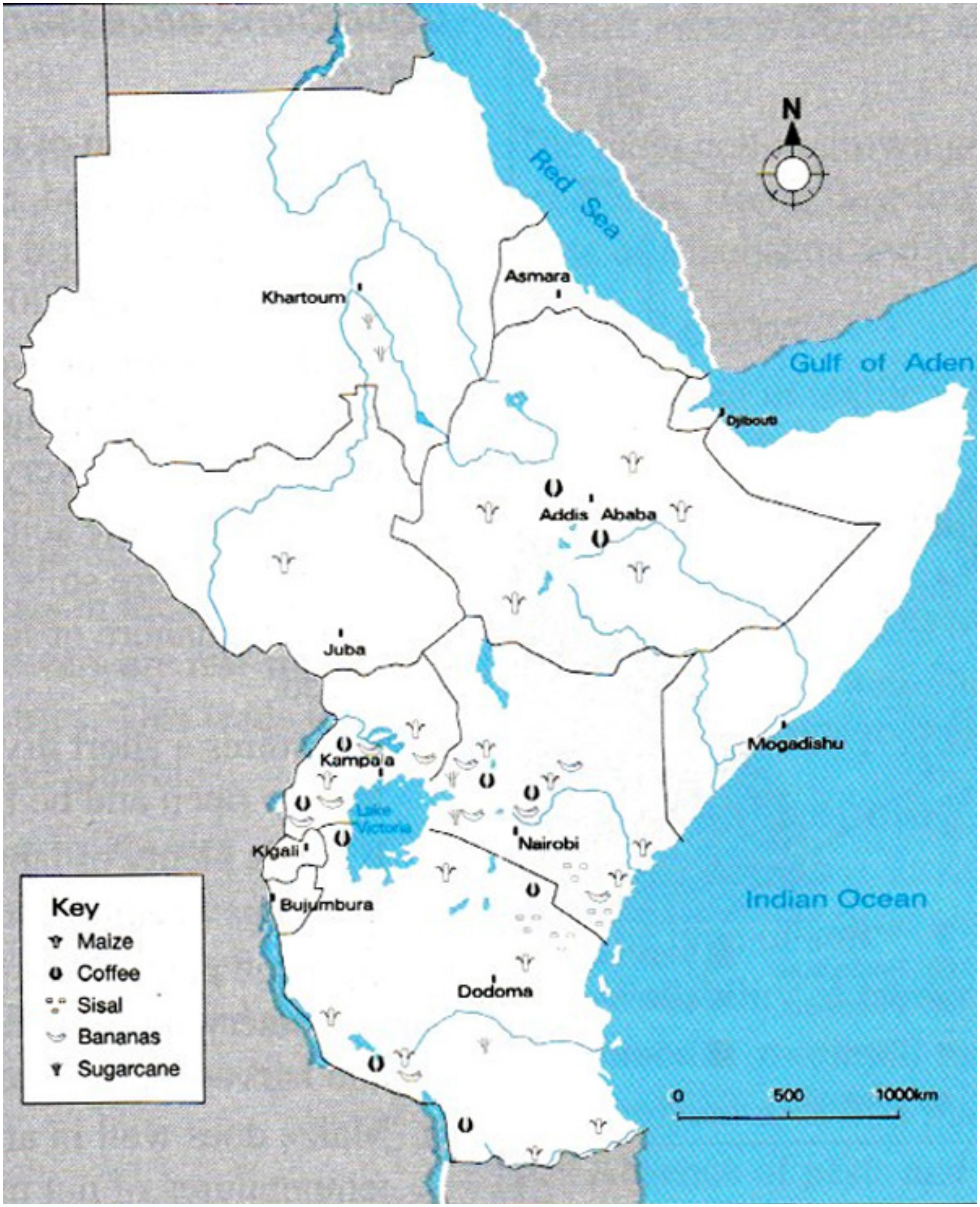
*Source:* Statsoid (2015) and Cacho, Moss, Thornton and Herrero (2020)

*Figure C.5*. Regions and AEZ of Uganda



*Source:* Bernard et al. (2013) and Bernard (2018)

