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Analysis

# Differential Impacts of Conservation Agriculture Technology Options on Household Income in Sub-Saharan Africa

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ABSTRACT

Conservation agriculture (CA), which consists of minimum soil disturbance, crop residue retention and crop rotation, is claimed to generate a number of agronomic, economic and environmental benefits. Recognising these potential benefits, CA is widely promoted in efforts towards sustainable agricultural intensification. However, there has been an intense debate about its suitability in smallholder farming environments, and this has stimulated a growing interest in the adoption and impacts of CA technologies in sub-Saharan Africa (SSA). Using survey data from maize-growing households in nine SSA countries, this paper seeks to add to the extant literature by examining the drivers and welfare impacts of individual and combined implementation of the three components of CA. We employ inverse-probability-weighting regression-adjustment and propensity score matching with multiple treatment estimators. Overall, results show that adoption of a CA technology significantly increases total household income and income per adult equivalent. Disaggregating the CA components, we find that adoption of the components in combination is associated with larger income gains than when the components are adopted in isolation, and the largest effect is achieved when households implement the three practices jointly. Nevertheless, implementation of the full CA package among the sampled households is very low, with an average adoption rate of 8%. We identify key factors that might spur increased adoption, including education, secure land rights, and access to institutional support services. Results further show that the determinants and impacts of the CA components vary considerably among the study countries, suggesting location specificity of CA. Our results are consistent across alternative estimators.

## 1. Introduction

Producing sufficient food to meet growing demand is an issue of great concern, particularly in sub-Saharan Africa (SSA) where agricultural productivity is very low and about 307 million people (31% of the population) are estimated to be severely food insecure (van Ittersum et al., 2016; FAO et al., 2017). Unfortunately, the challenges of climate change, land degradation, rapid population growth, urbanisation, exacerbate the situation (Godfray et al., 2010). Moreover, agriculture contributes to environmental problems through the emission of greenhouse gases and the degradation of natural resources. Thus, the increasing demand for food must be met while simultaneously mitigating environmental problems emanating from agriculture (Foley et al., 2011; Tittonell et al., 2016). This calls for sustainable agricultural intensification (SAI), that is, producing more food while conserving natural resources and the environment (The Montpellier Panel, 2013). In recent years, increasing attention has been paid to promoting SAI practices, and notable among them is conservation agriculture (CA).

CA combines profitable agricultural production with environmental conservation and sustainability through the simultaneous application of three principles, namely, minimum soil disturbance, permanent organic soil cover or crop residue retention, and crop rotation (FAO, 2017). Soil tillage has been associated with structural degradation of soil, which leads to soil erosion and a reduction in soil organic matter in the long term (Kassam et al., 2009). Conversely, the introduction of minimum soil disturbance, which involves shifting from the conventional plough-based farming systems to minimum or zero tillage, or seeding directly into untilled soil, may help to curb the negative impacts of soil tillage and to improve the quality of soil structure (Hobbs et al., 2008; Kassam et al., 2009). Permanent soil cover entails retaining the residues of planted crops on the farm all year round. It can also be achieved through cover cropping and green manuring. Among the advantages of

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this practice are the protection of the soil from the physical impact of rain and wind, the lowering of the soil temperature in the surface layers, the improvement of infiltration and retention of soil moisture, and the increase in the availability of plant nutrients (Jarecki and Lal, 2003). The third principle involves the rotation of cereals with legumes. This practice increases plants nutrients, limits pest build-up (and thus decreases the need for pesticides), and enhances biodiversity (Kassam et al., 2009). Thus, beyond the agronomic benefits of crop yield improvement through increased organic matter, water conservation and improved soil structure, the sustained adoption of CA practices also generates environmental benefits, such as increased biodiversity, reduced soil erosion, improved water quality and increased soil carbon (FAO, 2017). Therefore, CA can play an essential role in sustainable intensification efforts.

However, despite the potential contribution of CA to sustainable food production, it has been a highly contested agricultural technology (Giller et al., 2009). There are diverse views on its potential impact by the many proponents and sceptics of the technology. While CA is associated with the aforementioned benefits, its adoption is hampered by several challenges, including the lack of mulch or competing uses for crop residues, the high cost of necessary farm equipment and labour constraints (Knowler and Bradshaw, 2007; Giller et al., 2009; Arslan et al., 2014). Based on its widespread adoption in the Americas and the increased challenges of soil degradation, labour shortage and poor productivity in SSA, CA is being increasingly promoted to SSA farmers by international research and development organisations (Andersson and Giller, 2012; Corbeels et al., 2014a). Considering the challenges involved in its adoption, however, there has been an intense debate about its suitability and impacts for African farmers, the majority of whom are smallholders (Giller et al., 2009; Andersson and D'Souza, 2014).

