Study on

"Documenting the adoption of Conservation Agriculture and Agroforestry in Malawi and Zambia"

Final Report

Economic and Policy Innovations for Climate-Smart Agriculture (EPIC) Team
Agricultural Development Economics Division (ESA) of FAO

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Acronyms and Abbreviations

AEZ	Agro-Ecological Zones
AF	Agroforestry
ARC	Africa Rainfall Climatology
CA	Conservation Agriculture
CF	Conservation Farming
CFU	Conservation Farming Unit
CGIAR	formerly the Consultative Group for International Agricultural Research
CR	Crop Rotation
CSA	Climate-Smart Agriculture
CSO	Central Statistics Office
EAs	Enumeration Areas
ECMWF	European Centre for Medium-Range Weather Forecasts
EPIC	Economic and Policy Innovations for Climate Smart Agriculture team
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations
FISP	Farmer Input Support Program
GAPs	Good Agricultural Practices
GDP	Gross Domestic Product
HWSD	Harmonized World Soil Database
IAPRI	Indaba Agricultural Policy Research Institute
ICRAF	International Centre for Research in Agroforestry
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IHPS	Malawi Integrated Household Panel Survey
LSMS-ISA	Living Standards Measurement Study - Integrated Surveys on Agriculture
MACO	Ministry of Agriculture and Cooperatives
MASAF	Malawi Social Action Fund
MGDS	Malawi Growth and Development Strategy
MSD	Minimum Soil Disturbance
MSU	Michigan State University
NCATF	National Conservation Agriculture Task Force
NRM	Natural Resource Management
RALS	Rural Agricultural Livelihoods Survey
SAPP	Sustainable Agriculture Production Programme
SIDA	Swedish International Development Cooperation Agency
SLM	Sustainable Land Management
SPIA	Standing Panel on Impact Assessment
SSA	Sub-Saharan Africa
TLU	Tropical Livestock Unit
WFP	World Food Programme
ZARI	Zambia Agricultural Research Institute

Documenting the adoption of Conservation Agriculture and Agroforestry in Malawi and Zambia

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This study provides a comprehensive cross-country understanding of the determinants of the adoption of conservation agriculture (CA) practices and agroforestry, as well as empirical evidence on their impacts on productivity in Malawi and Zambia. Using unique panel data sets from geo-referenced agricultural household surveys combined with long-term climatic data on rainfall, temperature and soil properties, we model farmers' adoption decisions for multiple practices simultaneously in order to capture the complementarities and/or substitutabilities among the different technologies controlling for the effect of both climatic risk factors and household-specific time-invariant unobserved heterogeneity. Furthermore, we also estimate the empirical association between the adoption of practices and the maize productivity, as well as the value of the production, taking into account potential confounders related to climate shocks, household characteristics, bio-physical soil characteristics, agro-ecological heterogeneity and government programs and institutions relevant for smallholder farmer production. The empirical analysis allows us to identify some lessons that are valid across the two countries. Our findings highlight the importance of promoting flexible technology packages that suit site-specific (climatic, agro-ecological and socio-economic) conditions in order to facilitate adoption and increase agricultural productivity and profitability.

Keywords: Conservation agriculture, technology adoption, climate change, adaptation, productivity, panel data, Malawi, Zambia

JEL codes: Q01, Q12, Q16, Q18

Project background

The Economic and Policy Innovations for Climate Smart Agriculture (EPIC) team has worked in Malawi and Zambia since 2012 as part of various projects that culminated in the establishment of a work programme on Climate-Smart Agriculture (CSA). The activities of this programme of work started with estimating adoption patterns and the performance of various agricultural practices including Agroforestry (AF), Conservation Agriculture (CA) and soil and water conservation structures controlling for historical trends in climatic variability and locally relevant weather shocks. The EPIC team continues to operate in both countries through the FAO offices and the Ministries of Agriculture and Livestock. Given the fact that the adoption rates at the national level of most of these practices are still relatively low in both countries, more in depth analysis is needed for a clear understanding of the barriers to and impacts of adoption. This study on "Documenting the adoption of Conservation Agriculture and Agroforestry in Malawi and Zambia", was funded by SPIA as part of the stream of studies to "document the impact of widely-adopted CGIAR research-related innovations" (Work Package 1). It builds on previous EPIC research using the newest panel data sets merged with other relevant data sets available to contribute to our knowledge of adoption and dis-adoption patterns in nationally representative samples in both countries.

In Zambia, over time the EPIC team has built strong partnerships with the Zambian research institutions including the Indaba Agricultural Policy Research Institute (IAPRI) and ZARI (Zambia Agricultural Research Institute). Given the lack of sufficient detail on some Natural Resource Management (NRM) practices of interest for CSA as well as some subtleties in defining CA in previous rounds of nationally representative agricultural household data (2004, 2008), new questions and modules were built into the 2012 and 2015 Rural Agricultural Livelihoods Survey (RALS).

With respect to Malawi, the EPIC team has implemented several studies on the adoption of CSA technologies and practices exploiting the data provided by the National Statistical Office of Malawi (NSO) and the Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA) project of the World Bank. These data have been collected within different waves of the Integrated Household Survey (IHS) that, since 2010, constitute the Integrated Household Panel Survey (IHPS). Noting the lack of detail in NRM practices relevant for CSA in earlier rounds of the IHS, EPIC team collaborated with the World Bank to improve these questionnaires, especially regarding the components of CA.

The analyses in this report build on previous EPIC research using newer and improved data sources to identify the adoption determinants and the related impact on several outcomes ranging from the household agricultural productivity to income and food security. Within this framework, a special focus has been devoted to the association between the long-term historical climate variability and

shorter term shocks and the adoption of improved soil and water management practices as well as the impact of climatic variables and adoption on the main outcomes.

The analysis in Malawi based on nationally representative data sources is complemented with an another analysis using a data set from IFAD with much more detail on relevant technologies. EPIC team is collaborating with IFAD, the Government of Malawi and Total Land Care in assessing the impact of the Sustainable Agriculture Production Programme (SAPP), whose main focus is the promotion and diffusion of Good Agricultural Practices (GAPs), with CA representing a key intervention of the programme. We use the baseline data collected in 2014 from treated and control households in 120 randomly selected Enumeration Areas (EAs) extending over all three regions of the country (Northern, Central, and Southern). These data include very detailed information on the adoption and adoption history of a large set of sustainable agricultural practices allowing us to validate the results from IHPS.

1. Introduction

Conservation Agriculture (CA) is being increasingly promoted as a combination of principles and practices contributing to sustainable production intensification (FAO, 2008)[1]. The ultimate goal of CA is to improve the utilization of agricultural resources relative to conventional practices through the integrated management of available soil, water and biological resources such that external inputs can be minimized (FAO, 2015)[2]. CA is expected to increase yields, reduce labour requirements, improve soil fertility and reduce erosion (Hobbs, 2007), while contributing to higher output and improving food and nutrition security (Neubert, 2011).

In Malawi and Zambia the promotion of CA is a high priority in agricultural policy documents and climate adaptation plans. Despite significant efforts to promote CA, adoption rates remain low. Providing evidence about the drivers of the adoption of these practices, as well as assessing the related productivity implications, this paper contributes to strengthen the evidence base to support specific policies on sustainable agriculture. Taking advantage from two nationally representative panel datasets together with high resolution climatic data from Malawi and Zambia, this analysis updates previous evidence on the topic (Arslan et al. 2014, 2015 and Asfaw *et al.*, 2016). It also draws upon the similarities and the differences between the two countries to derive lessons for further promotion of agricultural technologies that have the potential to improve productivity and food security.

[1] Documents available at http://www.fao.org/ag/ca/doc/conservation.pdf
[2] Documents available at http://www.fao.org/ag/ca/11.html

The specific contributions of this study are threefold. Firstly, we combine geo-referenced household panel data with long-term climatic data on rainfall and temperature to create a unique data sets. This rich dataset allows us to model the technology adoption decisions taking explicitly into account different measures of locally relevant climate risk as possible determinants (Kassie *et al.*, 2013; Asfaw *et al.*, 2014; Arslan *et al.*, 2017). Secondly, we simultaneously model farmers' adoption decisions on different practices to capture the complementarities and/or substitutabilities among the different practices controlling both for climatic risk factors and household-specific time-invariant unobserved heterogeneity. Thirdly, we assess the empirical association between technology adoption and household farm productivity controlling for climate shocks, household characteristics, soil characteristics, agro-ecological heterogeneity and government programs and institutions relevant for smallholder farmer production (e.g., the FISP and the MASAF programme in Malawi and the FISP and the role of the Food Reserve Agency in Zambia).

The rest of the report is organized as follows. Section 2 describes the two countries of analysis and provides a background on the promotion of CA practices and agroforestry in Malawi and Zambia. Section 3 introduces the data and presents the relevant descriptive statistics. Section 4 is devoted to explaining our empirical strategy to estimate the determinants of adoption and yields. Section 5 presents our results and Section 6 provides some policy implications to conclude.

2. Conservation Agriculture (CA) in Malawi and Zambia

2.1. Malawi

Malawi, with more than 17 million of people and an estimated land area of 11.8 million hectares (of which Lake Malawi occupies one-fifth of the total), is one of the most densely populated countries in SSA. The country is characterized by complex economic and environmental problems mostly due to the growing population. Agriculture is the most important sector accounting for about 40% of the GDP. More than 85% of the total population lives in rural areas, where most of the arable land is under traditional/customary tenure system. The increasing pressure on land has led to declining per capita land holdings. Nowadays, almost two-thirds of the rural farmers are smallholders possessing less than 2 hectares of land. Most of them are subsistence farmers while a small percentage of the agricultural land is operated by estates on leasehold or freehold land. The latter provide over 80 percent of agricultural exports, mainly tobacco, sugar, tea and, to a lesser extent, tung oil, coffee and macadamia.

The agricultural sector in Malawi is the backbone of the economy. Although agricultural development is in the forefront of government and international organizations' attention, low productivity combined with increasing population pressure on agricultural land have brought marginal areas under cultivation and poses a major threat to sustainable agriculture. Reduced opportunities for fallow periods and crop rotation to restore soil fertility have pushed an increasing number of smallholders to cultivate on

marginal, less fertile soils not suitable for intensive cultivation. As a result, woodland depletion, soil degradation and erosion are affecting the livelihoods of millions of people in the country, making Malawi one of the most vulnerable country to climate change (Davis, 2011; Abson, Dougill and Stringer, 2012). The agricultural system is largely rain-fed, therefore highly vulnerable to weather shocks (such as droughts, rainfall irregularities and floods) which are likely to impact smallholder food security (Chinsinga, 2014).

Over the past 20 years, Malawi has been hit by a number of extreme events including two serious droughts and a prolonged dry spell in 2004, a significant flooding in 2015 followed by a serious drought in 2016 as a consequence of "El Niño". All these events had pronounced negative effects on the agricultural sector and smallholder livelihoods. As a consequence increasing the climate resilience and the sustainability is one of the major concerns for the Malawian agricultural sector in the long term (MoAIWD, 2015).

Within this context, upscaling the adoption of sustainable land management (SLM) practices has been advocated by international organizations, government institutions and NGOs to improve the soil health, reduce labor demand, and minimize negative effects of agriculture on the environment. In particular, adoption of CA practices including minimum soil disturbance (hereafter MSD), permanent soil cover (organic cover crop and/or residues retention) and crop associations (legume intercropping and/or crop rotation) is expected to moderate the impact of climate change on farm productivity, and to increase the adaptation capacity to adverse weather conditions.

Historically, CA has been promoted in Malawi through the action of the National Conservation Agriculture Task Force (NCATF) and the National Smallholder Farmer's Association of Malawi (NASFAM), alongside the Consultative Group for International Agricultural Research (CGIAR) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). The aim of the interventions implemented by these organisations has been to develop best practices to maximize the benefits of CA adoption for different crops under different agro-ecological circumstances. A key point of emphasis for CA promotion in Malawi is to encourage the adoption of MSD as a starting point for building a robust CA system. This is because it was recognized that only few farmers could incorporate all three CA principles from the beginning because of severe economic constraints. Another important pillar of the promotion of CA in Malawi has been the setting of a capacity-building knowledge "chains" in order to link national policies to district extension workers, to lead farmers and then to collective farmers clubs or associations (Kumwenda, 2013).

