Feed the Future Innovation Lab for Food Security Policy

Research Paper 132 May 2019

IS CONSERVATION AGRICULTURE CLIMATE-SMART, OR CAN IT BE? A SYNTHESIS FROM SUB-SAHARAN AFRICA

By

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Authors' Acknowledgments

Parts of Section 1 and 2 draw heavily from the first author's PhD thesis, Conservation Agriculture, Livelihoods and Deforestation in Zambia, School of Economics and Business, Norwegian University of Life Sciences. The authors wish to thank Patricia Johannes of MSU for editorial and document preparation assistance.

This research is made possible by the generous support of the American people through the United States Agency for International Development (USAID) through funding to the Feed the Future Innovation Lab for Food Security Policy (FSP), and the USAID Mission to Zambia through the Indaba Agriculture Policy Research Institute (IAPRI) in Lusaka. Additional funding was obtained through IAPRI from the Swedish International Development Agency (SIDA). The contents are the responsibility of the study authors and do not necessarily reflect the views of USAID, the United States Government or SIDA.

Published by the Department of Agricultural, Food, and Resource Economics, Michigan State University, Justin S. Morrill Hall of Agriculture, 446 West Circle Dr., Room 202, East Lansing, Michigan 48824, USA.

ABSTRACT

Conservation Agriculture (CA) aims to concurrently promote agricultural productivity, climate resilience and other environmental objectives related to sustainability. The evidence base for CA and other practices of climate-smart agriculture (CSA) in Sub-Saharan Africa is becoming better established. We review this evidence to address whether CA meets CSA objectives and why adoption rates by smallholders remain generally very low. As part of the review, we develop hypotheses for expected CA adoption under different socioeconomic and agro-ecological conditions, and consider promising options for enabling CA to better contribute to the CSA objectives.

Our results are largely in agreement with the nascent literature where CA is found to contribute positively to CSA productivity and adaptation/resilience objectives, although the degree of success varies considerably by regional, farm and household characteristics. The evidence is equivocal on the potential for CA to enhance soil carbon sequestration and reduce greenhouse gas emissions.

Overall, we find that capital-intensive (mechanized) CA is more likely to be adopted in areas of economic dynamism where capital is cheap relative to labor. Labor-intensive CA practices are more likely to be adopted in regions of economic stagnation where capital is expensive and labor is abundant and cheap. The climate-smartness of CA can be enhanced in a number of ways: reframing and adapting CA to location-specific economic and biophysical conditions, integrating CA with other CSA practices such as agroforestry, and by increasing the use of complementary productivity-enhancing inputs such as inorganic fertilizers and organic manure. Other options to make CA climate-smart include conditional subsidies, market and value chain development to improve farmers' access to CSA-promoting inputs, linking CA to payments for environmental service schemes (e.g., carbon credits), greater and more effective public spending on research and development to build evidence on the adaptation and mitigation potential of CA, and an improved enabling policy environment for private investment in input and farm commodity markets.

Keywords: Climate-smart agriculture (CSA), conservation agriculture (CA), Sub-Saharan Africa, productivity, adoption, Zambia

JEL Classifications: D1, Q12, O33

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ACRONYMS AND ABBREVIATIONS

AR5	Fifth assessment report
CA	Conservation Agriculture
CSA	Climate-Smart Agriculture
FSP	Innovation lab for Food Security Policy
GHG	Green House Gas
IAPRI	Indaba Agriculture Policy Research Institute
IPCC	Intergovernmental Panel for Climate Change
MT	Minimum tillage
MSU	Michigan State University
NDC	Nationally Determined Contributions
SIDA	Swedish International Development Agency
SSA	Sub-Saharan Africa
USAID	United States Agency for International Development

1. INTRODUCTION

The tight nexus between climate change and rural livelihoods is becoming increasingly clear. The fifth assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) concludes that climate change will worsen multidimensional poverty and create new poor in most developing countries including rural Sub-Saharan Africa (SSA) (Olsson et al. 2014). For these regions, agriculture is the primary impact channel for climate change because the majority of rural households depend on rainfed farming for their livelihoods (Thurlow, Zhu, and Diao 2012; Hallegatte et al. 2016). Climate change directly affects agricultural incomes, food security, and the poor's ability to escape poverty and indirectly, factor prices, the availability of alternative livelihood opportunities, and food systems (Olsson et al. 2014; Porter et al. 2014).[1]

SSA is projected to receive less rainfall, which will negatively affect long-term crop yield in the region (Lobell et al. 2008; Niang et al. 2014). In Zambia, rainfall is projected to reduce by 3% and 0.6% by 2050 and 2100, while temperature is projected to increase by 1.9ºC and 2.3ºC by 2050 and 2100 (Hamududu and Ngoma 2019). These changes in temperature and rainfall will likely reduce water availability by 13% in 2100 in the country (ibid), but with significant differences between regions, (the southern part likely to become the most affected).

The challenge for the region is twofold: i) to raise agricultural productivity to feed a growing population, projected to reach 2 billion by 2050 (Canning, Sangeeta, and Abdo 2015) and to meet their changing dietary preferences; and ii) to address the negative consequences of current and projected climate change and strengthen resilience. Climate resilient pathways are development trajectories that minimize climate change and its effects, while enhancing risk management to achieve sustainable development goals (IPCC 2014b).

The suite of CA practices is widely considered part of the solution that can contribute to the CSA objectives of i) raising productivity and household income, ii) enhancing adaptation and resilience, and iii) reducing greenhouse gas (GHG) emissions from agriculture (Thierfelder et al. 2017). CA has three principles: minimum tillage (MT), *in-situ* crop residue retention, and crop rotation. With varying degrees of success, CA is considered a viable option to intensify agricultural production and to enhance resilience in rainfed farming systems (Thierfelder and Wall 2010; Arslan et al. 2014; IPCC 2014b; Thierfelder et al. 2015; Droppelmann, Snapp, and Waddington 2017; Thierfelder et al. 2017).