*Figure C.6.* Map of locations where the maize is grown



Source: eLIMU (2015)

# Appendix D: Data

Table D.1. Descriptive statistics Ethiopia

| **Variable** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| *Dependent variable* | | | | | |
| Agricultural productivity, log (kg/acre) | 10, 194 | 5.33 | 1.34 | 0.60 | 11.70 |
| *CSA practices* | | | | | |
| Improved seed (1=Yes) | 10, 401 | 0.32 | 0.34 | 0 | 1 |
| Intercropped (1=Intercropped) | 10, 201 | 0.43 | 0.12 | 0 | 1 |
| Inorganic fertilizer (1=Application) | 10, 101 | 0.21 | 0.41 | 0 | 1 |
| *Production-specific factor* | | | | | |
| Organic fertilizer (1=Application) | 10,101 | 0.67 | 0.39 | 0 | 1 |
| Pesticide use (1=Yes) | 8,861 | 0 .65 | 0.86 | 0 | 1 |
| Irrigation system (1=Yes) | 10,101 | 0.42 | 0.33 | 0 | 1 |
| Traditional seeds (1=Yes) | 10,101 | 0.22 | 0.34 | 0 | 1 |
| *Economic factors* | | | | | |
| Maze price ($/100kg) | 10, 201 | 0.33 | 0.66 | 0 | 75.34 |
| Sold harvest (kg) | 10,502 | 123.48 | 222.32 | 0 | 8000 |
| Plot value, log ($) | 10,199 | 14.11 | 0.98 | 4.59 | 12.59 |
| Assets, log ($) | 8,366 | 52.63 | 0.32 | 3.81 | 71.82 |
| Plot size, log (Acre) | 8,126 | 0.52 | 0.64 | 0 | 4.91 |
| *Socioeconomic factors* | | | | | |
| Age of household head | 10,201 | 44.59 | 15.03 | 19 | 96 |
| Number of household members | 10,201 | 4.27 | 2.73 | 1 | 13 |
| Hired labor (1=Yes) | 10,201 | 0.23 | 0.48 | 0 | 1 |
| Extension program (1=Yes) | 10,201 | 0.59 | 0.46 | 0 | 1 |
| Sex (1=Female) | 10,201 | 0.14 | 0.43 | 0 | 1 |
| Food availability (nr meals/day) | 10,201 | 2.67 | 0.54 | 0 | 5 |
| *Infrastructure* | | | | | |
| Plot distance border (km) | 10,199 | 21.21 | 5.80 | 0 | 70 |
| Plot distance market (km) | 10,201 | 7.98 | 11.54 | 0 | 124 |
| *Climatological and agro-ecological factors* | | | | | |
| Shock length (months) | 10,323 | 5.84 | 2.10 | 0 | 12 |
| Climate shock (drought or floods) | 10,201 | 0.012 | 0.15 | 0 | 1 |
| Erosion (1=Yes) | 10,201 | 0.11 | 0.41 | 0 | 1 |
| Good soil quality (1=Yes) | 10,101 | 0.33 | 0.49 | 0 | 1 |
| Bad soil quality (1=Yes) | 10,101 | 0.27 | 0.38 | 0 | 1 |
| Temperature, annual (°C*10) | 10 ,101 | 220.26 | 18.81 | 154 | 390 |
| Precipitation, annual (mm*10) | 10,101 | 1127.97 | 202.96 | 544 | 2372 |
| Moderate nutrient constraint (1=Yes) | 10,101 | 0.06 | 0.29 | 0 | 1 |
| False onset rainy season (1=>AEZ mean) | 10,101 | 0.87 | 0.16 | 0 | 1 |
| Rainfall pattern change (1=>AEZ mean) | 10, 101 | 0.61 | 0.39 | 0 | 1 |