In spite of all the efforts made to promote CA in Malawi, the adoption rates have been much lower than expected (1-2% depending on the sample and the definition of CA) and the growth of sustainable agriculture in Malawi remains precarious (Phiri et al., 2012). Smallholder farmers face a number of

barriers constraining the adoption CA, ranging from economic constraints, information constraints and cultural norms.

2.2. Zambia

In Zambia, the agriculture share on the GDP is around 20 percent. In spite of this, agriculture is the main source of livelihood for 60 percent of the population. Furthermore, 64% of the total population lives in rural areas that primarily depend on rain-fed subsistence agriculture. These populations are highly vulnerable to various shocks, be it weather shocks or other shocks typical of the agricultural sector (input/output price shocks). The Zambia Vulnerability and Needs Assessment Report prepared as a response to prolonged droughts in the 2015 season shows that droughts increased food insecurity in 31 of 48 districts assessed, as around 800,000 people were in need of food relief (Zambia Vulnerability Assessment Committee, 2015). High climate variability and extreme whether events represent two binding constraints to the development of agricultural productivity in Zambia. In this framework, the adoption of CA is thought to be a suitable strategy for smallholder farmers that have no resources to adopt other fertility-enhancing strategies (inorganic fertilizer, improved seeds etc…).

CA has been actively promoted as conservation farming (CF) since the 1980s as a way to increase agricultural productivity on degraded soils due to intensive tillage, lack of soil cover and burning of crop residues (Baudron *et al.*, 2007).[3] In 1985, the Soil and Fertility (SCAFE) project was the first project to be launched aimed at promoting CA. It was first implemented in the Eastern province and then expanded to Central and Southern provinces, by the Ministry of Agriculture and Cooperatives (MACO, then named MAFF and now MAL), and funded by the Swedish Government (SIDA). The main objective of the project was the promotion of a wide range of erosion control measures including bunding, contour tillage and vetiver grasses; soil fertility enhancing techniques including crop residue management, green manures, cover crops, mulching, improved fallow, and conservation tillage (Haggblade and Tembo, 2003). Since late 1999s, the Ministry of Agriculture made the increase of CA adoption an official priority and started promoting it through several projects funded by different institutions such as, SIDA, FAO, the World Bank, WFP, and the EU.

Despite its promotion by the government and its different cooperating partners over time, adoption in Zambia is still relatively limited and unstable. Key constraints faced by households in adopting CA practices are increased labour and input costs, higher economic risk combined with limited increased (immediate) net gain, limited access to quality legume seeds and to crop markets other than maize. In 2002/3, for example, only 20 percent of CA farmers were found to be "spontaneous adopters", with

[3] In Zambia the Conservation Agriculture principles have been promoted as Conservation Framing (CF). Hereafter, in order to avoid confounders we will refers to CF as CA.

the remaining 80 percent practicing CA as a condition for receiving subsidised input packages (Haggblade and Tembo, 2003). In 2011, Conservation Farming Unit (CFU) declared that around 170,000 farmers (out of a total of around 1.2 million small/medium-scale farmers) in the country, had adopted CA on part or all of their land. Generally, the adoption of CA practices is observed to be incremental and partial with farmers using both conventional and conservation agriculture on their plots (Umar *et al.*, 2011). The previous literature highlights that climatic conditions and attitudinal and knowledge-based factors (Nyanga *et al.*, 2011) are key drivers for the adoption of CA. Since several CA projects include subsidized fertilizer and seed packages, farmers tend to adopt suggested practices because of the provision of a subsidy, input package or material rewards. Fifty percent of farmers tend to dis-adopt CA if they no longer qualify for such incentives (Baudron *et al.*, 2007; Nyanga *et al.*, 2011). Arslan *et al.* (2014) has documented very high dis-adoption rates using nationally representative panel data.

This report builds on previous studies in both countries by providing evidence based on the newest nationally representative panel data combined with high-resolution historical climate data as detailed below.

3. Data sources and descriptive analysis

3.1. Malawi Household Data

The household data in Malawi have been collected within the Living Standards Measurement Study (LSMS) of the World Bank gathering information from two waves: the 2009/2010 and the 2012/2013 rounds of the Integrated Household Surveys (IHS3 and IHS4).[4] We focus on households that lived in rural areas and cultivated at least a plot in both periods. Following this restriction we created a balanced panel of 1,715 households. At the baseline, the sample was selected to be representative at the national, regional, urban/rural levels and for each of the following 6 strata: (i) Northern Region - Rural, (ii) Northern Region - Urban, (iii) Central Region - Rural, (iv) Central Region- Urban, (v) Southern Region - Rural, and (vi) Southern Region - Urban.

We augment this dataset with geospatial rainfall, temperature, and soil quality data to describe the conditions faced by farmers. In addition to this, we add information on government programs relevant for smallholder farmer production (e.g. FISP, MASAF, credit institutions) that was collected by the FAO-EPIC team as part of the first CSA project implemented in the country.

Given the very low adoption rates of practices associated with CA as well as lack of detail on some of its components in the IHPS, we also use data on the adoption of CA practices from the SAPP (which refers to the 2013/2014 agricultural season) that was specifically designed to understand the adoption

[4] The two IHS surveys together are referred to as the Integrated Household Panel Survey (IHPS).

and impacts of such practices promoted by an ongoing IFAD project. The SAPP Baseline data cover 11 districts (5 of them considered control district) and within each of them 10 EAs and 15 households (20 EAs for the district of Lilongwe) have been randomly selected for a total of 1,800 geo-referenced households. As a result, the SAPP is only representative at district level in selected districts.

Exploiting the information available within the IHPS and the SAPP, we have built a number of variables related to CA practices to preserve the comparability and the consistency across the different data sources. Detailed tables with the descriptive statistics for those variables and their combinations alongside with other relevant practices have been prepared using relevant plot and household level data.

In order to understand adoption and dis-adoption patterns, we use transition matrices. However, we are constrained by the availability of longitudinal information in the IHPS data (as the improved questionnaire with EPIC support is only available in the second round), hence are able to construct the transition matrix of only the most widespread CA practice (i.e. the legume intercropping) based on IHPS. This information has been complemented with the retrospective questions included within the SAPP, which allows us to provide further information on the proportion of households who have adopted (at least once during the last three agricultural seasons) and who have dis-adopted each practice covered in this module. Finally, for both surveys we have prepared a number of maps in order to represent the geographic distribution (at the district level) of the adoption of CA practices and its evolution over time.

To the extent that the statistics have been calculated taking into account the specific sample design of each survey (weight and stratification), they are representative at the level of the reference survey. Comparing those results, we have also verified that, at least for the highly comparable variables, the average adoption rates from the two different surveys are highly similar, providing added support to the use of SAPP data to document adoption levels of practices that are not as well covered by the earlier rounds of the IHPS.

3.2. Zambia Household Data

For Zambia, we use the nationally representative household data from the 2012 and 2015 waves of the Rural Agricultural Livelihoods Survey (RALS) collected by the Central Statistics Office (CSO) in collaboration with Michigan State University (MSU) and the Indaba Agricultural Policy Research Institute (IAPRI). In 2015, a sample of 7,934 households has been interviewed, out of which 7,254 were interviewed in 2012 and 680 new households were added from different clusters in three provinces namely, Lusaka, Eastern and Muchinga. Given the lack of sufficient detail on some Natural Resource Management (NRM) practices of interest for CSA as well as some subtleties in defining CA in previous rounds of nationally representative agricultural household data (2004 and 2008), new questions and modules were built into the 2012 and 2015 rounds of the RALS. These new questions

are geared towards collecting detailed data on potential CSA practices (including but not limited to CA components) as well as a separate module on Agroforestry (AF) with a special focus on identifying the species of trees used in agroforestry systems as well as history of adoption and information sources.

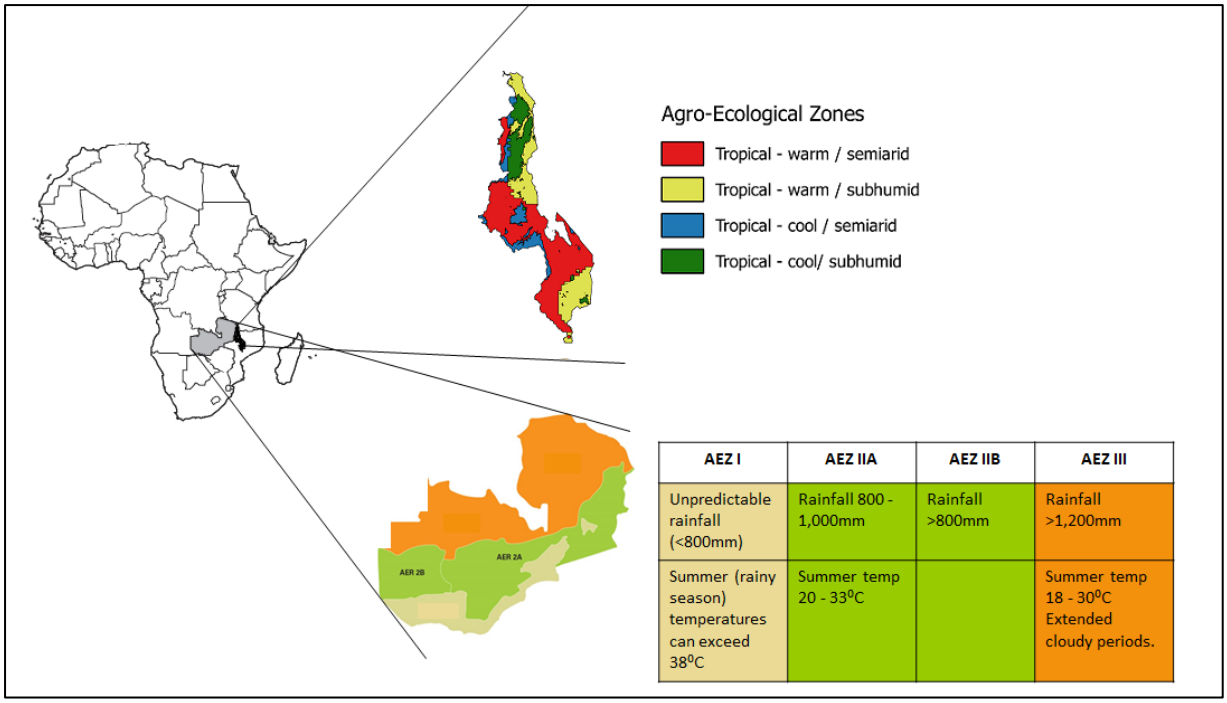
The variables used in this study are based on the three main principles of CF, i.e., reduced tillage using permanent planting basins and ripping, crop rotation/association with legumes and residue retention. Based on this definition, adoption of CA is analysed using the detailed questions on tillage methods, rotation and intercropping (including species used) and residue use available from the farm land and use section of the RALS questionnaire. Adoption of AF has been defined based on whether there are trees on each plot and divided into sub-categories using the information on the species on each plot that are decided in collaboration with ICRAF colleagues as part of WP7.