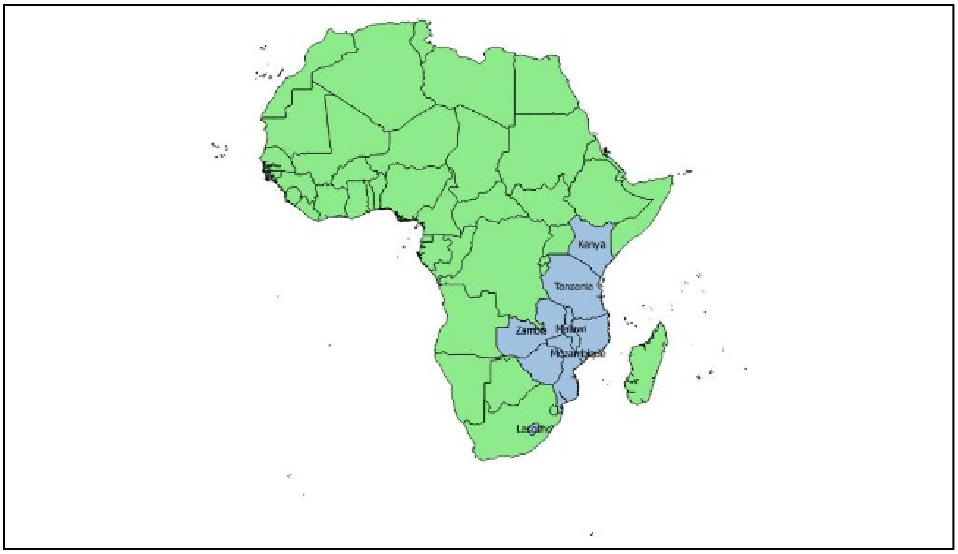
CA has evolved from its initial focus as a means to address declining soil productivity to include multiple, potentially climate-smart benefits such as sustainable intensification, climate change adaptation and mitigation, and biodiversity conservation (Baudron et al. 2009; Govaerts et al. 2009; Thierfelder and Wall 2010; UNEP 2013; IPCC 2014b; Powlson et al. 2016; Droppelmann, Snapp, and Waddington 2017).[2] CA garners strong political support. It is part of the regional agricultural

[1] Food systems refer to the whole range of processes and infrastructure involved in satisfying people's food security requirements (Porter et al. 2014).

[2] Powlson et al. (2016) posit that 'even if increases in soil organic carbon stock are small, and of limited value for climate change mitigation [under CA], there will almost always be an improvement in soil quality which would be expected to contribute to increased resilience to climate change'.

policies by the New Partnership for Africa's Development, the Common Market for Eastern and Southern Africa, and the Southern African Development Community (Giller et al. 2015).

Figure 1. Countries Where Conservation Agriculture Is Government Policy in Sub-Saharan Africa



Source: Authors illustration based on Giller et al. (2015).

CA is part of national policies in several SSA countries including Tanzania, Kenya, Malawi, Mozambique, Zimbabwe, Zambia, and Lesotho (Figure 1).

The multifaceted nature of CA engenders debates on the performance of the technologies. Even after years of actively promoting CA and in some cases providing subsidies, there is mixed evidence on the extent of its uptake and impacts on productivity, climate mitigation, and welfare among smallholder farmers in SSA (Giller et al. 2009; Andersson and D'Souza 2014).

There are questions on the extent of CA adoption (Andersson and D'Souza 2014), its compatibility with smallholder farming systems in the region (Giller et al. 2009; Andersson and Giller, 2012), its impacts on carbon sequestration, mitigation, deforestation, and environmental efficiency (Powlson et al. 2014; Abdulai and Abdulai, 2016; Powlson et al. 2016; Ngoma and Angelsen 2018). There are mixed results on its yield and welfare effects (Ngwira, Aune, and Mkwinda 2012; Arslan et al. 2015; Ngoma, Mason, and Sitko 2015; Thierfelder et al. 2015; Abdulai, 2016; Thierfelder et al. 2016; Ng'ombe, Kalinda, and Tembo 2017; Ngoma 2018).[3] These mixed results create an aura of uncertainty regarding the suitability of CA for smallholder farming systems (Giller et al. 2009), and lead to questions on whether there is a potential disconnect between the agronomic rationale for CA and it outcomes under smallholder farming systems in the region (Ngoma, Mason, and Sitko 2015).

Given its significant political support and potential benefits, we contend that CA will remain relevant in the development discourse into the foreseeable future. As such, this paper takes a step

[3] An extended and influential online discussion following (Giller et al. 2009) is here https://conservationag.wordpress.com/2009/12/01/ken-gillers-paper-on-conservation-agriculture/

back and assesses the extent to which CA as currently practiced in the region is climate-smart and how its climate-smartness can be enhanced. This paper complements and adds to existing nascent literature in three ways. First, we review the evidence on CA uptake and its impacts on productivity and farm incomes, carbon sequestration, and mitigation in SSA. Second, we assess the extent to which CA meets the CSA and sustainable intensification objectives. And, lastly, using the Boserupian and the induced innovation hypotheses (Boserup 1965; Hayami and Ruttan 1971), we consider contexts under which CA can be expected to better contribute to the CSA objectives. We hypothesize that population density and changes in factor prices can explain CA adoption and its climate-smartness in different contexts in SSA. Overall, the paper aims to provide some guidance on ways CA adoption can be scaled up to better contribute to CSA.

The rest of the paper is structured as follows. Section 2 reviews what constitutes CA adoption in SSA. Section 3 presents the conceptual framework linking CA to resilience. Drivers of adoption are discussed in section 4, while Section 5 considers the impacts of CA on productivity and livelihoods. Section 6 links CA and climate change mitigation. Section 7 presents a framework and derives hypotheses for CA adoption under different economic conditions and Section 8 proposes ways to make CA more climate-smart. The paper concludes in Section 9.

2. WHAT CONSTITUTES CONSERVATION AGRICULTURE ADOPTION?

Much of the debates on the extent of CA uptake boil down to lack of a common understanding on what CA adoption means. In part, this is due to conceptual challenges in defining adoption (Andersson and D'Souza 2014; Glover, Sumberg, and Andersson 2016). Following Ngoma (2016), a fundamental question is how to decide when a farmer qualifies as an adopter. Does a farmer have to use one, two, or all three core principles of CA in a given year? And, should CA be applied to all or most of her cultivated land? Can CA principles be used only once for the farmer to qualify, or must it be applied over a longer, a pre-defined period? The fact that some CA elements such as rotation are old-age practices prevalent even under conventional farming raises the question whether a farm that practices crop rotation alone is sufficient to be counted as a CA adopter.