Table D.2. Descriptive statistics Tanzania

| **Variable** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| *Dependent variable* | | | | | |
| Agricultural productivity, log (kg/acre) | 10, 184 | 5.23 | 1.34 | 0.45 | 10.70 |
| *CSA practices* | | | | | |
| Improved seed (1=Yes) | 10, 301 | 0.42 | 0.34 | 0 | 1 |
| Intercropped (1=Intercropped) | 10, 501 | 0.63 | 0.12 | 0 | 1 |
| Inorganic fertilizer (1=Application) | 10, 501 | 0.11 | 0.41 | 0 | 1 |
| *Production-specific factor* | | | | | |
| Organic fertilizer (1=Application) | 10,501 | 0.17 | 0.39 | 0 | 1 |
| Pesticide use (1=Yes) | 8,961 | 0 .45 | 0.86 | 0 | 1 |
| Irrigation system (1=Yes) | 10,501 | 0.22 | 0.33 | 0 | 1 |
| Traditional seeds (1=Yes) | 10,501 | 0.32 | 0.34 | 0 | 1 |
| *Economic factors* | | | | | |
| Maze price ($/100kg) | 10, 501 | 0.43 | 0.66 | 0 | 70.34 |
| Sold harvest (kg) | 10,502 | 124.48 | 222.32 | 0 | 7000 |
| Plot value, log ($) | 10,599 | 18.11 | 0.98 | 4.59 | 12.59 |
| Assets, log ($) | 8,566 | 55.63 | 0.32 | 3.81 | 71.82 |
| Plot size, log (Acre) | 8,626 | 0.92 | 0.64 | 0 | 4.91 |
| *Socioeconomic factors* | | | | | |
| Age of household head | 10,501 | 48.59 | 15.03 | 19 | 97 |
| Number of household members | 10,501 | 5.37 | 2.73 | 1 | 13 |
| Hired labor (1=Yes) | 10,501 | 0.23 | 0.48 | 0 | 1 |
| Extension program (1=Yes) | 10,501 | 0.59 | 0.46 | 0 | 1 |
| Sex (1=Female) | 10,501 | 0.14 | 0.43 | 0 | 1 |
| Food availability (nr meals/day) | 10,501 | 2.67 | 0.54 | 0 | 5 |
| *Infrastructure* | | | | | |
| Plot distance border (km) | 10,599 | 21.21 | 5.80 | 0 | 80 |
| Plot distance market (km) | 10,501 | 7.98 | 11.54 | 0 | 124 |
| *Climatological and agro-ecological factors* | | | | | |
| Shock length (months) | 10,523 | 5.84 | 2.10 | 0 | 12 |
| Climate shock (drought or floods) | 10,501 | 0.012 | 0.15 | 0 | 1 |
| Erosion (1=Yes) | 10,501 | 0.11 | 0.41 | 0 | 1 |
| Good soil quality (1=Yes) | 10,501 | 0.33 | 0.49 | 0 | 1 |
| Bad soil quality (1=Yes) | 10,501 | 0.27 | 0.38 | 0 | 1 |
| Temperature, annual (°C*10) | 10 ,501 | 220.26 | 18.81 | 154 | 390 |
| Precipitation, annual (mm*10) | 10,501 | 1127.97 | 202.96 | 544 | 2372 |
| Moderate nutrient constraint (1=Yes) | 10,501 | 0.06 | 0.29 | 0 | 1 |
| False onset rainy season (1=>AEZ mean) | 10,501 | 0.87 | 0.16 | 0 | 1 |
| Rainfall pattern change (1=>AEZ mean) | 10, 501 | 0.61 | 0.39 | 0 | 1 |