3.3. Geospatial Data and Agro-Ecological Zones

The socio-economic datasets have been augmented with geospatial rainfall, temperature, soil quality and agro-ecological information to control for the geographical and physical conditions faced by farmers. Rainfall data are extracted from the Africa Rainfall Climatology version 2 (ARC2) of the National Oceanic and Atmospheric Administration's Climate Prediction Centre (NOAA-CPC) at 10-day intervals over the period of 1983-2015. ARC2 data are based on the latest estimation techniques on a daily basis and have a spatial resolution of 0.1 degrees (~10km). Surface temperature measurements for each dekad covering the period 1989-2015 has been obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) at a spatial resolution of 0.25 degrees. The analyses also consider the heterogeneity arising from the different agro-ecological zones (AEZ) based on moisture (water availability), climate and thermal zones (warm or cool based on elevation). In Malawi, AEZ 1 (Tropical warm/semiarid) covers low lands of semi-arid areas found mainly on the shores of Lake Malawi and in the Rift valley areas of the Lower Shire. It lies between 500 – 1,000m above sea level (m.a.s.l) and receives less than 1000 mm annual rainfall. AEZ 2 (Tropical warm/sub-humid) covers the northern coast of Lake Malawi, the shore of Lake Chilwa, Blantyre and the areas around Makoko. This zone includes the lowest elevation point of the country (junction of the Shire River and international boundary with Mozambique 37 m) and receives about 1000 mm annual rainfall. AEZ 3 (Tropical cool/semiarid) covers highland plains of the Shire Highlands, Lilongwe, Kasungu and Mzimba lying at 1,000 – 1,500 m.a.s.l. This zone receives 1,000 – 1,500 mm annual rainfall. AEZ 4 (Tropical Cool/sub-humid) covers high altitude areas of the Vipya Plateau, Nyika plateau, Dowa and Dedza hills lying over 1,500 m.a.s.l. It has a total annual rainfall of over 1,500 mm. A high proportion of this zone encompasses forest reserves and national parks.

In Zambia, the western and southern parts of the country (AEZ I)[5] are exposed to low, unpredictable and poorly distributed rainfall in general, whereas the central part of the country (AEZ IIa & b) has the highest agricultural potential, with well-distributed rainfall (Jain, 2007).Zambia-specific climate models predict that rainfall will decrease and temperatures will increase in AER I and II, while rainfall will increase in the northern parts of the country (AEZ III) (Kanyanga et al., 2013). Combined with projections of prolonged droughts and dry spells, maize production is expected to be severely affected in these regions that cover the majority of Zambia's maize growing area. Increased rainfall on the already leached and acidic soils of AEZ III is expected to have a negative impact on crop production. Some of the most vulnerable parts of the country lie in the transition zones identified by Jones and Thornton (2009), where maize agriculture is expected to cease to be a "normal agricultural activity" and a transition to herding and income diversification will be necessary for adaptation.

Figure 1. Agro-Ecological Zones for Malawi and Zambia



AEZ I	AEZ IIA	AEZ IIB	AEZ III
Unpredictable rainfall (<800mm)	Rainfall 800 - 1,000mm	Rainfall >800mm	Rainfall >1,200mm
Summer (rainy season) temperatures can exceed 38^{0}C	Summer temp 20 - 33^{0}C		Summer temp 18 - 30^{0}C Extended cloudy periods.

Source: Authors' own elaboration

[5] Note that in Zambia the usual classification based on soil and rainfall corresponds to Agro-Ecological Regions (AER). AEZ are defined taking into account also agricultural production potential in Zambia, and there are 35 AEZ. In order to prevent potential confusion for the reader by using AEZ for Malawi and AER for Zambia in this report, we use AEZ also for Zambia to refer to AERs.

3.4. Descriptive Analysis

Table 1 shows percentages of farmers adopting CA practices for Zambia and Malawi. Although the share of households practicing the full set of CA strategies is extremely low in both countries, we can describe the level of adoption of different components being part of the CA approach as well as how variables are constructed in using different sources of household data. Figures from the SAPP baseline are meant to complement those from IHPS specifically on practices for which there is no or insufficient information (i.e. agroforestry and crop rotation) in the latter. Since the SAPP baseline is not representative at the national level, we do not expect to find exactly the same figures for all practices. Moreover, although for this study an effort has been made in order to construct all variables in a consistent way across all surveys, in some cases we have been constrained by the availability of information. As a result, some variables could not be defined exactly in the same way across surveys. This is the case of residue retention, which is identified as mulching in the IHPS (residues are cut and spread on the plot) while in the SAPP, the adopters have been defined as those who reported having used residues both for improving soil fertility and for soil conservation purposes.

Table 1. Percentages of farmers adopting CA by country and survey wave

	Malawi			**Zambia**	
	2011 IHS3	**2013 IHPS**	**2014 SAPP**	**2012 RALS**	**2015 RALS**
Practicing full set of CA	-	0.96	0.94	-	0.29
MSD	-	4.13	6.02	2.75	8.00
Crop rotation		-	31.02	51.49	55.10
Legume intercropping	33.97	52.22	46.99	4.17	8.32
Residue retention	-	8.00	1.0	-	4.19
Cover crop	-	30.84	12.21	-	-
MSD + Legume intercropping/CR	-	1.34	4.87	1.30	3.71
MSD + Crop residue	-	1.37	1.17	-	0.32

Note: [1]SAPP residues are residues used for soil conservation purpose only. [2]SAPP cover crop is only legumes cover.

In both countries the surveys asked farmers about the tillage method used for each plot in all survey rounds. In this study, we define the MSD indicator as practicing zero tillage, planting basins (potholes) or ripping on at least one plot. The percentage of farmers implementing MSD is quite low in both countries, although figures for Zambia show an increase from 3 to 8 percent of adoption between the two survey rounds.

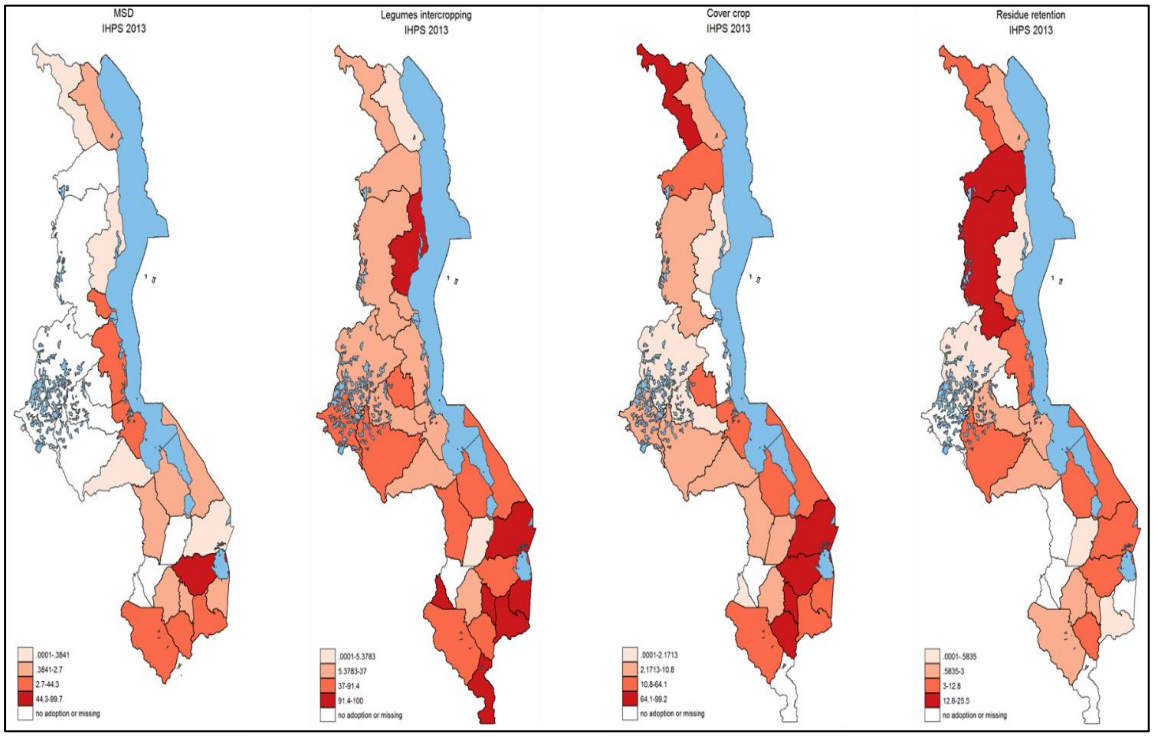
Legume intercropping variable is constructed using information on households cultivating more than one crop and, at the same time, any kind of legumes on the same field. The share of households adopting legume intercropping in Malawi has increased from 34 to 52 percent between 2011 and 2013. In Zambia legume intercropping adoption rates are much lower, despite the increase observed between the two waves from 4 to 8 percent. The indicator for crop rotation is created using the

information on main crop cultivated on each plot during the agricultural season of the interview, combined with those in the agricultural seasons before and after the survey year. In Malawi, IHPS does not allow to construct a variable for crop rotation, therefore we only have values for SAPP. The share of farmers adopting crop rotation is 31 percent in Malawi in 2014, and greater than 50 percent in Zambia, where it has increased from 51.5 to 55.1 between the two waves. Rotations represent an essential part of CA, and acquire more importance with legumes, with figures clearly showing that farmers in Zambia prefer rotating maize and legumes rather than intercropping them on the same plot.

Crop associations either as legume intercropping (Malawi) or crop rotation (Zambia) are the most widely adopted CA principles in both countries. Such high rates of adoption are likely due to the fact that legume intercropping and crop rotation are practices that are already part of the traditional farming systems. Growing legumes (either alongside with or rotating them with other crops) is used as a nitrogen supplement to increase yields as well as to reduce costs of fertilizer. Moreover, legumes are used as high protein fodder when other alternatives are limited given the budget constraints. Notwithstanding this, legume intercropping, and crop rotation fall into the definition of CA and can be considered CA practices regardless of the drivers of their adoption.

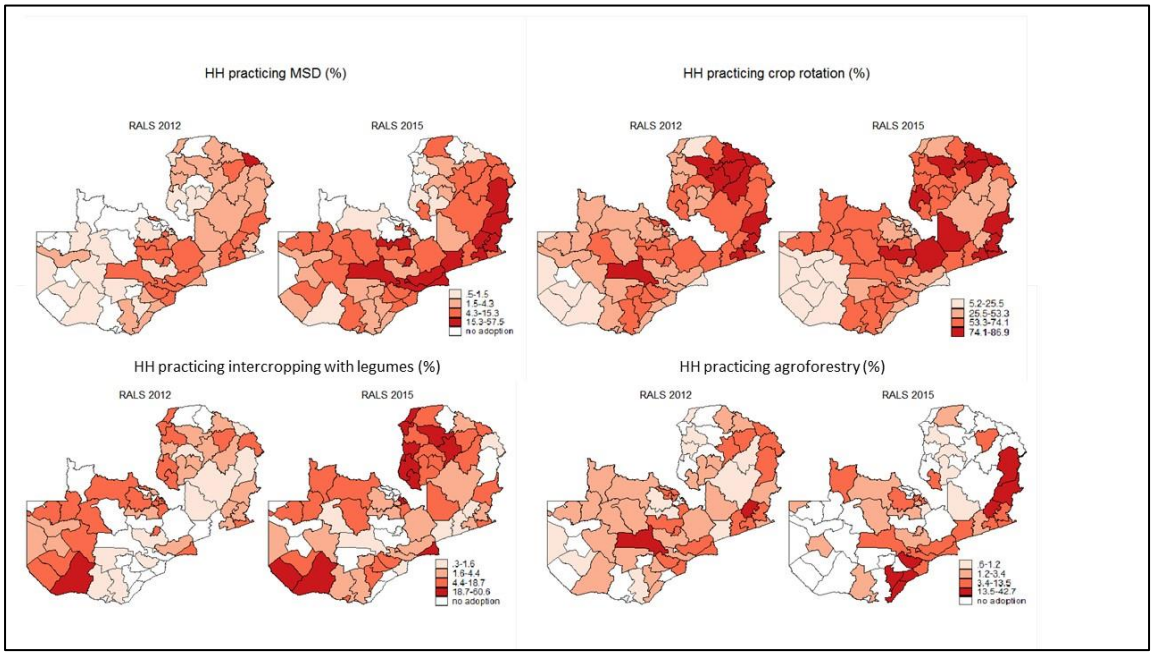
Permanent organic cover is the third pillar of CA and includes the adoption of residue retention and/or cover crops. In this framework, residue retention refers to the use of crop residues as surface mulch rather than removing or burning them. One advantage of this practice is the protection of soil, capturing rainfall and returning valuable organic matter to the soil. Since residue retention requires a joint effort of farmers to control burning as well as communal grazing (mainly by establishing by-laws) through the leadership structure of the community, its level of adoption is quite low in both countries (8 percent in Malawi using IHPS and 4 percent in Zambia). The information on cover crops are available only in Malawi. The practices refer to the cultivation of given crops to control weeds. In Malawi, the share of farmers adopting cover crops is 30 percent in the IHPS 2013 and around 12 percent in SAPP 2014. However, since legumes are widely used as cover crop, the explanation for the high rate of adopters is related more to the inclusion of legumes in the traditional system rather than a conscious adoption of the CA principles. As a result, the adoption of combination of two practices (i.e., MSD *plus* legume intercropping or crop rotation, MSD *plus* crop residue) is low (between 0.32 to 4.87%). Therefore, the adoption of the full package of CA principles is less than 1% in both countries.

