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To cite this article: Jonne Rodenburg , Lucie Büchi & Jeremy Hagggar (2020): Adoption by adaptation: moving from Conservation Agriculture to conservation practices, International Journal of Agricultural Sustainability, DOI: [10.1080/14735903.2020.1785734](https://doi.org/10.1080/14735903.2020.1785734)

To link to this article: <https://doi.org/10.1080/14735903.2020.1785734>



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Published online: 01 Jul 2020.



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Adoption by adaptation: moving from Conservation Agriculture to conservation practices

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ABSTRACT

Conservation Agriculture (CA) is a Sustainable Agricultural Intensification strategy based on minimum soil disturbance, permanent soil coverage by living or dead biomass, and diversification of crop rotations. We reviewed the literature on benefits, trade-offs, adoption and adaptation of CA in sub-Saharan Africa (SSA). While CA can improve soils and sustain crop yields, benefits are inconsistent and there are trade-offs with crop residue use, weeds and insect pests, labour demands and short-term yield penalties. Adoption rates by smallholders in sub-Saharan Africa are generally low. We hypothesize that underlying adoption constraints are 1) the magnitude of transformation of management practices required from farmers moving to CA, 2) the multiple inherent trade-offs associated with CA practices and 3) the incompatibility of CA practices to local conditions. We suggest CA adoption in SSA could be improved by focusing the promotion of CA to environments where it best fits, or by facilitating smallholders' adaptation of the practices of CA to respond to their conditions and constraints. We, therefore, propose to move from Conservation Agriculture to Conservation Practices by: (A) identifying and overcoming locally important CA trade-offs through adaptations and complementary practices, and (B) finding farm-specific optimal combinations of practices in terms of feasibility and benefits.

KEYWORDS

No-till; crop diversification; mulching; Africa; agroecology; smallholders; trade-offs

1. Introduction

Conservation agriculture has been defined as an integrated crop and soil management strategy that combines (1) minimum soil disturbance, (2) permanent soil coverage by crops, cover crops or crop residues and (3) diversification of crop rotations (FAO, 2008). Minimum soil disturbance is the most prominent and dominant component of this strategy, and both an enabling component as well as a precondition for crop residue mulching (CRM). Similarly, intensified and diversified cropping (e.g. cover and rotation crops) produces the additional biomass enabling CRM. The literature on CA in sub-Saharan Africa (SSA) distinguishes different crop establishment methods that allow minimum soil disturbance

thereafter; (1) the basin system, where planting pits are established to concentrate water and fertilizer, (2) the ripping or rip-line seeding system, whereby seeding is done in furrows drawn by an animal traction chisel-tine opener, (3) direct seeding whereby seeding is done by a pointed stick, a dibble stick, or a jab-planter, and (4) no-till tied ridging, whereby permanent ridges and furrows are created and ridges are closed every 80–100 cm with perpendicular smaller ridges to conserve rainwater (Thierfelder, Rusinamhodzi, Ngwira, et al., 2015). Here we focus primarily on CA systems based on direct seeding, which is the most frequently studied system and most compatible with the other CA components i.e. crop residue mulching and crop diversification.

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Conservation agriculture has been developed as a putative sustainable way of crop production on degradable or degraded soils, expected to deliver multiple agricultural and environmental benefits (e.g. Kassam et al., 2009). The permanent coverage of the soil by living or dead plant biomass and the reduced soil disturbance minimizes topsoil displacement and may restore soil organic carbon content and benefit soil moisture content and water use efficiency (e.g. Pittelkow, Liang, et al., 2015; Thierfelder, Rusinamhodzi, Ngwira, et al., 2015). Crop diversification, including seasonal crop rotation and the use of legume fodder or food crops as cover crops, can have a range of beneficial effects on pest and disease regulation, soil health, food security and poverty alleviation (e.g. Iversen et al., 2014; Snapp et al., 2010). For the above reasons, CA has been supported and promoted by international donors and 'research for development' organizations as a Sustainable Agricultural Intensification (SAI) solution to smallholder farmers in SSA. The extent to which conservation agriculture is adapted to, and therefore feasible for, smallholder farming systems in sub-Saharan Africa (SSA) has however been debated (Andersson et al., 2014; Giller et al., 2009; Sumberg et al., 2013). The aim of this review is (1) to assess the current status regarding adoption of CA in SSA, (2) to investigate the role of CA trade-offs and the adaptations proposed to address these trade-offs, and based on that, (3) to propose a way forward regarding the promotion and adaptation of CA among smallholders in this region.