Table D.3 Descriptive statistics Uganda

| **Variable** | **Obs** | **Mean** | **Std. dev.** | **Min** | **Max** |
|---|---|---|---|---|---|
| *Dependent variable* | | | | | |
| Agricultural productivity, log (kg/acre) | 10, 884 | 5.33 | 1.34 | 0.55 | 12.80 |
| *CSA practices* | | | | | |
| Improved seed (1=Yes) | 10, 801 | 0.32 | 0.34 | 0 | 1 |
| Intercropped (1=Intercropped) | 10, 801 | 0.53 | 0.12 | 0 | 1 |
| Inorganic fertilizer (1=Application) | 10, 801 | 0.21 | 0.41 | 0 | 1 |
| *Production-specific factor* | | | | | |
| Organic fertilizer (1=Application) | 10,801 | 0.27 | 0.39 | 0 | 1 |
| Pesticide use (1=Yes) | 8,861 | 0 .65 | 0.86 | 0 | 1 |
| Irrigation system (1=Yes) | 10,801 | 0.82 | 0.33 | 0 | 1 |
| Traditional seeds (1=Yes) | 10,801 | 0.72 | 0.34 | 0 | 1 |
| *Economic factors* | | | | | |
| Maze price ($/100kg) | 10, 801 | 0.13 | 0.66 | 0 | 73.34 |
| Sold harvest (kg) | 10,802 | 125.48 | 222.32 | 0 | 7000 |
| Plot value, log ($) | 10,899 | 18.11 | 0.98 | 4.59 | 12.59 |
| Assets, log ($) | 8,866 | 55.83 | 0.32 | 3.81 | 71.82 |
| Plot size, log (Acre) | 8,826 | 0.98 | 0.64 | 0 | 4.91 |
| *Socioeconomic factors* | | | | | |
| Age of household head | 10,801 | 49.59 | 15.03 | 20 | 97 |
| Number of household members | 10,801 | 5.37 | 2.73 | 1 | 13 |
| Hired labor (1=Yes) | 10,801 | 0.23 | 0.48 | 0 | 1 |
| Extension program (1=Yes) | 10,801 | 0.59 | 0.46 | 0 | 1 |
| Sex (1=Female) | 10,801 | 0.14 | 0.43 | 0 | 1 |
| Food availability (nr meals/day) | 10,801 | 2.67 | 0.54 | 0 | 3 |
| *Infrastructure* | | | | | |
| Plot distance border (km) | 10,899 | 21.21 | 5.60 | 0 | 70 |
| Plot distance market (km) | 10,801 | 7.98 | 11.74 | 0 | 114 |
| *Climatological and agro-ecological factors* | | | | | |
| Shock length (months) | 10,823 | 5.84 | 2.90 | 0 | 12 |
| Climate shock (drought or floods) | 10,801 | 0.012 | 0.35 | 0 | 1 |
| Erosion (1=Yes) | 10,801 | 0.11 | 0.11 | 0 | 1 |
| Good soil quality (1=Yes) | 10,801 | 0.33 | 0.19 | 0 | 1 |
| Bad soil quality (1=Yes) | 10,801 | 0.27 | 0.18 | 0 | 1 |
| Temperature, annual (°C*10) | 10 ,801 | 220.26 | 18.11 | 159 | 370 |
| Precipitation, annual (mm*10) | 10,581 | 1127.97 | 202.16 | 548 | 2272 |
| Moderate nutrient constraint (1=Yes) | 10,801 | 0.06 | 0.29 | 0 | 1 |
| False onset rainy season (1=>AEZ mean) | 10,801 | 0.87 | 0.16 | 0 | 1 |
| Rainfall pattern change (1=>AEZ mean) | 10, 801 | 0.61 | 0.39 | 0 | 1 |