Figure 2. Adoption of CA practices in Malawi



Source: Authors' elaboration based on IHPS 2013 data

Figure 3. Adoption of CA practices in Zambia



Source: Authors' elaboration based on RALS 2012 and 2015 data

The geographical distribution of adopters in both countries is also very heterogeneous. Figures 2 and 3 show the distributions of adoption of selected CA practices at the district level in Malawi and Zambia, respectively. Adoption of most CA components is more concentrated in the southern parts of

Malawi, except residue retention, which seems to be more dispersed around the country. In Zambia, the adoption of MSD has increased over time but remained concentrated in the Eastern parts of the country. Crop rotation in Zambia and legume intercropping and organic cover in Malawi are more evenly distributed as they have been practiced by farmers traditionally regardless of promotion activities.

Table 2 presents a comparison of national transition matrices for legume intercropping between the two survey rounds for the two countries. The first row of each matrix shows the adoption status in the later year of farmers that did not adopt the CA practice in question in the base year. The second row describes the change in adoption patterns for farmers who were already adopters in the first round.[6] Hence, while in Malawi the adoption of this practice is widespread, with 42 percent of non-adopters starting to adopt legume intercropping in 2013, in Zambia the share of new adopters between 2012 and 2015 is around 8 percent, with 69 percent of dis-adopters in the same period (the dis-adoption rate in Malawi is around 27 percent).

One of the reasons for the difference in the rates of adoption (and dis-adoption) between the two countries may be found in the difference in their agricultural subsidy programs. Whereas legumes are an important component of the agriculture sector in Malawi, being included in the Malawi Growth and Development Strategy (MGDS) II (2011-2016), in Zambia, the Farmer Input Support Program (FISP), since its inception, has focused on improving maize production. Since 2009 rice, sorghum, cotton and groundnut seeds were included in the FISP, but in minor quantities (Mason et al. 2013). The dis- adoption rates in the two countries may also reflect the long period prior to reaping the full yield benefits of CA, or the fact that some farmers are susceptible to dis-adopt if other farmers dis-adopt (Marenya and Barrett, 2007; Moser and Barrett, 2006).

Table 2. Transition matrices for Legume intercropping using data for Zambia and Malawi (percentages in parentheses)

Legume intercropping

Malawi

		2013 IHPS		
		No	***Yes***	***Total***
2011 IHS3	**No**	701	457	1158
		(57.8)	(42.2)	(100)
	Yes	167	390	557
		(27.3)	(72.7)	(100)
	Total	868	847	1715
		(47.3)	(52.7)	(100)

Zambia

		2015 RALS		
		No	***Yes***	***Total***
2012 RALS	***No***	5,989	483	6,472
		(92.5)	(7.5)	(100)
	Yes	216	85	301
		(68.8)	(31.2)	(100)
	Total	6,205	568	6,773
		(91.5)	(8.5)	(100)

[6] In the first row, a No-No combination means that farmers never adopted between 2012 and 2015, whereas No-Yes means they adopted the practice between the survey waves. In the second row, a Yes-No means farmers dis-adopted between the survey waves.

Table 3. Transition matrices for Minimum Soil Disturbance (MSD) and Crop rotation (CR) using data for Zambia (percentages in parentheses)

MSD

		2015 RALS		
		No	***Yes***	***Total***
2012 RALS	***No***	6108 (93.1)	646 (6.9)	6754 (100)
	Yes	194 (85)	50 (15)	244 (100)
	Total	6,302 (92.8)	696 (7.2)	6,998 (100)

CR

		2015 RALS		
		No	***Yes***	***Total***
2012 RALS	***No***	1,606 (54.9)	1,382 (45.1)	2,988 (100)
	Yes	1,285 (34.6)	2725 (65.4)	4,010 (100)
	Total	2,891 (44.3)	4,107 (55.7)	6,998 (100)

Table 3 presents national transition matrices for Minimum Soil Disturbance (MSD) and Crop Rotation (CR) using RALS data for Zambia. Between 2010/11 and 2013/14 agriculture seasons out of 244 households that used MSD at the beginning 194 have stopped using it, corresponding to a 85 percent dis-adoption rate. There were 646 new adopters in 2013/14 season (corresponding to around 7 percent of farmers), which resulted in a slight increase in the percentage of households adopting MSD at the national level (see table 1). For crop rotation, the share of new adopters in 2015 is 45 percent, the one of dis-adopters between the two waves is around 35 percent, whereas the share of continuing adopters is 35 percent. Although results from RALS are in line with previous results using data from 2002/03 and 2006/07 seasons (Arslan et al., 2013), we observe an increase in the adoption of these two CA practices over time (together with a lower level of dis-adoption), which may be explained by new methods of promotion of soil management practices, as well as the expansion of markets for legumes (e.g., groundnuts, soy beans), aimed at improving smallholder agricultural production and incomes in the country (Sitko and Chisanga, 2016).

Table 4 presents descriptive statistics of main control variables used in the analyses for each wave of IHPS and RALS, as well as SAPP 2014 for Malawi.

Climate variables include the long-term (1983-2014) Coefficient of Variation (CoV) of rainfall during the cropping season and the cropping season rainfall, both of which are expected to affect decisions on input use and technology adoption. While the CoV captures farmers' expectations on long term variation in rainfall, the millimetres of total rainfall in the season captures the immediate effect of rainfall on productivity. On the other hand, other climate events such as the false start to the rainy

season can affect technology adoption decisions as well as the crop establishment and productivity.[7] Previous studies show that when maximum temperature exceeds 28˚C, maize productivity decreases significantly, as well as with false start and dry spells (Tadross *et al.*, 2009; Thornton and Cramer, 2012). Therefore, we include a dummy variable that is equal to one when the average the maximum temperature during the agricultural season exceed on average 28˚C. Our figures show a low probability of false start of around 2-3 percent in both countries.

Table 4. Descriptive summary of selected variables

	Malawi			Zambia	
	2011 IHS3	**2013 IHPS**	**2014 SAPP**	**2012 RALS**	**2015 RALS**
Climate variables					
CoV of rainfall*	0.229	0.221	0.235	0.192	0.192
Cropping season rainfall (mm)	837	832	849		875
False start (%)	2.3	2.1	-	3.2	2.9
Late onset (%)	-	-		57.8	51.8
Max temp≥28°C (%)	28.0	13.5	-	34.2	51.8
Household socio-demographic			-		
Head is female (1=yes)	0.251	0.271	0.297	0.241	0.259
Age of household head (years)	44	46	43	45	48
Number of household members	4.915	5.193	4.84	5.439	6.650
Education of household head (years)	6.4	6.9	5.5	7.5	7.8
Household wealth					
Land size (ha)	0.705	0.709	1.036	2.85	4.23
Oxen/Cattle ownership (TLU)	0.10	0.12	0.10	1.85	2.47
Land characteristics & inputs					
Soil pH (soil pH * 10 in H2O)			58.56		
Slight/no soil constraint	0.668	0.669		-	-
Moderate soil constraint	0.281	0.281	-	0.381	0.382
Severe/very severe soil constraint	0.012	0.012	-	0.349	0.346
HH applies inorganic fertilizer (1=yes)	0.816	0.801	0.890	0.494	0.618
HH uses hybrid seeds (1=yes)	0.707	0.761		0.627	0.667
Access to market & Institutions					
FISP access (share in EA)	0.605	0.514	-	0.368	0.413
Ext. agents (nr/10,000 district pop.)	-	-		1.765	1.779
Agric. Extension and Develop. Agents (share in district)	0.351	0.390	-	-	-
Banks, Tobacco & cotton buyers (share in EA)			0.475	0.435	0.432
Access to credit (share in EA)	0.024	0.033	0.121	-	-

*Coefficient of Variation of November-May rainfall between 1983 and 2013 for Malawi and, Coefficient of Variation of October-April rainfall between 1983 and 2014 for Zambia.

[7] False start is defined as two consecutive dekads of at least 50 mm rain starting at the beginning of the expected rainy season in each country (around mid-October), followed by a dry dekad (< 20 mm rainfall) within 20 days of the false start (Tadross et al., 2009)."

The effect of the gender of household head on adoption decisions is ambiguous ex-ante. There is evidence that in some cases female-headed households may adopt CA more than male-headed households due to increased labour demand for weeding (mostly a female activity) of CA practices (Blackden and Bhanu, 1999; Mutune *et al.*, 2011). There is also evidence indicating that female heads may adopt less as they may not be able to make the initial investment required for adoption (Chompolola and Kaonga, 2016), and/or may be discriminated in extension message delivery (Langyintuo and Mungoma, 2008). In the years covered by our surveys, the share of female-headed households is between 24 and 30 percent in both countries.

The age of household head measured as the number of completed years, may be expected to have a negative effect on adoption decisions mainly because older farmers may be less likely to take the risk of adopting a new technology compared to younger households, who may also have more information on CA following active participation on extension activities (Polson and Spencer, 1991 and Adeogun *et al.*,2008). On the other hand, older farmers may have a comparative advantage in terms of capital accumulated, contacts to extension services and credit worthiness (Langyintuo and Mekuria, 2005). Our figures show an average household head age that ranges between 43 and 48 years across various surveys.

Education is measured as the maximum level of schooling of the household head, expressed in number of years attended. The variable is expected to positively influence the adoption decisions due to the fact more educated households are able to gather and analyse relevant information for farm decisions (Huffman, 2001). The average farmer in Zambia is slightly more educated with around 7.5-7.8 years of education against 6.4-6.9 years in Malawi.

Indicators of household wealth include land holdings and draft animal ownership based on the idea that households owning more productive assets are wealthier and more likely and able to take risks associated with the adoption of new technologies (Kaumbutho and Kienzle, 2007; Mutune *et al.*, 2011; Moshi and Isinika, 2016). Total amount of land owned by the household reflecting the level of resource endowment, corresponds to less than one hectare in both surveys for Malawi,[8] and 2.9 and 4.2 hectares in Zambia in 2012 and 2015, respectively. Figures show a significant difference in livestock ownership between the two countries. In particular, in Zambia, farmers own around 2 animals (in TLU terms), whereas in Malawi farmers have on average less than 0.1 animals in TLU[9] consistent with previous reports of low animal ownership in the country (FAO, 2000). Livestock

[8] In SAPP, farmers declare to own on average one hectare of land.

[9] In Malawi animal population is low with 710,000 Malawi Zebu cattle, 12,000 dairy cattle - Freisian and crosses, 110,000 sheep and 1,260,000 goats (FAO, 2000). Survey data confirm a very low incidence of livestock with only 7 percent of the households owning livestock.

ownership is expected to have a mixed effect on CA adoption. On the one hand, livestock is a proxy for wealth, therefore it may be positively correlated with the adoption decisions (Shiferaw and Holden, 1998). Livestock is also generally used as a source of draft power, considered a complementary element to the adoption of CA strategies providing manure in addition to traction (Chompolola and Kaonga, 2016). On the other hand, animal ownership may be seen as a substitute to crop farming activities leading to a decreasing demand for CA, as well as create competition for crop residues that they consume decreasing the amount left as soil cover – one of the CA pillars.