A related dimension is adoption intensity: If one quarter of a plot has planting basins and minimum tillage while the rest of that plot and the households' other three plots are under conventional land preparation, is the farmer regarded as a CA adopter? Does a hectare of minimum tillage count the same as two three-meter rip lines or five planting basins in the backyard? Should there be a minimum threshold for adoption? It may not be necessary for analysts and practitioners to agree on the answers to all these questions, but it would be analytically a step forward for studies to clearly explain how CA adoption is defined in their studies, which would then make it easier to assess why adoption rates apparently differ across studies in the same area.

In this study, we define MT as a tillage system with reduced soil disturbance concentrated only in planting stations. MT has three main variants—ripping, planting basins, and zero-tillage. Rip lines are made with ox- or tractor-drawn rippers, planting basins are made with hand-hoes. Zero-tillage is based on handheld or mechanized direct planters. Residue retention requires leaving at least 30% of crop residues to serve as mulch or cover crop, while crop rotation involves planting cereals and nitrogen-fixing legumes in succession on the same plot in order to improve soil fertility (Haggblade and Tembo 2003). Full adoption involves use of all the three CA principles; partial adoption involves the use of MT alone or with either rotation or with residue retention.

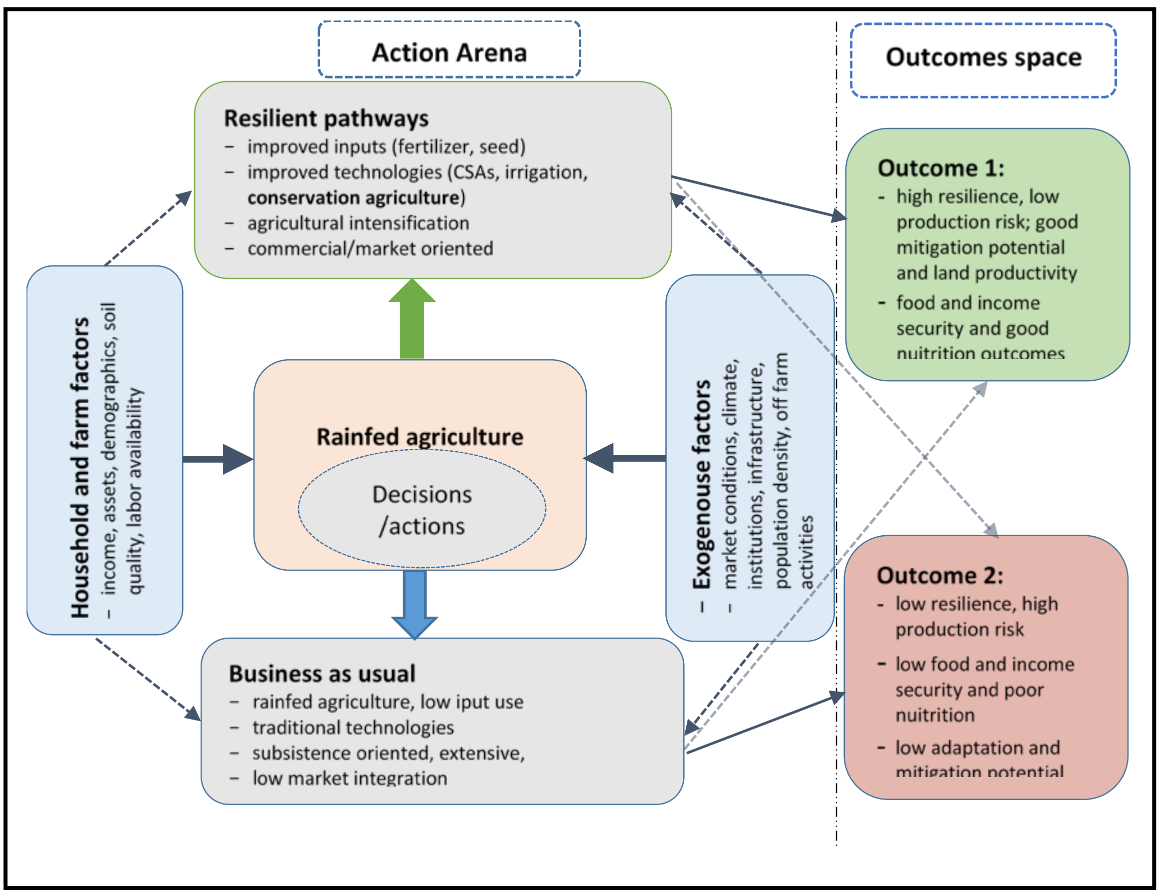
3. CONCEPTUAL FRAMEWORK: LINKING CA TO RESILIENCE

Figure 2 presents the conceptual thinking around CA and resilience. According to IPCC-AR5, resilience is the capacity of rainfed farming systems to cope with current and projected climate change and variability so that they maintain their essential function (IPCC 2014b). Resilience can also be defined as the ability of a system to respond to transitory effects such as shocks or the more persistent adverse trends such as stressors (Hoddinott 2014). CA can play a significant role in enhancing farm household's resilience.

Day to day farming decisions by individual farmers are central in our framework. In line with the livelihood framework of, for example, Ellis (2000), several factors directly or indirectly influence farmer choices of farming systems: household (e.g., demographics and socioeconomics) and farm characteristics (e.g., soil quality and productive assets), as well as exogenous, higher-scale factors such as market conditions, weather, institutions, population density and off-farm income opportunities (Boserup 1965; Binswanger and Rosenzweig 1986; de Janvry, Fafchamps, and Sadoulet 1991; Ellis 1998; IPCC 2014c; Cacho et al. 2018).

At the conceptual level, Figure 2 provides a basis for analyzing how farming decisions influenced by multiple factors can result in climate resilient or non-climate resilient outcomes.

Figure 2. Conceptualizing Linkages between Conservation Agriculture and Resilience



Source: Authors illustration, adapted from (IPCC 2014c; Cacho et al. 2018).

However, specific economic models are needed to test specific hypotheses and theories drawn from key relations in the figure. Agricultural household models are an obvious choice (Singh, Squire, and Strauss 1986) given their wide application in studying the economic behavior of rural households (de Janvry, Fafchamps, and Sadoulet 1991).