2. Literature review

The search terms 'conservation agriculture' and 'Africa' were used to generate a database of scientific papers. This resulted in 432 papers in Web of Science and 264 in Scopus, and 525 unique titles which have been reviewed individually for their relevance. Conference papers, papers only focussing on one of the CA practices and papers primarily focussing on the planting basin or the permanent raised bed system were not considered for this review. This resulted in a selection of 252 relevant papers, 64 of which were review or opinion papers and 188 research papers. Among the research papers, 84 were specifically focussing on adoption, trade-offs and/or adaptation on CA, which is the focus of the current paper. The remaining 104 were primarily dealing with the agroecological or socio-economic assessments of CA, which is summarized in the next section.

The vast majority of the selected studies on CA adoption, trade-offs and/or adaptation focus on East and Southern Africa (Figure 1). The most frequently studied staple crop was maize, followed by sorghum and rice, while cotton was the most important cash crop studied. The selected literature on conservation agriculture in sub-Saharan Africa expresses considerable concern about adoption, while agronomically it mostly focusses on the use of crop residues and methods to achieve minimum soil disturbance, and much less so on the crop diversification component (Figure 2).

3. What are the impacts of Conservation Agriculture?

3.1. Environmental impact

Improvement of soil quality has been observed following residue retention and legume cultivation in maize-based no-till systems in semi-arid and sub-humid environments (e.g. Muzangwa et al., 2019) but such improvement is usually a long-term process (Corbeels et al., 2014; Sithole et al., 2019; Thierfelder, Mwila, et al., 2013; Thierfelder & Wall, 2012). More specifically, CA practices have been reported to positively affect soil microbial biomass nitrogen, mineralizable nitrogen and extractable phosphorus (Njaimwe et al., 2018), soil organic carbon, mineralizable carbon and microbial biomass carbon levels (Ngwira et al., 2012; Sithole et al., 2019), as well as the biological activity of soil beneficial and detrimental microfauna (Brevault et al., 2007). The crop residue management seems to be the most important practice as Okeyo et al. (2016) show that when crop residue was incorporated with tillage, the soil improvement benefits were greater than crop residue mulching with minimum soil disturbance. Minimum soil disturbance alone, on the other hand, resulted in a smaller SOC increase than when CA practices were combined. Another potential environmental benefit of CA practices is that they can increase infiltration (Sithole et al., 2019) and water use efficiency and decrease soil and water losses in agricultural production processes (Nyamadzawo et al., 2012). Under CA practices, soil water storage was (21%) higher than under conventional practices (Liben et al., 2017) and mulching of the soils with crop residues contributes to a large extent to such increases (Mupangwa et al., 2007).

The common claim regarding the potential contributions of CA to climate change mitigation is more debatable. A large-scale assessment on farms in