Consequently, there is a large and growing body of literature on the adoption and impact of CA. One strand of the literature has focused on using field experiments to assess the effect of the CA principles on crop yields, with mixed findings. For instance, Pittelkow et al. (2015) conducted a global meta-analysis of 610 field experiment-based studies and showed that conservation tillage reduces crop yields relative to conventional tillage, but the negative yield effects are minimised when conservation tillage is combined with the other two CA principles of residue retention and crop rotation. However, the study also stressed that under certain conditions, conservation tillage could generate equivalent or better yields than conventional tillage. Similarly, conducting meta-analysis of 41 CA experiments in SSA, Corbeels et al. (2014b) found that conservation tillage without mulch and/or crop rotation leads to a decrease in crop yields, but conservation tillage with mulching produces higher yields than conventional tillage, again suggesting the importance of combining the CA practices. The results of the numerous on-farm experiments, however, may not reflect the performance of CA under farmers' management conditions.

A second strand of the literature has examined the factors that influence farmers' adoption of CA practices (e.g., Mazvimavi and Twomlow, 2009; Arslan et al., 2014; Grabowski et al., 2016; Ngoma et al., 2015). In their review and synthesis of 31 such studies, Knowler and Bradshaw (2007) identified a plethora of variables that significantly affect adoption of CA, but noted that there are only a few variables that universally explain adoption across the various studies. Another strand includes more recent studies that analyse the implications of adoption of CA practices for crop productivity and household welfare (e.g., Nkala et al., 2011; Ngoma et al., 2015; Abdulai, 2016; Tsegaye et al., 2016; Mango et al., 2017; Ng'ombe et al., 2017). The findings have been relatively inconsistent across studies. For example, Nkala et al. (2011) found that CA technology adoption is significantly associated with higher crop productivity but not with household income and food security in Mozambique, while Abdulai (2016) showed that the adoption of CA technology significantly increases maize productivity and reduces household poverty in Zambia. Here, we contribute to the literature by analysing the impact of CA adoption options on household welfare using data from nine SSA countries. In particular, we aim to address three questions: (1) what factors influence the adoption of CA practices when adopted independently or jointly?; (2) what is the impact of the adoption of CA practices on household income?; and (3) does the adoption of CA practices in combination result in larger income gains than when adopted individually? To address these research questions, we employ the inverse-probability-weighted regression-adjustment (IPWRA) approach, which allows us to attenuate problems of selection bias. Additionally, propensity score matching (PSM) with multiple treatment estimations are conducted as robustness checks.

Our paper differs from previous studies in that we analyse the determinants and impacts of adoption of CA technologies individually and in combination. In order to realise the full benefits of CA, farmers are encouraged to adopt the complete package of minimum soil disturbance, residue retention and crop rotation (FAO, 2017). However, implementation of the full package is often challenging in resource-poor and smallholder environments, hence, partial adoption is very common (Mazvimavi and Twomlow, 2009; Arslan et al., 2014; Pittelkow et al., 2015). Thus, farmers may adopt a single practice or a combination of two practices or the full package. However, previous analyses of the determinants and impacts of CA have often overlooked these different adoption options. Most existing literature has either analysed a single CA practice or has aggregated the three CA practices by defining adopters as farmers who were practicing at least one of the CA principles. These approaches may obscure important information about the combination of CA practices. Recently, Ng'ombe et al. (2017) attempted to address this gap in the CA literature, but they only analysed the impact of CA adoption on crop revenue using data from Zambia. Implementation of the CA principles may result in resource reallocation that may indirectly affect household income, which is a more comprehensive measure of welfare.

The rest of this paper is structured as follows. Section 2 provides an overview of the data and estimation methods. Estimation results are presented and discussed in Section 3, and Section 4 concludes.

## 2. Methods

### 2.1. Data

Our analysis is based on a cross-sectional sample of 3155 smallholder maize-producing households in over 100 villages in nine countries across SSA (see Fig. 1). The study countries include Ghana and Nigeria (West Africa); Ethiopia, Kenya, Tanzania and Uganda (East Africa); and Malawi, Mozambique and Zambia (Southern Africa). The data was collected by the Africa and Intensification (*Afrint II*) project in 2008.[1] The Afrint II project adopted a multistage sampling technique, involving purposive sampling of countries, regions and villages, and random sampling of households. First, countries were purposively selected with respect to their production potential of four important staple food crops in SSA (maize, cassava, rice and sorghum). Regions within countries and then villages within regions were purposively selected based on their agricultural potential and agro-ecological differences. Finally, farm households were randomly drawn from the selected villages. Thus, the sample is not representative of the selected countries but captures a wide range of agro-ecological conditions and smallholder production systems across SSA. The survey focused on agricultural intensification, staple crop production, adoption of production technologies, land resources, commercialisation of major staple crops, institutional conditions, household income, and demographic and socioeconomic characteristics of households. A detailed description of the data and sampling strategy can be found in Djurfeldt et al. (2011).

### 2.2. Empirical Strategy

As already described, CA involves three practices that may be adopted jointly or independently. Thus, adoption of a CA technology

[1] The data is publicly available at the Afrint database: http://www.keg.lu.se/en/research/research-projects/current-research-projects/afrint. Accessed in August 2017.