Top soil characteristics are found to be among the drivers of the adoption of CA practices (Gould, Saupe and Klemme, 1989). Using the HWSD, we define three categories of nutrient availability constraints: slight, moderate and severe/very severe. Whereas 69 percent of the districts in Malawi face limited soil constraint, around 30 percent face moderate constraint, and a negligible proportion face higher constraint levels. In Zambia 38 and 35 percent of districts face moderate and severe/very severe soil nutrient availability constraints, respectively.

Access to extension services that are the typical means of promotion of CA practices is grouped among the variables under the access to market and institutions cluster. Increasing levels of information are expected to increase the probability of adoption (Sarungbam and Prasad, 2011). Given the availability of the information, the access to the agricultural extension officers is proxied with two different variables in Malawi and Zambia. Figures show a stable presence of extension agents over time in both countries.

Given the role that other institutions play in the adoption of CA strategies, we use a set of variables to capture the access to relevant institutions including the participation in the Farmer Input Support Subsidy Programme (FISP) programme and the access to credit. The FISP is one of the most important agricultural programmes in both countries. In Malawi, FISP aims at achieving national food sufficiency and increasing the income of resource-poor smallholder farmers through increased maize and legume production driven by access to improved agricultural inputs (Chirwa *et al.*, 2015). In Zambia, the programme provides fertilizers and seeds to "vulnerable but viable" farmers (i.e., those that have the ability to cultivate maize on at least 0.5 ha of land) that are members of cooperatives/farmer groups, with around 900,000 intended number of beneficiaries since 2010 (Mason, Jayne and Mofya-Mukuka, 2013). Depending on the specific interventions (e.g. the seeds distributed together with fertilizers, or the information associated with it), such programmes can increase or decrease incentives for adoption. We use the share of households in a given EA who received FISP support to control for the role of FISP on adoption of CA practices and impact on crop production. Access to FISP is high in both countries with values ranging from 41 percent in Zambia in 2015 to 54 percent in Malawi in 2013. As for the access to credit, since the formal sources of credit are very limited in both countries, we use the number of banks per 100 km^2 in Malawi, and the share

of tobacco and cotton buyers, who are the main suppliers of agricultural credit, within the enumeration areas in Zambia.

4. Empirical strategy

In order to identify the determinants of adoption of a particular agricultural practice/technology and the related impacts on agricultural productivity, our empirical strategy encompasses two complementary steps. In the first part, we simultaneously analyse the drivers for the adoption of the different practices falling under the CA definition. In the second one, we model the effects of the adoption of different practices on agricultural productivity, which we measure by maize yields (which is the main crop in both countries) as well as the total value of the production per hectare.

4.1. Drivers of the adoption of CA practices

We empirically model the farmers' adoption decisions based on the theoretical implications of the utility maximisation in an agricultural household setting with imperfect markets. Households decide to adopt one or more CA practices if and only if the expected utility from adoption is higher than otherwise. Since interrelationships between observed and unobserved factors shape farmers' decisions, in the first step of our empirical strategy we derive the choice of adopting CA practices or not from a latent variable model. We assume that the latent variable C_{it}^{*} is the utility difference between adopting a practice or not, and if the difference is positive the farmer would adopt the practice in question. Therefore, since the farm household i's decision to adopt (or not) a given practice is observed only at time t, the latent variable translates into the following observed binary outcome C_{it}:

$$C_{it} = \begin{cases} 1 \;\; if \; C_{it}^{*} > 0 \\ 0 \;\; otherwise \end{cases}$$

We model this outcome with the following estimating equation:

$$C_{it} = X_{it}\beta + \epsilon_{it} + \gamma_i \qquad with \;\; i = 1, \dots, n; \; t = 1, \dots, k \qquad (1)$$

Where, C_{it} represents the observed adoption decision for farmer i in year t, X_{it} is a vector of exogenous, household and farm characteristics including climatic and agro-ecological variables, ϵ_{it} represents the random error term that is assumed to be uncorrelated with the explanatory variables X_{it} and strictly exogenous, and γ_i is a time-invariant random component. Specifically, we formulate a multivariate probit (MVP) model to jointly analyse the factors that influence the probability of adopting each CA practice (Train, 2003; Greene, 2008). A MVP approach models simultaneously the effect of a set of regressors on each outcome modelled, while allowing for potential correlation among unobserved factors as well as inter-relationships among adoption decisions. One source of correlation

may be complementarities (positive correlation) and substitutabilities (negative correlation) between different practices, which we explicitly assess using the MPV model (Belderbos *et al.*, 2004). [10]

4.2. Impact models: yields and value of production

After analysing the determinants of adoption decisions, we model the effects of the use of different practices on agricultural production using the following estimating equation:

$$Y_{pt} = \alpha' W_{pt} + \beta' X_{pt} + \varepsilon_{pt} \qquad \text{with } p = 1, \dots, n;\ t = 1, \dots, k;\ and\ \varepsilon_{pt} = u_{pt} + v_p \qquad (2)$$

Where, Y_{pt} is productivity outcome (either the maize yield or the value of total crop production) on plot p at time t, W_{pt} is a vector of dummy variables indicating maize plots cultivated with a specific practice in year t, X_{pt} includes household and plot characteristics, including climatic and agro-ecological controls, and $\varepsilon_{pt} = u_{pt} + v_p$ is the error term which includes a normally distributed error term independent of the regressors (u_{pt}), and time invariant unobserved effects v_p. In order to model time-invariant heterogeneity, we use fixed (FE) and random (RE) effects estimation models (Wooldridge, 2009). Whereas, the FE models treat unobservables as parameters to be estimated that can be correlated with explanatory variables, RE models treat them as a random variable uncorrelated with regressors, whose probability distribution can be estimated from data. Following Chamberlain (1984) and Wooldridge (2009), we also control for possible additional correlations between time-varying explanatory variables and random effects, and we parameterize the distribution of v_p by including the means of the time-varying characteristics (for variables that exhibit a variability greater than 10% between the two years of the survey).

5. Empirical results

The first objective of the empirical analysis is to understand the determinants of adoption in order to identify variables that hamper or foster the adoption of CA practices by farmers. In the first two sub-sections we report the results of the probability of adoption of CA practices for Malawi and Zambia, respectively. Because of data availability, we have estimated MVP models using cross-sectional data for Malawi and panel data for Zambia[11], as well as a panel probit model for the adoption of legume intercropping in Malawi[12] in order to test the results obtained in a cross-sectional environment. For the purpose of this study the coefficients associated with climate variables, agro-

[10] Failure to capture unobserved factors and inter-relationships among adoption decisions regarding different practices will lead to bias and inefficient estimate (Greene, 2008). We assume that the error terms jointly follow a multivariate normal distributions (MVN) with zero conditional mean and variance normalized to unity to be able to identify the parameters of the model.
[11] Results are confirmed by a multivariate probit (MVP) approach using cross sectional data, See table A2 in the Annex.
[12] Within the Malawian IHPS data, information on CA practices at panel level are available for legume intercropping only.

ecological zones and soil quality assume particular relevance to guide the targeting of CA promotion activities.

The last two sub-sections of this section present the results of models analyzing the determinants of maize yield and value of the total production per hectare as a function of adoption of CA practices as well as other relevant explanatory variables. Maize is the most widespread crop in both countries. We also analyse the monetary value of production of all cultivated crops to capture the impacts of CA practices on a larger set of indicators of livelihoods. This is particularly relevant because the literature often highlights that intercropping systems give higher cash returns to smallholder farmers relative to mono-cropping (Seran and Brintha, 2010), especially when the intercropping system includes legumes (Oseni, 2010; Osman *et al.*, 2011).

5.1. Adoption of CA practices in Malawi

Table 5 reports the results from the drivers of the adoption of CA practices in Malawi. Overall, we observe that the robustness of the cross-sectional results is confirmed when compared with the panel model results for the legume intercropping presented in the last column. The results obtained through a random-effects probit model confirm those obtained in a cross-sectional framework relaxing the concerns related to the potential unobserved heterogeneity.

Both of the indicators of climate risk are associated with a higher probability to adopt at least one of the CA practices. In particular, the results highlight that the more the farmers are exposed to rainfall variability the more they are likely to adopt all the practices considered. Similarly, the more they are exposed to a false start of the rainy season, the greater is their likelihood of adopting legume intercropping.[13]

Sociodemographic characteristics do not seem to be significant drivers CA adoption in Malawi. The only exception is related to the gender of the household head, as we find that a female household head reduces the probability of residue retention adoption. Conversely, in the panel setting, the variable is positively associated with the adoption of legume intercropping. This is probably due to budget constraints, that are more likely to bind for female headed households, which would lead them to rely on legumes to provide nitrogen to the soil and fodder for livestock. This conjecture is also supported by the negative correlation between the adoption of most practices and access to credit (captured by the presence of commercial bank).

[13] False start is defined as an onset (two consecutive dekads of at least 50 mm rain starting at the beginning of the expected rainy season), followed by a dry dekad (< 20 mm rainfall) within 20 days of the onset (Tadross et al., 2009).

Table 5. Probability of adoption of CA practices for Malawi (results from cross-section and panel data)

	Min. Soil Disturbance (1)	**Legume intercrop.** (2)	**Cover crop** (3)	**Residue retention** (4)	**Legume intercrop.** (Panel)
Climate variables					
CoV rainfall	11.763***	5.530***	8.205***	3.549**	11.024***
False start	-0.047	0.061***	0.008	0.017	0.041***
Household socio-demographic					
Household size	0.034	-0.005	0.007	0.023	0.004
Age of household head (years)	0.006	0.000	0.002	-0.002	-0.001
Head is female (1=yes)	-0.049	0.082	0.055	-0.208*	0.124*
Max Education of household head	0.020	0.008	-0.017	-0.017	0.014
Land characteristics & inputs					
Land owned (ha)	-0.270	0.010	0.091	0.246***	-0.061
Number of oxen or cattle in TLU unit	0.015	-0.177***	-0.031	-0.059	-0.155***
No or Slight Constraint on land	0.898**	0.030	0.354***	-0.253**	-0.095
Access to market & Institutions					
% HH receiving Gov. Ext. advice in the EA	0.049	0.013	0.039*	-0.011	-0.028
% HH borrowing from MFI/Bank in the EA	-0.408	-1.551***	-2.135***	0.641	-1.078**
% HH accessing to the FISP in the EA	-1.090***	-0.050	0.402**	-0.029	0.222
% HH accessing to MASAF in the EA	1.002***	0.343**	0.006	-0.846***	0.398**
Location and time variables					
AEZ=Tropic-warm/semiarid	-0.433***	-0.386***	-0.911***	-0.056	-0.596***
AEZ=Tropic-cool/semiarid	(dropped)	-0.381***	-1.474***	0.206	-0.297***
AEZ=Tropic-cool/sub-humid	-0.584	-0.735***	-0.891***	0.387**	-0.628***
Year (2013=1)	-	-	-	-	0.677***
Correlation residual equations (1)-(2)		-0.168*			
Correlation residual equations (1)-(3)		0.020			
Correlation residual equations (1)-(4)		0.217**			
Correlation residual equations (2)-(3)		0.509***			
Correlation residual equations (2)-(4)		-0.041			
Correlation residual equations (3)-(4)		0.019			
Number of observations		1,713			3,393

As for the explanatory variables related to input and land ownership, the results are mixed and depend on the specific practice considered. Land ownership is positively correlated with the probability of adopting residue retention, potentially because using the residues for fodder or mulching purposes is more feasible if the farmer has a sufficient quantity of residues produced on larger land. Cattle holdings measured by TLU decrease the probability of adoption of legume intercropping only, and surprisingly has no significant impact on residue retention. This may be because its effects are captured through other variables correlated with TLU (land size, land quality…etc.). We find that the probability of adoption of residue retention is higher on nutrient constrained soils, providing suggestive evidence that households use this practice to deal with the nutrient constraints in harsh biophysical conditions.