Table D.4. Explanation of variables and expected impact

| **Factor** | **Explanation** | **Expected sign** |
|---|---|---|
| *CSA practices* | Since CSA is of particular interest in this study, the three practices; *inorganic fertilizer, intercropping* and *improved seed* represent the key explanatory variables. Other practices that are not CSA (such as organic fertilizer, pesticides, traditional seeds) are also central for this study. Nevertheless, these are not considered key variables and will be added as covariates under production-specific factors. Within the data, each plot owner was asked if CSA practices were applied on their plot, whereas they answered "yes" or "no". Thus, the CSA practices were transformed into dummy variables to allow econometric analysis. | (+) |
| *Socioeconomic factors* | Beyond the farmer's economic situation, scholars stress the importance of human capital and quality of life when examining agricultural productivity (Asadullah & Rahman, 2009; Feder et al. 1985; Nelson & Phelps, 1966). The countries of interest in this research; Ethiopia, Tanzania, and Uganda, may have climatological similarities but major differences in terms of societal development. To account for such factors, the analysis includes data on the *age of household head*, *labor access*, inclusion in *extension program*, *sex, number of household members* and *food availability* (number of meals eaten per day).<br>The latter mentioned is highly relevant since *food availability* determines whether the farmer can work effectively on their farm. Maize is an important crop for nutritional intake, and a lack of basic needs impairs a farmer's health and prosperity. In addition, studies have proven that the *number of household members* is relevant when analyzing food availability. More household members mean a higher expenditure on food and lower commercial use of the harvest (since the maize crop is mainly used within the household). On the contrary, a big household also means a greater workforce that can maintain a stabilized production on the plot (Feder et al. 1985).<br>Regarding *extension programs*, CIAT and World Bank (2017) stress that farmers who worked continuously with production improvements and learning hubs receive a 'certificate' or a stamp of their participation in a training program. Being part of a CSA extension program does not necessarily mean that the farmer connects with other farmers via a regional network; further, the farmer receives examples on best practices and implementation guidance from the CSA team. Receiving guidance on implementing innovative techniques allows the farmer to learn and incorporate the local assistance team into strategic planning. Further, this gives farmers more confidence when using new and knowledge-intensive techniques on their plots (Barrett et al. 2002; Swinkels & Franzel, 1997; Nkonya et al. 2004).<br>In addition to the variables mentioned above, this research also accounts for *labor access, sex,* and *age of household head.* In line with Nelson and Phelps (1966) findings, this paper also emphasizes the hypothesis that older farmers are more likely to have more experience when facing extreme weather conditions and when executing risk assessments for new agricultural techniques (which are promising and which are not?). Still, older farmers might have physical limitations | (+) |

| | | |
|---|---|---|
| | when working on their plots which could worsen their productivity. Most of the agricultural production in Ethiopia, Uganda, and Tanzania are executed by hand or through cattle-driven ox plows meaning that the work requires strong physical abilities. Yet, *labor availability* is a factor that could complement a farmer's physical limitations and it is important to include this aspect into the estimations (Feder et al. 1985). Lastly, whether the household head is a female is also important to consider. A study by Ragasa et al. (2013), highlights that *sex* plays a crucial role when accounting for income and access to extension services. According to their study, limitations for women-led households usually decrease productivity when compared to male-headed households. | |
| *Economic factors* | Scholars such as Reardon et al. (1994), Nkonya et al. (2004), Scherr & Hazell (1994), and Clay et al. (1998) emphasize economic factors when analyzing agricultural productivity. They argue that the economic situation of the farmer's household plays a crucial role when implementing productive agricultural methods. Scholars have proven that farmers who are engaged in activities outside their farm, such as being engaged in economic associations or running external businesses, are more likely to invest in improved agricultural techniques. Due to high liquidity and earnings outside their farm, they also have advantages in decisions with high-risk management (Nkonya et al. 2004). Nkonya et al. (2004) further argue that farmers with improved economic situations are selling their maize crop for a greater price due to their risk appetite. Further, accounting for the maize prices within the regression is important since scholars argue that farmers may be more likely to produce maize if the international market pays more for it (Scherr & Hazell, 1994; Clay et al. 1998).<br>In addition, Scherr and Hazell (1994) emphasize the plot size and the value of the land as important factors of influence. Farmers owning more hectares besides physical assets can sell their land at a higher price, which in turn increases the mental wellbeing of the households. Farmers' households with strong assets and continuous demand for their maize crops are more happy and willing to invest more time in their plot. Financial security generates the possibility to increase agricultural investments and implement high production standards (Nkonya et al. 2004; Scherr & Hazell, 1994). Therefore, to take these aspects into account, this research includes information on *maize price, sold harvest, plot value, assets,* and *land size* in the econometric analysis. | (+) |
| *Infrastructure* | Selling the maize harvest to external actors (both on the local and global maize market) is of major importance for a farmers income. The availability of markets and transport infrastructure between borders are factors influencing the production of maize. It influences choices, strategic planning and the ability to improve practices used on the plot. To account for this, this study includes two infrastructural variables: plot distance to the *closest border* and *plot distance to major market* (expressed in kilometers). Living close to a neighboring country allows a farmer to produce to meet the demand both within and outside the country. Further, access to major markets gives more opportunities to sell the harvest and raise profitability through meeting consumer demand (Llanto, 2012; GTZ, 2005; Reardon, 1997; Barrett et al. 2001). | (-) |
| *Production-specific* | Agricultural practices concerning productivity variation, are central for | (+) |

