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REVIEW

Conservation agriculture practices: Adaptation and yield

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Abstract

Conservation agriculture (CA) has been promoted in sub-Saharan Africa (SSA) to increase crop productivity and for climate change adaptation. CA is the simultaneous application of the three principles: no-till, mulch cover, and crop diversification. The potential benefits are largely linked to moisture conservation of crop residues, reduced run-off and erosion, increased infiltration, and reduced evaporative losses. This study uses a review of recent literature in SSA under rain-fed conditions to synthesize evidence of the effect of CA on yield and climate change adaptation. Web of Science and Google Scholar were used for literature searches. Crop productivity results in the literature suggest that CA increases yield in certain circumstances such as well-drained soils and moderate rainfall, and that poorly drained soils in combination with excessive rains lead to depressed yields. The yield benefits reported range from as low as 4% and as high as 16%, with negative effects also reported. Stability analysis used as a proxy for adaptation revealed only a marginal benefit of CA above conventional practices suggesting the significant effect of seasonal rainfall on crop productivity. The results suggest the need to target CA practices to different agroecologies and other pragmatic local agronomic practices that may be required in cases of excessive rainfall and extended mid-season dry spells. The benefits of CA reported are largely plot level, and only a few studies consider the whole farm, especially within the holistic livelihood framework. In addition, adoption of CA remains low among smallholder farmers, and the widespread benefits of the practices cannot be realized at multiple scales.

Keywords: sub-Saharan Africa, smallholder farmers, sustainable intensification, yield stability, targeting, adoption

Introduction

Conservation agriculture (CA) has shown great potential to improve crop yields and adaptation to climate change and has been at the centre of scientific inquiry and programming of development organizations for the last 20 years in much of sub-Saharan Africa (SSA). The classic definition of CA is provided by FAO (FAO, 2011) as "*the practical application of context-specific and locally adapted three interlinked principles of (i) minimum mechanical soil disturbance; (ii) permanent maintenance of soil mulch cover and (iii) diversification of cropping system.* The local adaptation component of the definition suggests the existence of a mosaic of CA forms and practices across regions in SSA. This review highlights the different forms of CA and their potential effects on crop productivity and climate change adaptation using data reported in the literature.

The positive benefits of CA are premised on the ability of the system to conserve soil, moisture (Vogel, 1993), and nutrients through the reduction of run-off and soil erosion, by increasing infiltration (Thierfelder and Wall, 2009) and reducing evaporative losses from the soil surface. The illustration of mechanistic relationships of the components of CA are illustrated and summarized in Fig. 1 (Rusinamhodzi *et al*., 2011). In much of SSA, crop production is predominantly rain-fed and most soils are degraded and characterized by multiple nutrient deficiencies (Sanchez, 2002) thus options that conserve water and nutrients are important. The adoption of CA in much of SSA remains low (Pangapanga-Phiri *et al*., 2024) but has been practiced in several forms such as the *Zài* system (Roose *et al*., 1999) in West Africa, planting basins (Rusinamhodzi, 2015), cereal-legume intercropping under no-till, CA with trees – combining CA with agroforestry (Ndoli *et al*., 2018), and the many forms of achieving no-till such as direct seeders, jab planter, dibble sticks, ripper tine and matracas (Sims and Kienzle, 2015).

In addition to moisture retention, the retention of crop residues on the soil surface in CA systems is important for soil health. There is abundant literature to support the hypothesis that CA systems have a positive effect on soil organic carbon, though such results need nuances because of the interplay of several factors including climate, soil type and the baseline SOC content (Page *et al*., 2020; Thapa *et al*., 2023). In an earlier opinion article, Powlson *et al*. (2014) observed that the potential for carbon sequestration in CA systems for mitigation is widely limited. However, new evidence has shown that the potential estimate of annual carbon sequestration in African agricultural soils through CA amounts to 143 Tg of C per year, that is 524 Tg of CO_2 per year (Gonzalez-Sanchez *et al*., 2019). Therefore, CA systems can contribute to improved soil health which can support high productivity and reduce greenhouse gas emissions in some situations.