The effects of institutional variables depend on the interactions between the specific programme and the single practice. For example, we find that extension advice increases the probability of adoption only for cover crops, and the access to credit (banks) is negatively correlated with most of the adoption probabilities. The probability of adopting organic cover is higher for households that live in enumeration areas with a high FISP coverage, but they are less likely to adopt MSD. This result highlights a potential trade-off between the two important policy priorities in the country.

The coefficients of the AEZ indicators are interpreted as compared to the tropical warm/sub-humid AEZ, which is the base category. We find that the probabilities of adopting CA practices are relatively lower in all other AEZs compared to the benchmark.

Finally, one of the reasons for using an MVP approach rather than a bundle of single equations model is the relationships of complementarities or substitutabilities among the different practices reported in the lowest panel of the table 5. Being part of the same technology package, we expect that all practices analysed would be complementary to each other, however findings are mixed. In Malawi, MSD is substitutable with legume intercropping, but complementary with residue retention, while legume intercropping and organic cover are complementary as expected. Understanding the inter-relationships among the different practices included in the CA package sheds more light on the differences in terms of adoption rates highlighted in the descriptive section.

5.2. Adoption of CA practices in Zambia

Table 6 reports comparable estimates on adoption of CA practices in Zambia. It is worth noting that in this case, we use the long term probability of late onset rather than the false start[14], as the variability of this variable is greater in Zambia allowing us to better capture the impact of exposure to this specific extreme weather event.

The correlations between the probabilities of adoption and climate risk related variables are highly heterogeneous across the practices considered. Farmers are more likely to adopt legume intercropping and crop rotation in wards that have a higher probability of experiencing a late onset to the rainy season. Consistently, MSD is positively and significantly correlated with historical rainfall variability. However, the probability of adopting legume intercropping is lower in areas characterized by a higher historical rainfall volatility. Overall the results support the idea that CA practices are adopted as adaptation strategies to the changing climate conditions (Pittelkow *et al.*, 2014) and to the related risk of market and crop failure (Kamanga *et al.*, 2010). In fact, legume intercropping is also more likely to

[14] The long term probability of late onset is identified as the share of rainfall seasons that started late relative to the historical onset period. Given this definition, a false start is always associated with a late onset but not *vice-versa*.

be adopted in the most unpredictable agro-ecological zone (AEZ I), where the rainfall has been low, unpredictable and poorly distributed over the past 20 years (Jain, 2007).

Sociodemographic characteristics, such as education level and age of the household head are both associated with a higher probability of adopting MSD. Older farmers may have a comparative advantage in terms of capital accumulated, contacts to extension services and credit worthiness leading to higher probabilities of technology adoption (Langyintuo and Mekuria, 2005). Similarly, more educated households may be able to gather and analyse relevant information for decisions (Huffman, 2001) and may be more likely to adopt complex technologies. The finding that the probability to adopt crop rotation decreases with the age of the household head does not contradict the previous statement since crop rotation is a part of the traditional agricultural system in Zambia.

The area cultivated is an important driver of adoption of CA practices in Zambia. The positive association of land size with MSD and legume intercropping is probably related to the fact that larger farm holders face lower opportunity costs for adopting sustainable land management practices. The adoption of crop rotation, which it creates a trade-off between maize production and other crops, seems to be more feasible if rotation can be applied on a (rotating) portion of a larger plot, as expected.

Access to credit proxied by the presence of commercial banks, tobacco and cotton buyers, is negatively related to legume intercropping. Similar to the findings in Malawi, this is probably due to the use of the CA practice as an ex-ante strategy to deal with risk and/or cash constraints, which may decrease in importance as credit access improves. Farmers living in areas with higher availability of extension agents are less likely to adopt MSD while they are more likely to adopt legume intercropping. The probabilities of MSD and crop rotation adoption are higher in areas where more households accessed the FISP, whereas this variable is negatively correlated with legume intercropping adoption. These results highlight a potential trade-off between the support to inorganic fertilizer and the adoption of legume intercropping as expected.

The inter-relationships between the probabilities of adoption of different practices are reported in the lowest panel of table 6. We find a positive correlation (i.e. complementarity) between adoption of MSD and crop rotation, while the two practices composing the crop association pillar of CA, namely legume intercropping and crop rotation, are substitutes.

Estimated results for the two countries of analysis show that conservation agriculture is more likely to be adopted (and therefore has higher utility) in contexts characterized by harsh, variable and dry weather and biophysical conditions. The drivers of each specific practice vary from country to country depending on the influence of sociodemographic variables, the institutional environment, the average land endowment and the inclusion of particular CA practices within the traditional agricultural system.

Table 6. Probability of adoption of CA practices for Zambia (results from panel data)

	Min. Soil Disturbance (1)	Legume Intercropping (2)	Crop rotation (3)
Climate variables			
CoV of rainfall	0.033***	-0.029***	0.005
Late onset	0.094	0.121*	0.130***
Household socio-demographic			
Household size in AE	0.001	0.005	0.026***
Age of household head	0.208**	-0.025	-0.139***
Head is female (1=yes)	-0.117	0.104	0.013
Max Education of household head	0.019**	-0.004	-0.017***
Land characteristics & inputs			
Land owned (ha)	0.088***	0.108***	0.313***
Oxen/cattle (TLU)	-0.004	-0.001	-0.004***
Moderate soil constraint	-0.166**	0.157**	-0.118***
Severe/very severe soil constraint	-0.269***	0.142*	0.153***
Access to market & Institutions			
HH accessing FISP (% in the SEA)	0.214*	-0.983***	0.573***
FRA depots in district (Nr.)	-0.007***	0.004	-0.000
Extension agents (Nr./'0000 dist. pop.)	-0.046*	0.084***	0.000
Tobacco buyer or cotton buyer (1=yes)	0.047	-0.197**	0.171***
Location and time variables			
AEZ IIa; 800-1000mm/year	0.441***	-0.651***	0.413***
AEZ IIb; 800mm/year, Semi-Arid	-0.005	-0.397***	-0.644***
AEZ III: 1000-1500mm/year	0.187*	-0.196**	0.414***
Year (2014=1)	0.331***	0.550***	-0.053*
Constant	-4.460***	-0.754*	-0.425*
Correlation residual equations (1)-(2)		-0.077	
Correlation residual equations (1)-(3)		0.133***	
Correlation residual equations (2)-(3)		-0.083*	
Number of observations		9,457	

note: *** p<0.01, ** p<0.05, * p<0.1

5.3. Impact models for Malawi

5.3.1. Panel Data Analysis

Table 7 reports results from the analysis of determinants of maize yields and total value of production using panel data for Malawi. Since legume intercropping is the only CA practice available in the panel data, the model is estimated considering only its adoption as explanatory variable. Figures point out that the association between legume intercropping and maize productivity is never statistically different from zero. According to Dwivedi *et al.* (2015) in regions with acidic soils, hence limited phosphorus availability, the contribution of legumes in terms of nitrogen fixing could be low or negligible. In fact, the soil quality for the great majority of household farmers in Malawi fits into this

description explaining these figures. Kamanga *et al.* (2010) find that the impact of maize-legume intercropping in terms of maize productivity could be low, but highlight that the main benefits from legume intercropping lie in reducing market and crop failure risk through diversification, or increasing market/commercialization opportunities. Accordingly, the results show that legume intercropping is always positively associated with the value per hectare of the total crop production. A factor explaining this result may be the presence of legume exporters in the country. Exporting Trading Group (ETG), TranGlobe Produce Export, RAB processor, and Commodity Processor limited are leading players in the Malawian agro-industry. A number of intermediate buyers act as a linkage between small-scale farmers and the processors of pigeon peas often by setting up a small procurement center within the community during the harvesting season. This is likely to ensure the presence of a stable market for legumes produced by smallholders, increasing the profitability of legume intercropping.

As expected, the climate variables influence productivity outcomes. Moreover, in places where the maximum temperature has been higher than 28 degrees Celsius on average during the rainy season the value of total production is lower.

Land size is negatively correlated with yields but it is positively associated with the value of the production. Since the value of total production per hectare has been calculated considering the prices of all crops at the district level, the discrepancy between productivity and value could be due to the fact that large landholders are able to produce crops with a higher value added. The bio-physical characteristics of the soils, captured by the nutrient retention capacity variable, shows that plots with no nutrient constraints exhibit higher maize productivities on average, though this correlation is not significant using the value of the total crop production as an outcome. The age of the household head is negatively correlated with the maize productivity and the value of the total production, suggesting that younger farmers, who have been found more likely to adopt CA practices in the previous section, are also more productive. These two empirical results are particularly relevant for targeting purposes.

Table 7. Malawi – Impact of CA practices with maize yield and total crop value per hectare (Pooled OLS, Random Effects, Fixed Effects and Correlated Random Effects Models)

	Maize yield				Total value of production per hectare			
	OLS	**RE**	**FE**	**CRE**	**OLS**	**RE**	**FE**	**CRE**
CA adoption practices								
Minimum Soil Disturbance	-	-	-	-	-	-	-	-
Legumes intercropping	-0.032	-0.032	0.097	0.101	0.706***	0.707***	0.756***	0.754***
Cover crop	-	-	-	-	-	-	-	-
Residue retention	-	-	-	-	-	-	-	-
Climate variables								
Cropping season rainfall (mm)	0.002***	0.002***	0.001	0.001	0.001	0.001	0.000	0.000
Max temp≥28°C	-0.126	-0.126	0.006	0.003	-0.330***	-0.306***	-0.069	-0.072
Household socio-demographic								
Number of household members	-0.023*	-0.023*	-0.045	-0.041	0.012	0.016	0.054**	0.058**
Age of household head (years)	-0.004**	-0.004**	0.010	-0.004**	-0.005***	-0.005***	0.002	-0.006***
Max Education of household head	0.025	0.025	0.026	0.014	0.207***	0.207***	-0.117	-0.125
Head is female (1=yes)	0.025	0.025	0.026	0.014	-0.207***	-0.207***	-0.117	-0.125
Land characteristics & inputs								
Land owned (ha)	-0.448***	-0.448***	-0.541***	-0.530***	0.553***	0.513***	0.215***	0.218***
Number of oxen or cattle in TLU unit	0.080*	0.080*	-0.034	-0.032	0.127***	0.121***	0.066*	0.067
Soil Quality: No or Slight Constraint (1=yes)	0.183**	0.183**	-0.704*	0.199***	0.041	0.036	-0.536	0.062
Access to market & Institutions								
Price of fertilizer at EA level (MK/kg)	-0.000	-0.000	-0.001	-0.001	0.000	0.001	0.001	0.001*
Ganyu wage at EA level (MK/day)	0.121	0.121	0.021	0.022	0.110	0.082	-0.028	-0.025
Price of maize grain at EA level (MK/kg)	0.001	0.001	0.000	0.000	-0.000	-0.000	0.000	0.000
% HH receiving Gov. Ext. advice in the EA	-0.004	-0.004	-0.159**	-0.158**	-0.008	-0.003	0.026	0.024
% HH borrowing from MFI/Bank in the EA	1.113	1.113	0.719	0.748	-0.086	0.039	0.530	0.506
% HH accessing to the FISP in the EA	0.046	0.046	0.876**	0.859***	0.583***	0.556***	0.274	0.284
% HH accessing to MASAF in the EA	0.069	0.069	0.064	0.042	0.099	0.025	-0.239	-0.257
Location and time variables								
AEZ=Tropic-warm/semiarid	0.105	0.105	-0.754	0.111	-0.082	-0.075	2.513**	-0.117*
AEZ=Tropic-cool/semiarid	0.222**	0.222**	-0.736	0.216**	-0.013	-0.002	1.663***	-0.075
AEZ=Tropic-cool/subhumid	0.158	0.158	-0.549	0.131	0.306**	0.323***	0.440	0.242***
Year (2013=1)	-0.045	-0.045	0.268	0.293	0.897***	0.873***	0.723**	0.740***
Number of observations	4,754	4,754	4,754	4,754	3,329	3,329	3,329	3,329
R2 Within		0.012	0.025	0.023		0.386	0.406	0.404
R2 Between		0.036	0.000	0.039		0.268	0.001	0.281
R2 Overall		0.031	0.002	0.037		0.321	0.026	0.336
R2	0.031		0.025		0.321		0.406	

Note: *, ** and *** denote significance at the 10, 5 and 1% levels, respectively.
Standard error are cluster robust across enumeration areas
Results from the pooled OLS and the RE models are identical this is because the estimate of the variance of the unobserved effect is negative, in this case the software set the sigma U to zero and the GLS correspond to the OLS.