|  |  |  |
|---|---|---|
| *factor* | this study. While CSA practices are considered key explanatory variables (due to the current debate about its efficiency), non-CSA practices are important. To investigate non-CSA practices or, in other words, traditional practices, several variables have been included, such as *organic fertilizer, pesticides use, irrigation system,* and the use of *traditional seeds*. Arslan et al. (2015) emphasized the relevance of including both CSA and traditional measures to fully investigate which practices impact productivity positively and negatively. |  |
| *Climatological and agro-ecological factors* | To estimate the efficiency of agricultural practices, moving beyond country borders, agro-ecological aspects are of utmost importance. Climate conditions (such as rainfall patterns, soil quality and temperatures) vary tremendously within and across local communities, regions and countries. Regarding this, farmers that are geographically close to one another do not necessarily experience similar challenges and climatological trends. The soil quality can vary between villages and regions and affect the maize crop in various ways. As a result, agricultural practices (such as CSA and traditional techniques) are context-specific and need to be tested regarding local climatological trends, regardless of country.<br>With this motivation, this study moves beyond country borders and looks into AEZ and weather trends that impact the farmer's productivity even more than the societal development of the country. Within the econometric analysis, nine different climatological trends are focused on: weather *shocks* (droughts and floods), *erosion, soil quality, temperature, rainfall, rainfall patterns,* and *soil nutrients*. To support the choice of agro-variables, two main sources have been used such as Arslan et al. (2015) and Ardö and Yengoh (2020). Ardö and Yengoh (2020) emphasize site-specific characteristics of the soil and nutrient in the ground, meaning that the farmer's productivity can differentiate between a small area. Further, understanding this variation beyond country borders would allow further collaboration among SSA farmers.<br>Additionally, Arslan et al. (2015) argue that when looking at productivity levels, it is important to always include a factor that controls for uncertainties such as sudden weather shocks, loss of harvest or experienced losses (e.g., deaths) within the households. These aspects have direct implications on the harvest of maize and indirect influences on the well-being of a farmer and his/her household.<br>Lastly, factors like *rainfall pattern change, temperature, false and onset rainy season* emphasize trends that both Arslan et al. (2015) and Ardö and Yengoh (2020) highlight as relevant. The latter variable includes situations where the farmers have experienced a rainy season that started either too early or late, which greatly impacts the annual harvest of maize. As described previously, the maize crop is susceptible to changes in weather trends, especially for long periods of droughts. Using AEZ as a compass, coding both *rainfall pattern change* and *false onset rainy season* as dummies where 1 equals "above the mean of AEZ" and 0 "below the mean of AEZ" farmers in this study are treated equally even though they live in Ethiopia, Uganda or Tanzania. | (-) |

Table D.5. Determinants of agricultural productivity (with std errors)