At the household level, CA has been associated with small machinery and tools that lead to labour savings. However, the

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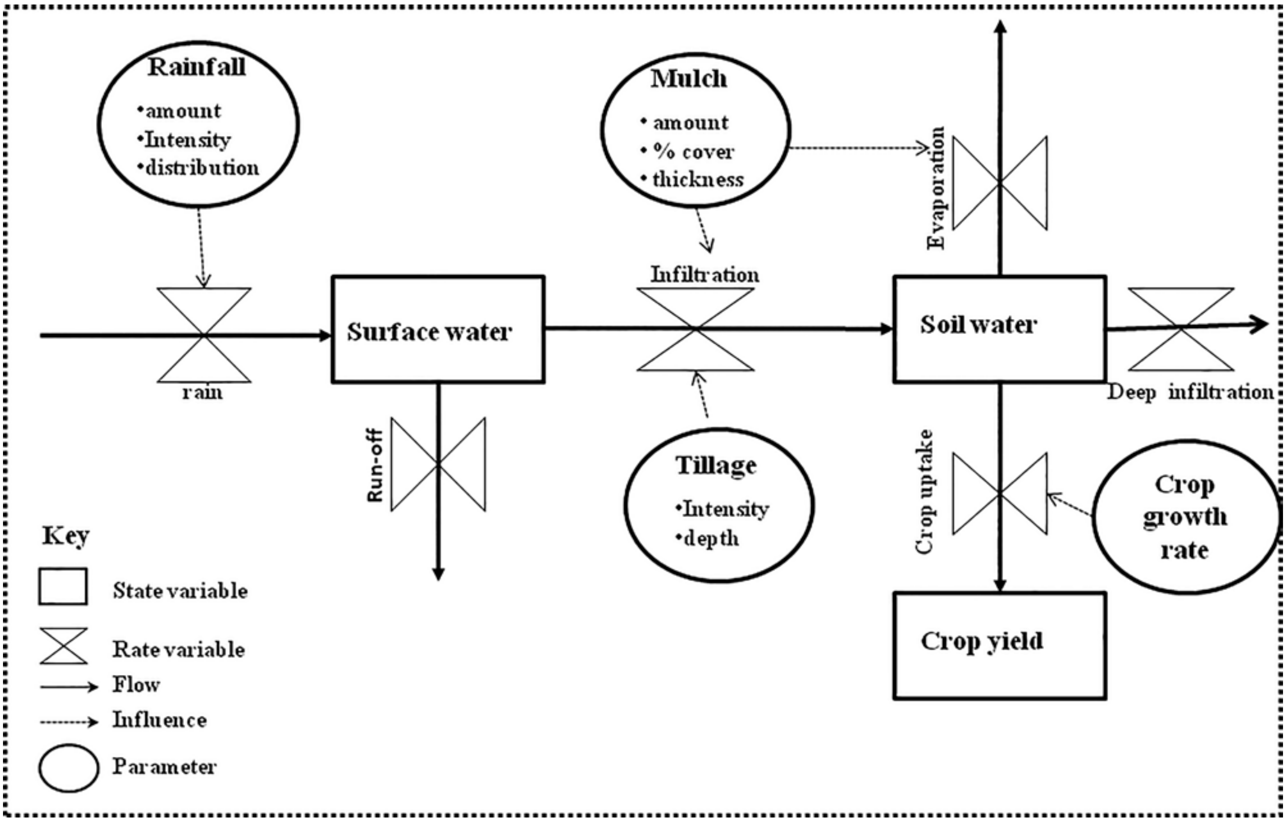

Fig. 1. The major components of conservation agriculture (CA) showing how tillage and mulch management affect infiltration, soil moisture availability, and crop growth (Rusinamhodzi *et al*., 2011).

equipment is purchased at a cost often beyond the reach of most smallholders. In addition, savings in labour are only beneficial if there is an opportunity cost for labour. For example, Bouwman *et al*. (2020) observed that technologies that save labour may inadvertently assist the richer farmers at the expense of the poor because they reduce the opportunity for the poor farmers to earn from the richer by selling their labour– thereby aggravating food insecurity and inequality.