Farming choices made in the action arena can lead to either climate resilient pathways or business as usual (Figure 2). The former is preferable from a CSA and climate perspective. Under the resilient pathway, smallholder farmers use improved inputs and technologies such as inorganic fertilizers and hybrid seed, CA, and irrigation. Farming is intensive and market oriented. However, it is the polar opposite under business as usual where production is extensive and rudimentary with little or no external input use and market integration, and farming is largely subsistence. This typology does not suggest that business as usual is necessarily irrational. For example, household members may not be able to devote sufficient farm labor to adopt CA practices because they are engaged primarily in off-farm employment or educational pursuits. Nevertheless, as framed in Figure 2, *business as usual* farming is bad for the environment and vulnerable to climate shocks because it is rainfed, extensive, and less resilient. Successful CA implementation and outcomes require these constraints on CA adoption need to be overcome at scale for millions of farmers in the region.

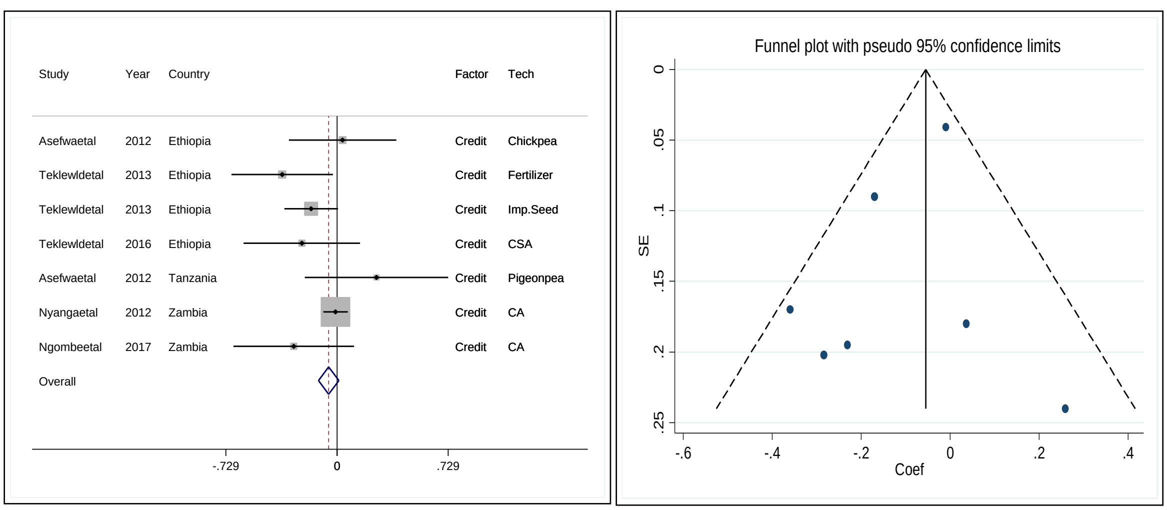
4. WHAT DRIVES ADOPTION OF CA PRACTICES IN SUB-SAHARAN AFRICA?

This is an age-old question but remains relevant given the strategic position of CA as a means to address climate change, increase food production, and household incomes in SSA. We use data from studies published in referred journals on SSA in the between 2007 and 2018 to partly answer questions on drivers of CA adoption. To do this, we searched for 'Adoption of' or 'Impacts' of 'Conservation Agriculture on yield or livelihoods' in 'Sub-Saharan Africa' in Google Scholar and Scopus. We narrowed down our analysis to include only studies that focus on discernible and well-defined agricultural technologies and report both the effect size and the standard error. By these metrics, our list of studies is biased towards those in economics, but we reviewed a large body of literature from on-station experiment studies.

We used forest plots to collate results from various studies on the effects of access to credit, farm size, and labor availability on CA adoption and more broadly CSA.[4] These factors are among the major impediments to the spread of CA in the region (Thierfelder et al. 2015; Ngoma 2016). For each factor, we present the results in a forest plot (on the left) showing the study name, year, country, effect size, explanatory variable/factor and the specific technology. Each forest plot is accompanied by a funnel plot (on the right) to measure publication bias or small study effects.

Although access to credit is considered a major enabler of technology adoption in agriculture, the evidence for CSA practices is mixed in SSA (Figure 3). For the studies reviewed, the effect of credit on adoption is negative and statistically insignificant on average, suggesting that farmers in the region face other immediate non-financial impediments to adoption.

Figure 3. The Effects of Access to Credit on the Adoption of Various CSA Practices in Sub-Saharan Africa

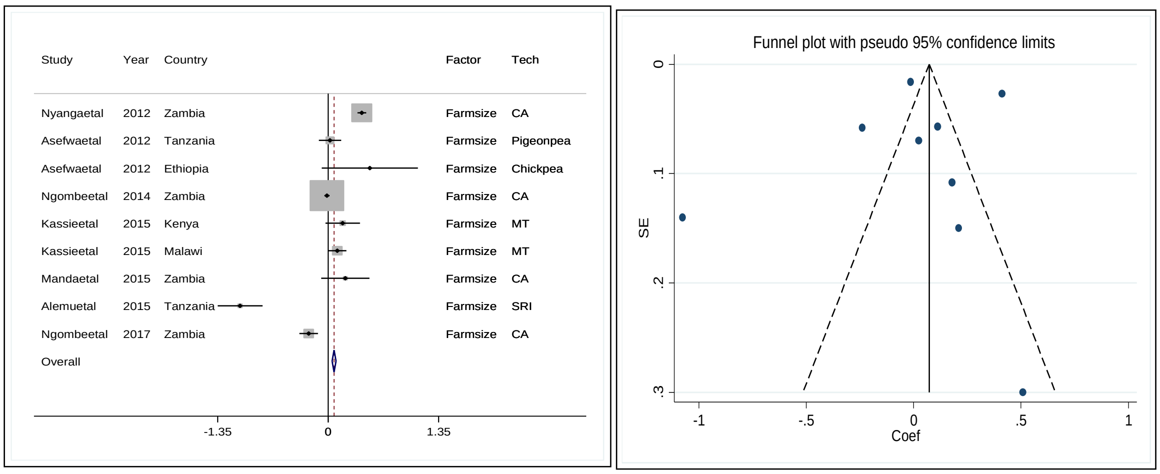


Source: Computed from (Asfaw et al. 2012; Nyanga 2012; Teklewold, Kassie, and Shiferaw 2013; Ng'ombe, Kalinda, and Tembo 2017). Notes: The horizontal lines in the forest plots are the confidence intervals (CIs) and the grey areas are study weights generated in the meta function. CIs

4 A forest plot is a graphical display of estimated results from a number of scientific studies addressing the same question, along with the overall results.

that cross the zero line indicate statistical insignificance with those on the left and right showing negative and positive statistically significant effects. CSA denotes combined technologies.