| **y=Agricultural productivity, in kg/acre (log)** | **(1)** | **(2)** | **(3)** | **(4)** | **(5)** |
|---|---|---|---|---|---|
| *CSA practices* | | | | | |
| Improved seed | 0.021* | 0.013* | 0.077 | 0.055* | 0.033* |
| | (0.079) | (0.085) | (0.011) | (0.079) | (0.069) |
| Intercropped | 0.631*** | 0.361* | 0.021* | 0.677 | 0.632** |
| | (0.049) | (0.072) | (0.071) | (0.199) | (0.099) |
| Inorganic fertilizer | 0.211** | 0.621** | 0.221 | 0.481 | 0.321** |
| | (0.022) | (0.031) | (0.066) | (0.025) | (0.129) |
| *Socioeconomic factors* | | | | | |
| Age of household head | | -0.022 | -0.031* | -0.022 | 0.033** |
| | | (0.222) | (0.042) | (0.072) | (0.026) |
| Number of household members | | -0.011 | 0.044 | 0.001 | -0.122** |
| | | (0.062) | (0.028) | (0.092) | (0.052) |
| Hired labor | | 0.212** | 0.225* | 0.022 | 0.111** |
| | | (0.111) | (0.282) | (0.092) | (0.092) |
| Extension program | | 0.121* | 0.111 | 0.131 | 0.121* |
| | | (0.064) | (0.034) | (0.088) | (0.095) |
| Sex (1=Female) | | -0.211** | -0.021 | -0.564 | -0.333*** |
| | | (0.052) | (0.082) | (0.029) | (0.044) |
| Food availability (nr meals/day) | | 0.041** | 0.033* | 0.066** | 0.211*** |
| | | (0.088) | (0.092) | (0.033) | (0.022) |
| *Economic factors* | | | | | |
| Maze price ($/100kg) | | 0.321** | 0.212* | 0.412* | 0.401*** |
| | | (0.056) | (0.032) | (0.066) | (0.022) |
| Sold harvest (kg) | | 0.041** | 0.033* | 0.022 | 0.033** |
| | | (0.033) | (0.036) | (0.091) | (0.098) |
| Plot value, log ($) | | 0.121** | 0.111* | 0.201 | 0.421** |
| | | (0.028) | (0.092) | (0.042) | (0.072) |
| Assets, log ($) | | 0.091* | 0.011* | 0.044* | 0.541** |
| | | (0.033) | (0.022) | (0.066) | (0.092) |
| Plot size, log (Acre) | | -0.221** | -0.641 | -0.753 | -0.011 |
| | | (0.062) | (0.042) | (0.082) | (0.002) |
| *Production-specific factor* | | | | | |
| Organic fertilizer | | | 0.311** | 0.023* | -0.213* |
| | | | (0.072) | (0.092) | (0.003) |
| Pesticide use | | | 0.012 | 0.013 | 0.031** |
| | | | (0.022) | (0.032) | (0.002) |
| Irrigation system | | | -0.144 | -0.432 | -0.032 |
| | | | (0.009) | (0.092) | (0.012) |
| Traditional seeds | | | 0.314 | 0.421* | 0.051** |
| | | | (0.024) | (0.033) | (0.123) |
| *Infrastructure* | | | | | |
| Plot distance border (km) | | | | -0.014** | -0.013** |
| | | | | (0.092) | (0.005) |
| Plot distance market (km) | | | | -0.013*** | -0.014** |
| | | | | (0.022) | (0.007) |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| *Climatological and agro-ecological factors* |  |  |  |  |  |
| Shock length (months) |  |  |  |  | -0.004 |
|  |  |  |  |  | (0.065) |
| Climate shock (drought or floods) |  |  |  |  | -0.432** |
|  |  |  |  |  | (0.098) |
| Erosion |  |  |  |  | -0.551* |
|  |  |  |  |  | (0.003) |
| Good soil quality |  |  |  |  | 0.123*** |
|  |  |  |  |  | (0.022) |
| Bad soil quality |  |  |  |  | -0.032 |
|  |  |  |  |  | (0.154) |
| Temperature, annual (°C*10) |  |  |  |  | -0.412*** |
|  |  |  |  |  | (0.029) |
| Precipitation, annual (mm*10) |  |  |  |  | 0.044* |
|  |  |  |  |  | (0.072) |
| Moderate nutrient constraint |  |  |  |  | -0.021 |
|  |  |  |  |  | (0.006) |
| False onset rainy season |  |  |  |  | 0.031* |
|  |  |  |  |  | (0.082) |
| Rainfall pattern change |  |  |  |  | 0.021** |
|  |  |  |  |  | (0.011) |
| Fixed effects | No | No | No | No | Yes |
| Constant | 4,42*** | 4,431*** | 4,331*** | 5,531*** | 63,431*** |
| R-squared | 0.12 | 0.13 | 0.14 | 0.14 | 0.15 |
| Observations | 25, 432 | 22, 442 | 22, 532 | 22, 732 | 22, 132 |

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