The objective of this review is therefore to synthesize recent literature on CA in SSA focusing on maize productivity, adhering to the strict definition of CA – having all three principles (no-till, mulch cover, rotation or crop mixture). Maize is a major staple food in this region and also a crop of global importance.

Review methodology

The review followed three main steps i.e. (a) framing the question, (b) finding the relevant studies, and (c) summarizing the evidence following the guidelines provided by Khan *et al.* (2003). The main question was whether CA improves crop yield and leads to climate change adaptation. We limited our review to maize production under rain-fed conditions in SSA. The studies were obtained through searches in Scopus, Google Scholar, and Web of Science online search engines and databases. The following search terms and their combinations were used: CA, crop yield, no-till, yield stability, and rain-fed conditions. Studies need to have been published in a refereed journal, book chapter, or peer-reviewed conference proceeding, including all the principles of CA. The summary included highlighting the major findings from relevant papers and nuances.

CA and crop productivity

CA has been shown to increase crop productivity in a larger proportion of the circumstances in which it has been tested. However, the magnitude of the increases and the significance especially at the farm level is frequently contested (Giller *et al*., 2009; Corbeels *et al*., 2020). Early research on CA has been focused on providing evidence of the yield benefit of CA, and there is abundant literature on the effects of CA on crop yields (Marongwe *et al*., 2011; Thierfelder and Wall, 2012; Thierfelder *et al*., 2015; Thierfelder *et al*., 2016). Using a meta-analysis of 933 observations from 16 different countries in SSA studies, average yields under CA were reported to be only 4% higher than conventional with the largest yield increase of 8.4% possible only when all CA principles were practiced under low rainfall and with herbicide use (Corbeels *et al*., 2020).

Similarly, in a synthesis of 7-year multi-locational research trials of CA in southern Africa, Nyagumbo *et al*. (2020) observed that the effects of CA were beneficial mostly under loam textured soils, with well-drained soils yield benefits were 16% higher than conventional but depressed yields by up to 33% on poorly drained soils. However, Mhlanga *et al*. (2022) reported similar positive effects of CA after analyses of two separate 6-year-long component omission experiments comparing CA and conventional agriculture, one on sandy and another on clay soils.

Results in the literature also suggest that the benefits of CA are larger in the longer term than short term. In a study (Ngwira *et al*., 2020) over three seasons in Malawi on the effects of maize-legume intercropping CA and conventional tillage (CT) on crop productivity, significantly more maize yield was recorded in the second and third seasons compared with the first. Additionally, the difference between CA and conventional widened with time. Similar results were reported by Thierfelder and Mhlanga (2022) who concluded that the crop yield benefit under CA is governed by many factors including edaphic, environmental, and agronomy management, and yield benefits of CA become more apparent with time.

CA and climate change adaptation

Manipulation of the G × E × M interactions provides a pathway for climate change adaptation. In CA systems, the use of drought-tolerant crop varieties in combination with mulch cover can potentially offset the negative effects of erratic rainfall. Thierfelder *et al*. (2016) reported that improved drought-tolerant maize varieties performed better than the common varieties by up to 46% under different management, across sites and cropping seasons. In a study of farmers' practices on CA in eastern Zambia, Umar (2021) mentioned the moisture retention capacity of planting basins and early planting as key to climate change adaptation. Similarly, Thierfelder *et al*. (2017) concluded after an elaborate review that the adaptation potential of CA is due to greater infiltration, moisture retention, and early planting. The other pathway for adaptation in CA comes from the aspect of crop diversity or mixtures through intercropping. Intercropping with different species offers an opportunity to harvest the legume in case of failure of the cereal crop component (Rusinamhodzi *et al*., 2012; Thierfelder *et al*., 2024). However, it should be noted that in extreme scenarios of waterlogging and prolonged dry spells negative results have been reported which may necessitate other management decisions. Dry spells of 3–4 weeks are manageable under CA practices (Thierfelder *et al*., 2017).