As for the institutions, the findings support the effectiveness of the input subsidy programme in terms of productivity. Conversely, the negative association with the share of governmental agricultural extension officers in the district could signal either the inefficiency of the extension services or can be due to the potential reverse causality. Using the Tropic-warm/sub-humid AEZ as a benchmark, the tropic–cool AEZs are associated with higher productivities and higher values of total production. Conversely, the value of total production in the warm/semiarid zone is on average lower than the benchmark.

5.3.2. Robustness checks using SAPP baseline data and cross sectional IHPS

As stated earlier, the IHPS data (especially the earlier round) does not have information on most of the practices analysed here. In order to test the robustness of the previous results and to expand the analytical framework introducing other variables in Malawi, in what follows we present the results obtained using the dataset based on the information included within the SAPP baseline. Since the final goal of the IFAD funded "Sustainable Agricultural Production Programme (SAPP)" was to contribute to the reduction of poverty and improved food security through the adoption of good agricultural practices (GAP), the baseline survey is particularly rich in information about the adoption of practices which fall within the definition of CA.[15]

The dataset also includes a section on the information received by farmers about each specific practice that are particularly relevant for the purposes of this study. This database has been expanded using information on rainfall from the Africa Rainfall Climatology version 2 (ARC2) and information on the on top soil characteristics from ISRIC SoilGrids250m.

In a further effort to assess more precisely the climate risk, in this specification we have introduced two new indices based on the Standard Precipitation Index. The Standardized Precipitation Index (SPI) is a tool which was developed primarily for defining and monitoring drought. It allows to determine the rarity of a drought at a given time scale (temporal resolution) of interest for any rainfall station with historic data. It can also be used to determine periods of anomalously wet events. In this study we have created two indices capturing the risk of extremely dry and extremely wet weather conditions faced by households based on their geographic location. In what follows, we comment only on the most relevant results in a comparative perspective with the results presented above based on IHPS.

The results from the estimation of the determinants and the barriers to the adoption of CA practices using SAPP baseline data substantially (Table 8) confirm the results obtained in the previous sections using the IHPS and different proxies. As an example, the results confirm that the probability

[15] After the collection of the baseline data, the programme has never been implemented

to adopt legume intercropping and cover crops (here associated with residue retention given the data constraint) is positively associated with the risk of extremely dry weather conditions. Furthermore, it is negatively associated with the historical mean of total rainfall, and with the soil quality (here proxied by the soil pH). All together these results confirm that legume intercropping and cover crops are likely to be used as adaptation strategies against the climate risk faced by households in rural Malawi.

Table 8. CA adoption determinants based on SAPP baseline survey (cross section)

	Min. Soil Disturbance	Crop rotation	Legume intercrop.	Cover crop\ Residue	Agroforestry
Climate variables					
Probabilities of extreme dry condition	0.029	-0.005	0.022*	0.039***	0.007
Probabilities of extreme wet	-0.053**	0.004	-0.012	0.020	0.010
CoV of Nov-May rainfall 1983-2013	-4.231	-0.958	0.905	-6.604***	-3.101
Mean of Nov-May rainfall 1983-2013	-0.002	-0.005***	-0.006***	-0.002*	-0.003***
Household socio-demographic					
HH size in AE	0.035	0.063*	0.011	0.063*	0.067*
Age of HH head	-0.002	-0.002	0.000	0.001	0.005*
Dummy female HH head	0.103	-0.048	-0.074	0.005	-0.288***
Highest years of education in the HH	0.040**	0.003	0.000	0.022	0.014
Dependency ratio	-0.045	-0.028	0.032	-0.009	0.014
Land characteristics & inputs					
Land owned (ha)	-0.007	0.103***	0.011	-0.002	0.021
Number of cattle in TLU unit	-0.045	0.036	-0.186**	-0.106	0.051
Soil pH (soil pH * 10 in H2O)	-0.044*	0.025	-0.038**	-0.035*	0.011
Access to market & Institutions					
HH received info on conservation agriculture (%)	0.011***	-0.003	0.000	0.001	0.006**
HH received info on inter-cropping/principles (%)	-0.011**	-0.007**	0.008**	0.008*	-0.005
HH received info on crop rotation/principles (%)	-0.000	0.011***	-0.003	-0.008**	0.004
Govt. Extension Worker in the area	0.432***	0.087	0.077	-0.090	0.310***
Tobacco Club exists in the comm.	-0.095	0.238***	0.042	0.061	-0.057
Share of HHs access. credit in the com.	0.298	0.125	0.399***	0.187	0.162
HHs in the community got fertilizer & seeds via FISP	-0.111	0.034	-0.048	-0.046	0.020
Regions					
Northern Region	-0.057	1.403***	-0.094	-0.200	0.264
Central Region	-0.521**	0.463***	-0.016	-0.107	0.201
Correlation residual equations (1)-(2)			0.251***		
Correlation residual equations (1)-(3)			0.146**		
Correlation residual equations (1)-(4)			0.112		
Correlation residual equations (1)-(5)			0.259***		
Correlation residual equations (2)-(3)			0.244***		
Correlation residual equations (2)-(4)			0.171***		
Correlation residual equations (2)-(5)			0.029		
Correlation residual equations (3)-(4)			0.241***		
Correlation residual equations (3)-(5)			0.168***		
Correlation residual equations (4)-(5)			0.166***		
Number of observations			1,628		

Note: Robustness check: re-estimating the models using the SAPP baseline survey

In this specification we can also estimate the determinants of practices excluded from IHPS namely crop rotation and agroforestry. The results confirm the positive association between crop rotation and land size found in Zambia. Furthermore, we also find a positive relationship between the presence of government extension in the area and the adoption of agroforestry and minimum soil disturbance.

The coefficients associated with the availability of information within the enumeration area are particularly interesting. The results confirm a positive association between the probabilities of receiving information on a specific practice and the adoption of the same practice. These findings support the idea that the adoption of CA is knowledge-intensive strategy, which needs targeted interventions aimed to build and develop farmers' capacities (Kumwenda et al. 2013).

Table 9. Cross sectional result of the adoption of CA practices on productivity across SAPP and IHPS survey waves

	MAIZE YIELD (Kg/ha)		**TOTAL VALUE OF PRODUCTION (MKW/ha)**	
	SAPP (2104)	***IHPS (2013)***	***SAPP (2104)***	***IHPS (2013)***
Minimum Soil Disturbance	0.020	-0.143	-0.058	0.232
Crop Rotation	0.089**	-	0.422***	-
Legume Intercropping last season	-0.017	0.010	0.102**	0.616***
Cover crop	0.073	-0.017	0.231***	0.207**
Residues retention		0.114		0.024
Any Agroforestry adopted last season	0.020	-	0.224***	-
Number of observations	2,031	2,451	1,624	1,636
R2	0.068	0.067	0.171	0.212

Note: Selected results relative to the variable of interest. The results for the rest of the explanatory variables are available upon request.

Moving to the estimation of the production functions (Table 9), the results about the association between the adoption of CA practices and the productivity confirm those obtained with the IHPS panel data. In particular, the adoption of legume intercropping and permanent organic cover (residues retention and/or cover crop) are positively associated with a higher value of the total production but not with the maize yield. Also in this case adopting MSD is not associated with either outcome measure (yield and total crop value). As for the practices missing in the IHPS panel, i.e. agroforestry and crop rotation, our results show several similarities with the results estimated using the RALS data in Zambia. In fact, both practices are positively and significantly correlated with the value of total production in Malawi, while the adoption of crop rotation is also associated with a higher productivity of maize.

To summarize, the analysis of the same outcome variables by re-estimating the models using a new dataset, which has allowed us to include more detailed variables (although limited by the cross-

sectional nature of the data set) confirms most of the previous results obtained in Zambia and Malawi. This robustness check provides results that support the narrative of the main part of this study based on nationally representative panel data sets.

5.4. Impact models for Zambia

Table 10 reports results from the analysis of the determinants of maize yields and the total value of production for Zambia. The adoption of MSD and crop rotation practices are associated with higher levels of maize productivity on average. Farmers adopting crop rotation are also characterized by a greater value of total production per hectare. However, the coefficient of MSD in this specification is no longer statistically different from zero, suggesting that MSD is likely not suitable for all types of crops and agro-ecological zones. These findings are in line with previous studies on CA adoption in the country. As an example, according to Pittelkow *et al.*, 2015 these two practices are likely to increase the productivity under rain-fed conditions in dry climates such those in Zambia. However, the authors also pointed out significantly declining yields (by 20.4 and 21.4%) on MSD plots for root crop categories such as cassava, cocoyam, potato, sugar beet, sweet potato, taro, and yam. In Zambia sweet potatoes and cassava are harvested on about 20% of the plots motivating the discrepancy between the results obtained using a partial and a total measure of famers' productivity.

Furthermore, results also highlight that farmers adopting legume intercropping are characterized with lower values of total production per hectare on average. These figures can be due either to the relationship of substitutability with crop rotation, or to the lack of a well-developed market for legumes in the country. The negative coefficient associated with legume intercropping is the major difference between the two countries analyzed, and further analysis would be needed to shed more light on these differences.

As for the climate variables, farmers living in wards characterized by higher rainfall exhibit higher maize productivity, as well as higher values of total production. This is an expected result in a rain-fed agricultural system. The positive association between the indicator for high growing season temperature and the total value of the production could be also due to a price-effect causing the prices of some crops to increase more than others in some areas experiencing high temperature during the cropping season.

The coefficients associated with household socio-economic characteristics highlight that the more educated is the household head the greater is both the productivity and the value of the total production. Conversely, similar to the findings for Malawi, older household heads have lower maize productivities on average.

As expected, land characteristics and input use affect both productivity and total value of the production. Land size is negatively correlated with the productivity but not with the value of the production. Farmers using inorganic fertilizer and those that received it on time are more productive

on average. Households using hybrid seeds are also more productive and have a higher total value of production on average. The nutrient availability constraints of soils are negatively correlated with the value of the total production as expected.

The institutional variables highlight a negative correlation between the percentage of households accessing to FISP in the enumeration area and value of the production. Investigating if this result is signalling the inefficiency of the programme or it is due to a reverse causality is beyond the scope of this study. The access to the input markets proxied by the distance to agro-dealers is positively associated with the monetary value of total production, but if cotton buyers are present in the area, the value per hectare of the production is lower on average. These results seem to suggest that the presence of input markets increase the value added of the production while access to the informal credit provided by tobacco and cotton buyers may encourage a shift toward relatively lower value added crops. Finally using the AEZ I as a benchmark, all other AEZ are characterized by higher maize productivities and higher total values of production per hectare than AEZ I.

Overall, the analysis of the two outcomes highlights more heterogeneity between the two countries than the analysis on the drivers of the adoption. CA practices have different impacts on outcome variables depending on context-specificity and relationships among the different practices falling under the definition of CA. Policy interventions aimed at scaling up the adoption of the practices analyzed here should be aware of similarities in terms of adoption drivers, but also differences in terms of effectiveness of each practice. Providing context-specific packages of practices, targeting younger farmers living in harsh climatic and agro-ecological conditions, and increasing the presence of institutions and programmes that take into account the complementarities and substitutabilities between different practices may help increase the adoption rate and the effectiveness of improved agricultural practices.