Figure 4. The Effects of Farm Size on the Adoption of Various CSA Practices in Sub-Saharan Africa



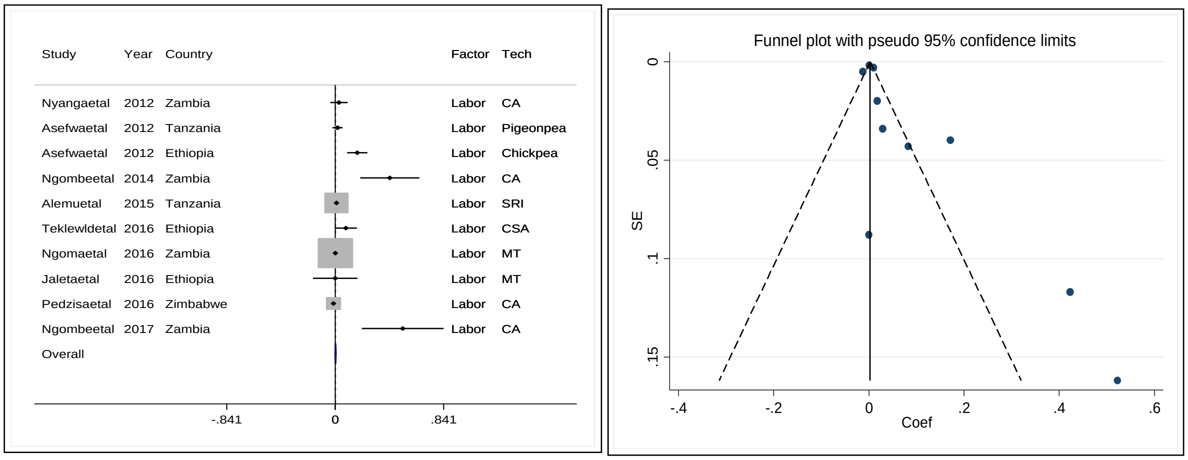
Source: Computed from (Alem, Eggert, and Ruhinduka 2015; Asefwa et al 2012; Kassie et al. 2015; Ng'ombe et al. 2014, Ng'ombe, Kalinda, and Tembo 2017; Nyanga et al. 2012).

Notes: The horizontal lines in the forest plots are the confidence intervals (CI) and the grey areas are study weights generated in the meta function. CIs that cross the zero line indicate statistical insignificance with those on the left and right showing negative and positive statistically significant effects. SRI denotes sustainable rice intensification.

The story on farm size is somewhat different. On average, farm size is positively correlated with the adoption of various CSAs in SSA (Figure 4 above). This result could reflect the importance of wealth (if farm size is taken as proxy for household wealth). It could also reflect the fact that larger farm holdings give farmers leverage to experiment with CSAs on some parts of their land, while maintaining the low-risk, low-return conventional methods on the rest of the farm.

Labor availability is another important factor in the adoption of CSA. For the studies reviewed, labor availability has an insignificant to a positive and significant effect on adoption (Figure 5 on the following page). It was positively correlated to the adoption of chickpea (a legume) in Ethiopia (Asfaw et al. 2012), CA practices in Zambia (Ng'ombe, Kalinda, and Tembo 2017) but insignificant to the adoption of MT in Ethiopia (Jaleta et al. 2016) and Zambia (Nyanga 2012; Ngoma, Mulenga, and Jayne 2016), and CA in Zimbabwe (Pedzisa et al. 2015). The insignificant results could be reflective of the high labor-intensity of some CA principles (e.g., basins) (Ngoma, Mulenga, and Jayne 2016), thus, even if family labor is available the labor costs (drudgery or alternative employment on-farm or off-farm) are deemed to be too high. Therefore, we conclude in line with Vaiknoras, Norton, and Alwang (2015) that if realized, labor saving in CA technologies could spur adoption.

Figure 5. The Effects of Labor Availability on the Adoption of Various CSA Practices in Sub-Saharan Africa



Source: Computed from (Asfaw et al. 2012; Nyanga 2012; Teklewold, Kassie, and Shiferaw 2013; Ngombe et al. 2014; Alem, Eggert, and Ruhinduka 2015; Pedzisa et al. 2015; Ngoma, Mulenga, and Jayne 2016; Ng'ombe, Kalinda, and Tembo 2017).
Notes: The horizontal lines in the forest plots are the confidence intervals (CI) and the grey areas are study weights generated in the meta function. CIs that cross the zero line indicate statistical insignificance with those on the left and right showing negative and positive statistically significant effects.

Adverse selection and incentive ('moral hazard') problems can influence CA adoption rates. Adverse selection may manifest where the wrong farmers (e.g., project-dependent) are targeted by CA projects as beneficiaries. Such farmers may pretend to adopt some components of CA for as long as they receive project benefits (e.g., input vouchers) but they still maintain most of their cultivated land under conventional tillage or are quick to revert to conventional methods as they await the next project (Ngoma, Mulenga, and Jayne 2016). This leads to problems of inclusion and exclusion where deserving farmers are excluded and those who are not supposed to be in the program are included. In other instances, adoption estimates are intentionally over-reported (impressionistic) to impress funding agencies or serve other interests. Farmers may also be reluctant to adopt CA due to lack of technical knowhow or due to culture and traditions (Zulu-Mbata, Chapoto, and Hichaambwa 2016).

Farmers' risk and time preferences, and risk perceptions also matter for CA adoption. Ngoma et al. (2018b) found that risk aversion, impatience, and farmers' subjective perceptions of the riskiness of CA significantly reduced the probability of adoption. Although CA is considered risk reducing, risk averse farmers may not adopt it because they may be unwilling to take on unfamiliar farming practices or because they do not understand the risk reducing capabilities of CA. Impatient farmers or farmers with high discount rates may not adopt CA if they believe that significant benefits from CA only accrue in the medium-to long-term, and yet their interests are short term.

Insights from behavioral and experimental economics could be key in advancing our understanding of the apparent CA-conundrum where even after several years of promotion, and given that CA presumably addresses the core problems facing smallholder agriculture—namely low productivity and climate change—its uptake does not spread like wildfire. To the best of our knowledge, Ngoma et al. (2018b) is among a few nascent studies integrating behavioral and experimental methods to explain CA adoption in SSA.