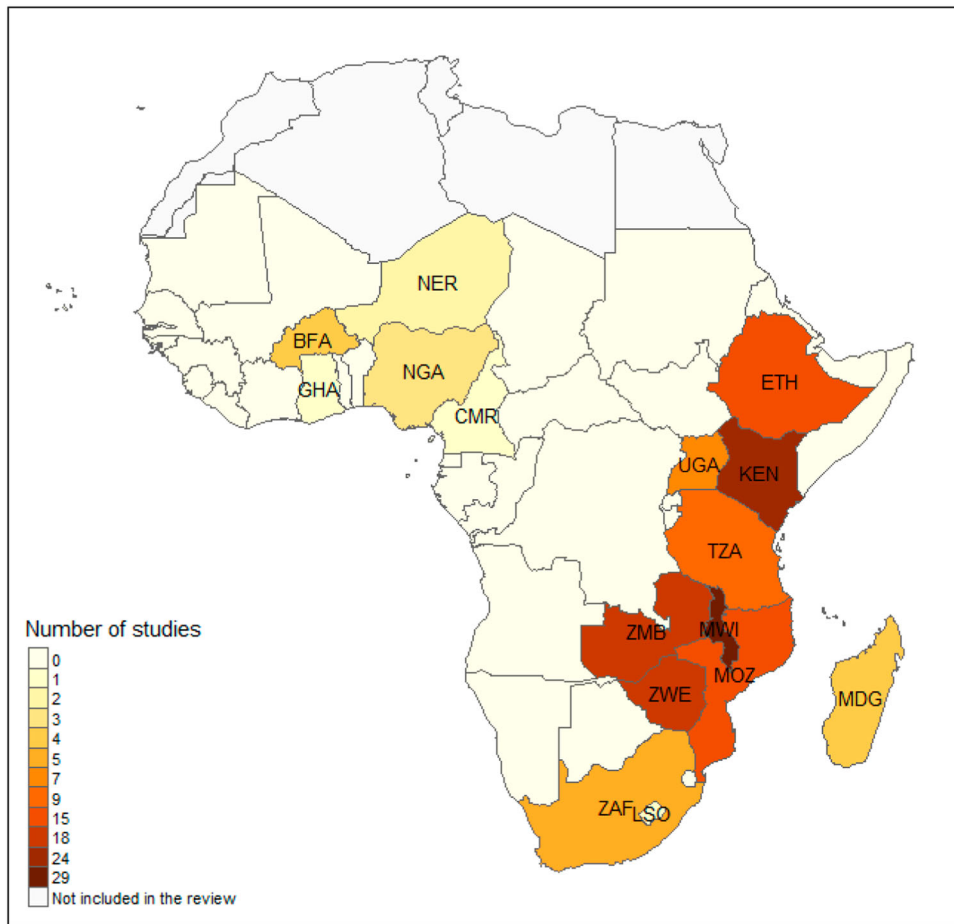


Figure 1. Geographic distribution of the 84 studies on trade-offs, adaptation and adoption of Conservation Agriculture in sub-Saharan Africa.

southern Africa showed that the potential for CA to enhance the carbon stocks in the soil was limited (Cheesman et al., 2016), but a recent meta-analysis on data from sub-Saharan Africa showed that CA can contribute significantly to soil carbon sequestration (Gonzalez-Sanchez et al., 2019), although only when all three CA principles are applied (Corbeels et al., 2019). When compared per unit of grain produced, GHG emissions under CA decreased by a third compared to conventional practices (Kimaro et al., 2016). In fact, the effects of CA on soil carbon sequestration and reduction in GHG emissions are variable because they depend on agroecological environments and the availability of crop residue biomass (Thierfelder et al., 2017).

3.2. Agronomic impact

A global meta-analysis of the impact of the most prominent components of CA (no-till and crop residue

mulching) on yield was conducted by Pittelkow, Linquist, et al. (2015), based on 5,463 paired observations, from 610 studies, 48 crops and 63 countries. This analysis showed that crop yields, while variable across locations and conditions, are generally lower in no-till systems, but when combined with crop residue mulching it may benefit yield in rainfed crop production systems in dry environments. The studies on CA yield effects from sub-Saharan Africa present a similarly variable pattern, both regarding the performance of individual and integrated components. A review of case studies from SSA showed that mulch alone, in both CA and no-till systems, did not contribute to maize yield increases (Mupangwa et al., 2019), while experiments conducted on four discrete sites in the Central Rift Valley in Ethiopia, showed that conventional tillage resulted in higher maize yields than minimum soil disturbance techniques (Sime et al., 2015).

Table 1. Factors enabling or constraining adoption of Conservation Agriculture among smallholders in sub-Saharan Africa, the number of times these are mentioned in the literature (#), whether they positively (+) or negatively (–) impact on adoption and the supporting literature sources.