Stability analysis can also be used to assess how yield in CA varies over time as a form of adaptation. Several factors and their interplay can lead to significant yield variability across years, such as rainfall (onset, amounts, and distribution), temperature, pest and diseases, soil fertility status, and general agronomic management. Rusinamhodzi *et al*. (2011) reported a smaller regression coefficient in sandy soils showing an advantage of mulch-based systems to optimize moisture availability in soils of poor drainage. However, the meta-analysis study was inconclusive on whether CA was maintained over the years largely due to the variability of rainfall in these water-limited environments.

Discussion

The summary of data in the literature suggests that CA has the potential to increase crop productivity and adapt to climate change though the context is important. Targeting is important because moisture conservation is relevant in mildly water-limited environments (dry spell of 3–4 weeks) but may be irrelevant or negative in high rainfall environments (Rusinamhodzi *et al*., 2011). The yield benefits are possible when the complete form of CA is practiced i.e. no-till × soil cover × diversification along with the required good agronomic practices such as weed control, variety choice, right plant population, pests and disease control (Thierfelder *et al*., 2018), and nutrient application (Vanlauwe *et al*., 2014). On smallholder farms with limited options for crop rotations along with the erratic nature of rainfall, intercropping offers an opportunity for improved productivity, human nutrition, and reduction of climatic risk (Rusinamhodzi *et al*., 2012).

The positive benefits of CA such as increased productivity and cost reduction are significant if economies of scale can be used – savings on production costs are due to less tillage operations (Mosquera *et al*., 2019). Much of the reported work on CA is based on intervention projects testing CA options on smaller pieces of the farm using funded inputs. Real adoption on significant portions of the farms remains low, and the benefits remain largely potential benefits or at most plot-level benefits. In some cases, even disadoption has been recorded (Pangapanga-Phiri *et al*., 2024). The reasons for the low adoption are many including acute competition between crop and livestock production for the use of crop residues during the dry season (Rusinamhodzi *et al*., 2015; Rusinamhodzi *et al*., 2016), investment costs for the required equipment, and the knowledge and management intensity needed (Thierfelder *et al*., 2013). Finally, farmers require access to a range of tools and resources to allow them to identify if the principles of CA are likely to be appropriate for their circumstances and well-designed, locally adapted systems to successfully overcome the agronomic, social and economic challenges that can be associated with its use (Page *et al*., 2020)

Despite widespread testing CA for several years in SSA, several knowledge gaps persist and are mostly linked to the scale of analysis. Most data are based on plot-level measurements and expressed per unit area. There is a need for a better understanding of what the positive plot-level results mean for different types of farmers and farming systems. Pragmatic solutions are needed to resolve competition for crop residues as feed or soil cover, especially in mixed crop-livestock systems (Kirkegaard *et al*., 2014; Rusinamhodzi *et al*., 2015). Studies on the complementarity of intercrops (crop x variety choices) are needed as well as how to integrate the doubled-up legume systems under CA systems (Mwila *et al*., 2021).

Conclusion

The potential benefits of CA for improved crop productivity and climate change adaptation exist but adoption of the practices has remained low in much of SSA. Most meta-analyses limit the yield increase to below 20% of conventional agriculture, and large increases are realized under sandy soils and limited moisture. The yield benefits of CA are more significant in the long term than in the short term. Results suggest that there is a need for proper targeting of CA options to farming systems and farm types for significant benefits. The potential benefits of CA are yet to be realized at multiple scales as adoption has remained low, and those farmers who have adopted only practice on small portions of the farms.

CONFLICT OF INTEREST

There is no conflict of interest.

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