5. IMPACTS OF CA ON PRODUCTIVITY AND LIVELIHOODS

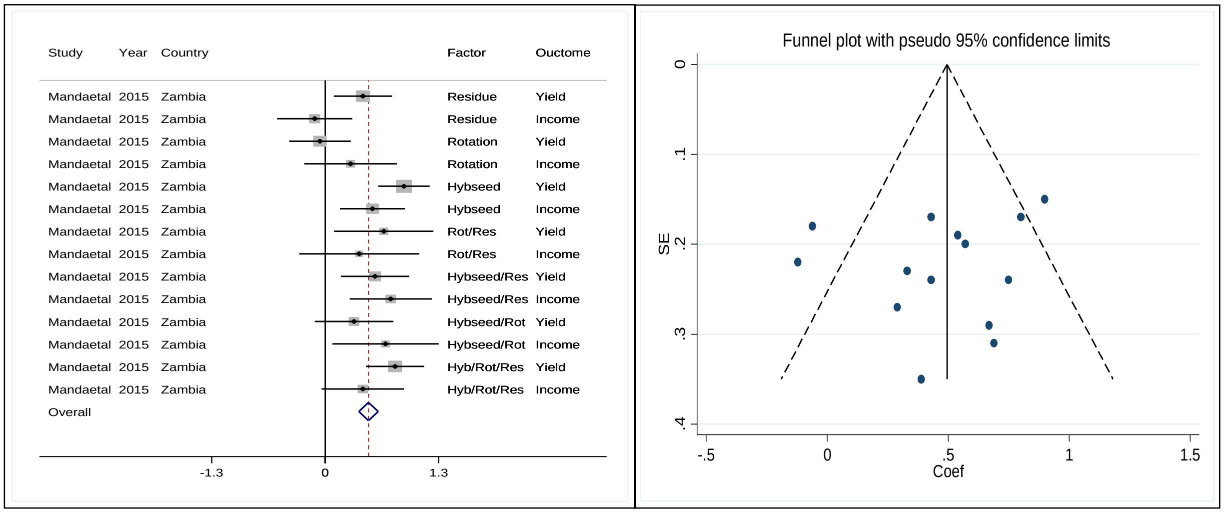
In general, there is still thin evidence on the impacts of CA on land productivity (yield) and livelihoods (income, food security) based on large observational data and beyond field/station experimental plots in SSA (Ngoma, Mason, and Sitko 2015). This is partly due to the fact that doing a proper and credible impact assessment is challenging; it requires accounting for what adopters would have earned had they *not* adopted and what non-adopters would have earned had they adopted, while controlling for confounding observables and unobservables.

There is, however, a nascent body of literature trying to fill this gap, with some finding positive impacts of adopting CA practices on maize/crop yield in Zambia (Kuntashula, Chabala, and Mulenga 2014; Ngoma, Mason, and N.J. Sitko 2015; Abdulai 2016; Ng'ombe, Kalinda, and Tembo 2017; Ngoma 2018), Tanzania (Arslan, Belotti, and Lipper 2017) and Ethiopia (Jaleta et al. 2016). There are also several studies based on experimental station or field data that show positive impacts of adopting CA on crop yield e.g., in Malawi (Ngwira, Aune, and Mkwinda 2012), Zambia (Thierfelder, Mwila, and Rusinamhodzi 2013), Zimbabwe (Nyamangara et al. 2014) and more generally across SSA (Rusinamhodzi et al. 2011; Thierfelder, Matemba-Mutasa*,* and Rusinamhodzi 2015; Thierfelder et al. 2015; Thierfelder et al. 2016).

A closer look at the results on the impacts of CA on crop yield reveals several nuances. While some studies find that CA confers immediate yield gains (Ngwira, Thierfelder, and Lambert 2013), others find that there are lags of 2-5 cropping seasons or longer before any significant yield gains (Giller et al. 2009; Thierfelder et al. 2017). Yet, other studies find that CA has no statistically significant yield effects (Arslan et al. 2015). There appears to be a tacit agreement that CA practices are viable climate change adaptation strategies for farmers in SSA (IPCC, 2014b), with clear links between rainfall variability and adoption (Arslan et al. 2014; Ngoma, Mulenga, and Jayne 2016; Arslan, Belotti, and Lipper 2017).

There is less agreement on the impacts of CA on household incomes, and some argue that the positive yield benefits from CA may be insufficient to offset the costs of implementation, at least in the short term (Jaleta et al. 2016; Ngoma 2018). Among the more favorable assessments, Tambo and Mockshell (2018) report significant income gains from full adoption of CA across nine SSA countries. Combining different CSAs seems to offer greater benefits, as was found in Manda et al. (2016) and shown in Figure 6 on the following page. There is also evidence from experimental studies suggesting that CA adopters have had higher incomes and profits than non-adopters in some instances (Ngwira, Thierfelder, and Lambert 2013).

Figure 6. The Effects of Various CSA Principles on Crop Yield and Household Income in Sub-Saharan Africa



Source: Computed from Manda et al. (2016).

Notes: The horizontal lines in the forest plots are the confidence intervals (CI) and the grey areas are study weights generated in the meta function. CIs that cross the zero line indicate statistical insignificance with those on the left and right showing negative and positive statistically significant effects.

6. CONSERVATION AGRICULTURE AND CLIMATE CHANGE MITIGATION

Country commitments to reduce emissions under the 2015 Paris agreement on climate change have brought back CA or more broadly CSA into the limelight (Ngoma 2016). Under the Nationally Determined Contributions (NDCs), countries pledged how much, where, and how they will reduce emissions as a contribution towards the United Nations Framework Convention on Climate Change (UNFCCC) Paris agreement goal of limiting global temperature rise to below 2ºC (or even 1.5 ºC) relative to the pre-industrial levels. About 64% and 80% of NDCs analyzed by Richards et al. (2015) include agriculture in their mitigation and adaptation targets, respectively, with CSA as a common means to do so.

There are good and valid reasons for this: agricultural emissions are significant, accounting for 5-5.8 $GtCO_2e$/year or about 11% of global anthropogenic GHGs (IPCC 2014b). Developing countries contribute about 35% of all agricultural emissions (Wollenberg et al. 2016).