Table 10. Zambia - Impact of CA practices on maize yield and total crop value per hectare (Pooled OLS, Random Effects, Fixed Effects and Correlated Random Effects Models)

	Maize yield				Total value of production per hectare			
	Pooled OLS	**RE**	**FE**	**CRE**	**Pooled OLS**	**RE**	**FE**	**CRE**
CA adoption practices								
Minimum Soil Disturbance	0.118***	0.106**	-0.022	0.100**	0.015	0.013	-0.014	0.015
Legume intercropping	0.012	0.024	0.020	0.010	0.024	0.051	0.029	0.041*
Crop rotation	0.068**	0.045*	-0.020	0.048*	0.042*	0.040*	0.029	0.041*
Climate variables								
Cropping season rainfall (mm)	0.075***	0.076***	0.083***	0.077***	0.078***	0.066***	-0.006	0.065***
Max temp≥28°C	0.014	0.020	0.073	0.070	0.057*	0.064**	0.077	0.103**
Late onset	-0.020***	-0.020***	0.055	0.067	-0.004	-0.002	0.148*	-0.003
Household socio-demographic								
Number of household members	0.018	0.024	0.085	-0.037	0.001	0.002	0.015	0.004
Age of household head	-0.093**	-0.087**	0.026	-0.068*	-0.038	-0.031	0.129	-0.029
Max Education of household head (years)	0.012***	0.013***	0.000	0.013***	0.012***	0.011***	0.001	0.011***
Head is female (1=yes)	-0.044	-0.047	0.092	0.130	-0.082***	-0.088***	0.005	-0.033
Land characteristics & inputs								
Cultivated land under maize (ha)	-0.024	-0.075**	-0.422***	-0.075**	-0.000	-0.006	-0.060***	-0.006
HH applies inorganic fertilizer (1=yes)	0.317***	0.304***	0.180**	0.287***	-0.116	-0.139	-0.215	-0.137
HH uses hybrid seeds (1=yes)	0.419***	0.415***	0.420***	0.416***	0.210***	0.187***	0.129*	0.189***
Fertilizer received on time	0.168***	0.160***	0.094*	0.161***	0.030	0.035	0.082**	0.035
Oxen/Cattle ownership (1=yes)	0.003**	0.003***	0.008***	0.005	0.001*	0.001*	0.001	-0.000
Moderate constraint	0.037	0.036		0.033	-0.088**	-0.100**		-0.100**
Severe/very severe constraint	-0.029	-0.029		-0.036	-0.074*	-0.076*		-0.078*
Access to market & Institutions								
HH accessing FISP (% in the SEA)	0.159*	0.160*	-0.046	0.188**	-0.179**	-0.168**	-0.039	-0.173**
Agro-dealer, distance in km	0.000	0.001	0.001	0.001	0.001***	0.001***	0.000	0.001***
Tobacco buyer or cotton buyer (1=yes)	0.042	0.053		0.064	-0.122***	-0.132***		-0.134***
Location and time variables								
AEZ IIa; 800-1000mm/year	0.399***	0.434***		0.424***	0.001***	0.001***	0.000	0.001***
AEZ IIb; 800mm/year, Semi-Arid	0.020	0.002		0.021	0.234***	0.243***		0.234***
AEZ III; 1000-1500mm/year	0.383***	0.409***		0.413***	1.008***	1.043***		1.059***
Year (2014=1)					0.465***	0.510***		0.491***
Constant	6.037***	6.010***	6.217***	5.809***	7.352***	7.441***	7.366***	7.475***
Number of observations	6,605	6,605	6,524	6,605	5221	5221	5221	5221
R-squared:	0.129				0.196			
Within		0.059	0.102	0.063		0.072	0.091	0.075
Between		0.138	0.013	0.143		0.234	0.002	0.236
Overall		0.128	0.016	0.131		0.195	0.001	0.197
Adjusted R-squared	0.125				0.192			

Note: *, ** and *** denote significance at the 10, 5 and 1% levels, respectively.
Standard error are cluster robust across enumeration areas

6. Conclusions and policy recommendations

In Malawi and Zambia, the promotion of CA is a high priority of the agricultural policy dialogue and climate adaptation plans. However, despite significant efforts to promote CA, adoption rates are still low in both countries. This study provides a comprehensive cross-country analysis of the determinants of the adoption of CA practices as well as evidence of the impacts of each practice on productivity. As the adoption of agricultural practices depends on a number of factors including household socio-demographic, agro-ecological, climatic, bio-physical characteristics of the soil, input use and availability, as well as institutional frameworks, we take advantage of unique databases obtained by merging different data sets. Exploiting the rich set of information available, we have simultaneously modelled farmers' adoption decisions of a set of practices falling within the definition of CA. Subsequently, we have estimated impact models in order to capture the correlations between the adoption of CA practices and two different measures of farm productivity (i.e., maize yields and the value of total crop production). One of the objectives of this analysis is to draw upon the similarities and the differences between the two countries to derive lessons for further promotion of agricultural technologies that have the potential to improve productivity and food security.

Notwithstanding the numerous differences between the two countries, this study has identified some lessons that are valid across both of them. First of all, climate, agro-ecological and bio-physical soil characteristics matter. Although these results sound straightforward, it is particularly relevant documenting that the historical rainfall patterns as well as the agro-ecological and the nutrient availability constraints do influence the decisions of technology adoption at the household level. Our findings provide evidence that the adoption of CA practices is more likely in areas characterized by high variability, low moisture or low soil nutrient retention capacities. The higher probabilities of adoption are indirect evidence that farmers may be motivated by expected contributions of CA practices in improving soil structure and fertility.

Furthermore, our results suggest that the adoption of CA practices may be also a risk-mitigating strategy allowing households to lower the risk of crop and market failures. This is particularly true for those practices that fall under the definition of "crop association" (i.e. legume intercropping, crop rotation, cover crops). These practices are indeed more widely adopted in both countries. In particular, the results of multivariate probit analyses suggest that the probability of adoption of legume intercropping and crop rotation is consistently higher in zones characterized by high rainfall variability, dry or unpredictable rainfall histories and lower quality soils. The fact that the probability of adoption of these practices is lower for households living in areas with higher access to credit reinforces the risk highlighting the potential of these practices as suitable adaptation strategies for farmers living in remote areas highly exposed to harsh climatic and agro-ecological conditions.

The policy implications of these results are related to the effective targeting of interventions aimed at promoting CA or other associated improved technologies. Although MSD is the founding and non-negotiable principle of CA (Aagaard, 2011), the adoption rate is extremely low in both countries. A more flexible approach of promoting CA practices paying attention to the constraints identified here and elsewhere, would be an effective strategy to improve productivity.

Secondly, land fragmentation is likely to be a constraint to the adoption of certain practices. In Zambia, land size is positively associated with the probabilities of adoption of all the practices analysed. In Malawi, the results suggest a similar pattern for the retention of crop residues (IHPS) and crop rotation (SAPP). This is probably due to the fact that certain practices are suitable/profitable only on relatively larger plots. Furthermore, since the land endowment can be also considered as a proxy for wealth, these results may be associated with farmers' opportunity costs and their discount rates. Larger landholders face lower opportunity and risk costs of adopting new land management practices. On the other hand, since smallholders are likely to be characterized by a higher intertemporal discount rate and the benefits of CA can be seen after a certain amount of time and/or under particular conditions (for example during extremely dry periods), international organizations and government institutions are called to fill this gap by providing incentives and assistance for the implementation of these practices. Combined, these findings indicate that CA may not be suitable for many smallholders in the absence of supportive credit or other risk management strategies. Notwithstanding this, the negative association between land size as well as the positive effect on value of total crop produced of legume intercropping in Malawi provide some evidence that the existence of well-functioning output markets (e.g. the market for legumes in Malawi) increases the profitability of adoption and helps to overcome the barriers related to the fragmentation of the land.

These results add more nuance to the policies that might be implemented alongside the promotion of CA, which is a well-established priority for both countries in spite of very low levels of adoption and multiple binding constraints. The development of well-functioning input and output markets should go together with the promotion of CA practices in order to lower opportunity and risk costs related to the adoption of these technologies. The institutional environment also affects the adoption of CA practices. Although the empirical evidence presented is highly country- and practice-specific and does not allow us to draw overarching lessons, this study finds that institutions with similar objectives in terms of improving climate resilience and livelihood of household farmers may have heterogeneous effects on adoption of practices. This underlies the importance of policy coherence (both across and within relevant agencies) to ensure sustained adoption and impact.

Policy interventions aimed at removing barriers to the adoption of improved practices and developing flexible technology packages that suit site-specific (climatic, agro-ecological and socio-economic) needs of households are essential for future policies to improve the productivity, the profitability and

eventually the food security of smallholder farmers in these two countries, as well as in the rest of SSA.

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Annex

Table A1. Percentages of CA adoption at plot level by country and survey wave

	MALAWI			ZAMBIA	
	2011 IHS3	**2013 IHPS**	**2014 SAPP**	**2012 RALS**	**2015 RALS**
Practicing full set of CA	-	0.48	1.06	-	0.15
MSD	-	2.45	6.09	1.58	4.34
Crop rotation	-	-	37.77	37.56	37.63
Legume intercropping	23.92	35.96	46.18	1.80	3.42
Residue retention[1]	-	6.52	0.08	-	2.09
Cover crop[2]	-	24.9	13.41	-	-
Practicing Agroforestry	-	-	16.4	0.61	1.71

Note: [1]Residues used for soil conservation purpose only. [2]Only legumes cover.

Table A2. Probability of adoption of CA practices for Zambia (from the MVP model using cross-sectional data)

	MSD (1)	**Legume Intercropping (2)**	**Crop rotation (3)**	**Residue Retention (4)**
Climate variables				
CoV of rainfall	0.030***	-0.046***	-0.001	0.005
Late onset	0.011	0.289*	0.191**	0.325**
Household socio-demographic				
(log) Household size in AE	0.019	0.000	0.043***	-0.001
(log) Age of household head	0.346***	-0.049	-0.185**	-0.216
Head is female (1=yes)	-0.187	0.044	0.012	0.100
Max Education of household head	0.009	-0.006	-0.005	0.002
Land characteristics & inputs				
(log) Land owned (ha)	0.105**	0.068*	0.212***	0.030
Oxen/cattle (TLU)	-0.011**	0.001	-0.004*	-0.002
Moderate soil constraint	-0.115	0.118	-0.042	-0.007
Severe/very severe soil constraint	-0.347***	0.146	0.336***	0.254
Access to market & Institutions				
HH accessing FISP (% in the SEA)	0.242	-0.935***	0.443***	-0.043
FRA depots in district (Nr.)	-0.003	0.006	-0.003	-0.021***
Extension agents (Nr./'0000 dist. pop.)	0.001	0.115*	-0.040*	-0.057
Tobacco buyer or cotton buyer (1=yes)	-0.059	-0.218	0.136	0.039
Location and time variables				
AEZ IIa; 800-1000mm/year	0.479***	-0.414*	0.327**	-0.184
AEZ IIb; 800mm/year, Semi-Arid	-0.481**	-0.592**	-0.738***	1.002***
AEZ III: 1000-1500mm/year	0.130	-0.003	0.389***	0.206
Year (2014=1)	-4.440***	0.366	-0.122	-1.408*
Constant	0.479***	-0.414*	0.327**	-0.184
Correlation residual equations (1)-(2)		0.246***		
Correlation residual equations (1)-(3)		-0.016		
Correlation residual equations (1)-(4)		0.005		
Correlation residual equations (2)-(3)		-0.026		
Correlation residual equations (2)-(4)		0.064		
Correlation residual equations (3)-(4)		-0.205***		
Number of observations		4,591		

note: *** p<0.01, ** p<0.05, * p<0.1