Furthermore, expanding agricultural land into forests accounts for about 80% of the deforestation at the global level (FAO 2017). Land use changes—mainly tropical deforestation—account for a similar share (1/10) of global emissions (IPCC 2014b). Ngoma and Angelsen (2018) found that smallholder farmers in Zambia clear on average 0.14 ha of forest per household per year for agriculture production, translating to about 210,000 ha of forest converted to cropland per year at the national level. CSA practices in general and CA in particular are often considered to be viable mitigation pathways that can reduce emissions from agriculture through soil carbon sequestration (UNEP 2013; IPCC 2014a) or through their direct–yield effects on deforestation (Ngoma and Angelsen 2018).

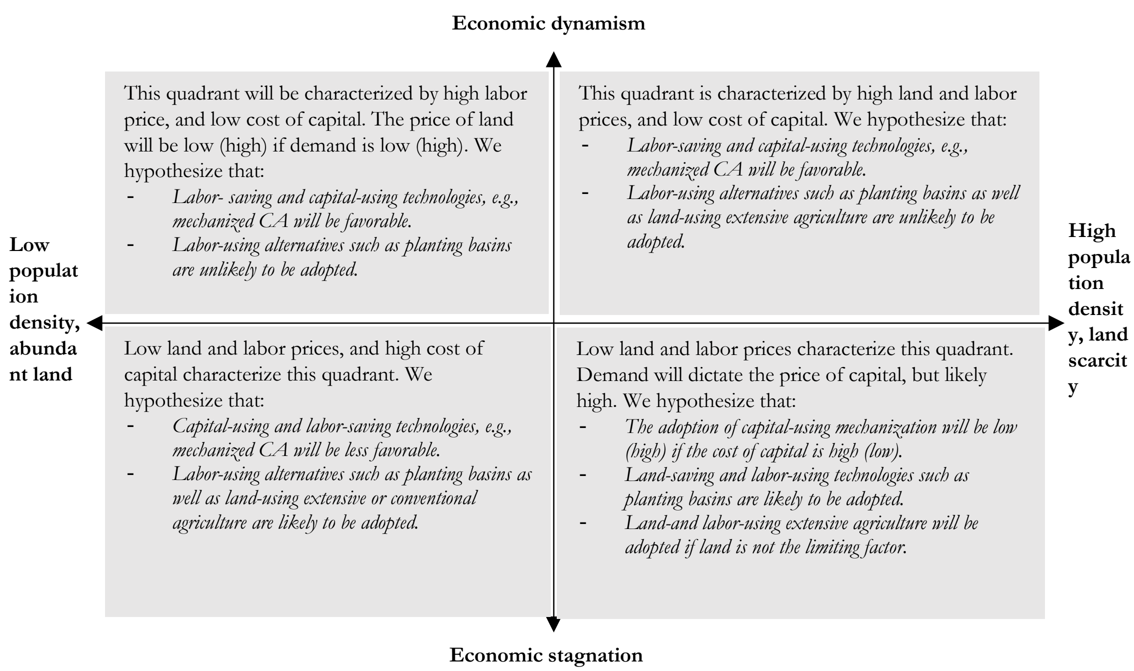
However, the science on the mitigation potential for specific CSA principles such as no-till or CA in general is equivocal and inconclusive. There are arguments to the effect that it is a myth to suggest that no-till can mitigate climate change and 'stop the runaway train of global warming' (VandenBygaart 2016) and that the potential for no-till or more broadly CA to mitigate climate change is overstated (Powlson et al. 2014; Powlson et al. 2016). CA practices alone, like most technologies and practices that increase yield, have limited potential to reduce cropland expansion into forests (Byerlee, Stevenson, and Villoria 2014; Ngoma and Angelsen 2018). While it is often argued that CA can lead to land sparing outcomes through facilitating agricultural intensification, also known as the Borlaug hypothesis, the pathways from intensification to land sparing are not that straightforward. These depend on the commodity, price elasticity, and factor intensities of the technologies involved (Ngoma et al. 2018a). Higher yield from intensification makes agriculture more profitable, which may in turn, lead to land expansion or deforestation. This phenomenon is also known as the Jevon paradox (Ngoma et al. 2018a).

7. CA ADOPTION UNDER VARIOUS ECONOMIC CONDITIONS AND ALTERNATIVE WAYS TO MAKE CA MORE CLIMATE-SMART

We adopted a framework proposed in Jayne et al. (2019) to characterize when the adoption of CA is expected to be high or low depending on different economic scenarios. This framework is underpinned by the induced innovation and the Boserup hypotheses and provides a means to identify pathways that can explain CA adoption in Figure 2. The induced innovation hypothesis postulates that factors prices influence adoption of innovations in agricultural development, while the Boserup hypothesis suggests that, if land is abundant, farmers will tend to practice extensive agriculture before intensifying (Boserup 1965; Hayami and Ruttan 1971). We extend the basic framework in Jayne et al. (2019) and propose alternative options to strengthen the climate-smartness of CA under each expected adoption scenario.

We consider two conditioning or exogenous factors: economic dynamism and population density. We assess how these exogenous factors are likely to affect factor prices for labor, land and capital, and therefore CA adoption. We posit that land, labor, and capital are necessary for CA adoption as discussed in section 4. Economic dynamism is characterized by functional input and output markets and economic growth, while economic stagnation is the polar opposite. The continuum for economic dynamism is represented by the vertical axis in Figure 7. High population density shown on the horizontal axis is characterized by increased land pressures, while as expected, land is abundant under the low population density scenario.

Figure 7. Expected Adoption of Types of Conservation Agriculture Based on Factor Prices as Determined by Population Density and Economic Dynamism Continuums



Source: Authors.

High land and labor costs, and low cost of capital characterize the NE quadrant in Figure 7 where there is economic dynamism (with functional factor and output markets) and high population density. The low cost of capital is likely to facilitate the adoption of capital-using and laborsaving mechanized CA technologies such as ripping. The high cost of labor and land will, however, limit the adoption of labor-intensive CA such as planting basins, and land-using extensive agriculture.

Low population density, abundant land, and economic stagnation is associated with low land and labor costs, and high cost of capital in the SW quadrant. Under this scenario, capital-using and laborsaving technologies such as mechanized CA will be less favorable, while labor-using alternatives such as planting basins as well as land-using extensive or conventional agriculture are likely to be adopted. Labor-intensive CA will only be adopted in this case if its returns are superior to conventional agriculture (Ngoma et al. 2018a). Labor-intensive farming systems, whether it is CA or conventional agriculture will only be adopted if the opportunity cost of labor is low.

Under low population density and economic dynamism in the NW quadrant, the cost of capital is expected to be low, while the cost of labor will be high. Given that land is abundant (and supply is fixed), the land price will be low (high) if demand is low (high). In this case, laborsaving and capital-using technologies such mechanized CA will be favorable, while labor-using alternatives such as planting basins are unlikely to be adopted. With high population density and economic stagnation in the SE quadrant, the land price is expected to be high, while the cost of labor will be low. The cost of capital will depend on the effective demand created by markets, but is likely to be high given economic stagnation. We would expect the adoption of capital-using mechanization to be low (high) if the cost of capital is high (low), whereas land-saving and labor-using technologies such as planting basins are likely to be adopted. Land-and labor-using extensive agriculture will be adopted if land is not the limiting factor and if the returns from labor-using CA are not higher than returns from conventional agriculture.

In sum, Figure 7 suggests that capital-intensive or mechanized CA is more likely to be adopted under economic dynamism where capital is cheaper but labor is expensive, while labor-intensive CA practices are more likely to be adopted under economic stagnation where capital is expensive and labor is cheap and abundant. This typology is important, but equally important is an understanding of how best CA practices can be more climate-smart and hence better contribute to the three CSA objectives of raising productivity, farm incomes and adaptation, and mitigation.

8. HOW CAN CONSERVATION AGRICULTURE BE MORE CLIMATE-SMART?

CA can contribute to the productivity objective at scale by facilitating intensification. Necessary attendant success factors include increased use of improved inputs such as inorganic fertilizers and hybrid seed, mechanization, irrigation and organic matter.[5] CA can also better contribute to the CSA productivity and adaptation objectives if it is combined with market and value chain development to improve market access and production support. Other enablers include policies that make receipt of agricultural subsidies conditional on verified CA adoption. The use of premium prices for produce with certified low carbon footprint is another market option.

These options can be complemented with improved public spending on research and development to build evidence on the adaptation and mitigation potential of specific CA practices and extension to encourage CA adoption and adaptation of CA to local contexts. Conditional input subsidies to limit cropland expansion and linking carbon credits from CA adoption to payments for environmental services are interesting alternative incentives that can be explored and used to incentivize mitigation under CA. A World Bank funded Community Markets for Conservation (COMACO) Landscape Management Project that promotes sustainable agriculture and forest conservation in Zambia is a good example of such initiatives.[6] Ngoma et al. (2018b) found that providing a green subsidy framed as an add-on incentive to the current farmer input subsidies for verified CA adopters raised the probability of adopting CA by 12 percentage points among smallholder farmers in the study areas in Zambia.

CA can also better contribute to the adaptation objectives if the full CA suite including crop diversification, rotation, and residue retention is applied. This improves infiltration and soil moisture conservation (Thierfelder et al. 2017). To better contribute to the mitigation objectives, CA would have to be integrated with other CSAs such as agroforestry to improve nitrogen fixation and boost soil organic matter and soil carbon. Duguma et al. (2017) shows that agroforestry has enormous potential to sequester carbon in agriculture. Agroforestry is part of several country NDCs (Richards et al. 2015).

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[5] The use of inorganic fertilizer may be at odds with mitigation objectives, but not so much at low levels of use.

[6] Documenting lessons from such initiatives will be important going forward. Project details here http://www.biocarbonfund.org/node/87

9. CONCLUSION AND IMPLICATIONS

Rapid population growth, which is expected to reach 2 billion by 2050, and the projected negative consequences of climate change on agriculture and livelihoods in Sub-Saharan Africa (SSA) require urgent and radical transformation of rainfed farming systems in the region. To respond effectively to the dual challenge, farming requires a paradigm shift to become more climate-smart. Conservation agriculture (CA) is largely seen as part of this transition towards climate-smartness in agriculture. We reviewed the evidence on the extent to which CA contributes to the CSA objectives of concomitantly raising productivity, adaptation/resilience and mitigation, and offer pragmatic options to enhance this contribution in SSA. We draw four main conclusions from the review.

First, we agree with Knowler and Bradshaw (2007) and conclude that there is no single driver of CA adoption in SSA. Context matters, but in general, adoption must be seen as a risk reducing and economically viable option for farmers to adopt CA, i.e., the perceived benefits—also in the short term—must outweigh the costs, including family labor.

Second, we conclude in line with Thierfelder et al. (2017) that CA appears to have positive productivity effects in the medium to long term due to its influence on soil health, but does not appear to have significant benefits on household incomes in the short-run. Turning this around may entail significant reframing and adaptation of CA to local contexts (Brown, Llewellyn, and Nuberg 2017), or support programs to enhance the short-term benefits.

Third, we conclude along the lines of Powlson et al. (2016) and Thierfelder et al. (2017) that the evidence on the potential for CA practices to sequester soil C and mitigate climate change among smallholder farming systems in SSA is thin and equivocal. CA appears to have limited mitigation potential, but more research is required.

Lastly, we are in agreement with Byerlee, Stevenson, and Villoria (2014), Ngoma et al. (2018a), and Ngoma and Angelsen (2018) and conclude that contingent on market conditions, characteristics of the commodity, farm practices and context, labor and capital intensities, and scale of adoption, agricultural technologies such as CA are unlikely to reduce cropland expansion into forests (and mitigate deforestation and climate change) unless these are complemented with measures to conserve forests. Such measures could include bans on cropland expansion into forests, land use zoning, certification, strategic placement of infrastructure, sustainability standards, and payments for environmental services (Ngoma et al. 2018a). Reconciling such conservation measures with food security goals will be crucial to achieving win-win outcomes.

Overall, we find that capital-intensive or mechanized CA is more likely to be adopted under economic dynamism where capital is cheap relative to labor, while labor-intensive CA practices are more likely to be adopted under economic stagnation where capital is expensive and labor is cheap and abundant. The climate-smartness of CA can be enhanced in a number of ways, including by reframing and adapting CA to local contexts, and integrating CA with other CSA practices such as agroforestry, and improved inputs and organic manure. Other options to nudge CA adoption and make it more climate-smart include conditional subsidies, market and value chain development to improve market access, linking CA carbon credits to payments for environmental services type schemes, enabling policy environment, and improved public spending on research and development to build evidence on adaptation and mitigation potential of CA.

There is an urgent need to confront the adoption problem in SSA for the options identified in this paper to be feasible. How to scale-up and scale-out CA effectively and efficiently, and have this backed by sufficient resources from national governments, NGOs and donors, remains an open question.

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