Factors	# (+/–)	Details
Access to information	12 (+)	Education (Tambo & Mockshell, 2018), extension and education (Brown, Nuberg, et al. 2018a; Kaweesa et al., 2018; Khataza et al., 2018; Kunzekweguta et al., 2017; Ntshangase et al., 2018; Marenja et al., 2017; Tsegaye et al., 2017), access to information (Thierfelder, Mutenje, et al., 2015; Fisher et al., 2018), farmer-to-farmer extension (Bell et al., 2018), information and knowledge (Brown, Llewellyn, et al. 2018b; Thierfelder, Mutenje, et al., 2015)
Market access and institutions	6 (+), 1 (–)*	Institutional support and land tenure (Tambo & Mockshell, 2018), distance to markets (Kunzekweguta et al., 2017), access to markets (Corbeels et al., 2014; Thierfelder, Mutenje, et al., 2015), loans (Dube et al., 2018; Senyolo et al., 2018) and subsidies (Abro et al., 2018; Marenja et al., 2017); * Subsidies may disincentivize adoption (Muzangwa et al., 2017)
Productivity and economic benefits	4 (+), 1 (–)*	Economic benefits (Brown, Llewellyn, et al. 2018a), total crop productivity (Baudron, Titttonell, et al., 2012) determining biomass (Dugue & Bassala, 2015; Pannell et al., 2014); *Local crop preferences may negatively impact adoption (Tsegaye et al., 2017; Umar et al., 2012)
Labour requirements	4 (–)	Labour requirements and management intensity (Dube et al., 2018; Nana et al., 2015; Pannell et al., 2014; Senyolo et al., 2018)
Farm size	4, 2(–), 2(+/–)	Farm size may have mixed effects on adoption (Kunzekweguta et al., 2017; Lalani et al., 2016, 2017; Ntshangase et al., 2018)
Access to production factors	3 (+)	Crop land and farm inputs (Corbeels et al., 2014; Kunzekweguta et al., 2017), multipurpose grain legumes, fertilizer and locally adapted water-conserving tillage methods (Droppelmann et al., 2017).
Experience and experimentation with CA	2 (+), 1 (–)*	(Kunzekweguta et al., 2017; Van Hulst & Posthumus, 2016); *Negatively affects adoption if risks are experienced (Thierfelder, Mutenje, et al., 2015)
Investments in social and human capital	2 (+)	(Marenja et al., 2017; Schaafsma et al., 2018)
Risks and uncertainties	2 (–)	(Pannell et al., 2014; Thierfelder, Mutenje, et al., 2015)
High initial costs	2 (–)	(Dube et al., 2018; Senyolo et al., 2018)
Lack of adaptation or local relevance	1 (–)	(Brown, Nuberg, et al. 2018b)
Livestock availability	1 (+)	(Senyolo et al., 2018)
Ownership of ox-drawn plough	1 (–)	(Kunzekweguta et al., 2017)
Drought	1 (+)	(Khataza et al., 2018)

between CA and conventional systems (Penot et al., 2015), including practices that address their specific production constraints (Penot et al., 2018). CA uptake by farmers in Africa is not only partial in terms of the adopted practices but also in terms of the share of farm area under CA practices. In Zambia for instance, minimum soil disturbance techniques were only implemented on 8% of the land of adopters (Ngoma, 2018) while in Malawi, Ngwira et al. (2014) reported 30% of land of adopters to be under CA.

A wide variety of factors have been suggested as drivers or constraints of adoption of Conservation Agriculture (Table 1). Interestingly, the most frequently mentioned are associated with access to information, markets and enabling institutions. The role of adequate agricultural extension services is perceived as critically important in this respect. Farmers' concerns with respect to increased labour requirements with CA practices also emerges as an important point of concern.

Adoption of CA is however hampered by high demands for labour and fertilizer inputs (Grabowski & Kerr, 2014; Ndlovu et al., 2014). Thus smallholder adoption constraints regarding CA practices, both at farm

(i.e. access to markets, social capital) and country level (i.e. agrochemical input subsidies, quantity/quality of extension services), are no different from those of any other agricultural technology (Marenja et al., 2017). Subsidies may make fertilizer inputs more affordable and thereby contribute to increased adoption, but such solutions are unlikely to be sustainable in the longer term (Ward et al., 2016) and may also indirectly de-incentivize the use of organic soil amendments (Khataza et al., 2017). A high reliance on government grants, rather than direct farm revenues as an income source, may also demotivate smallholders to adopt innovations like CA (Muzangwa et al., 2017).

The effect of farm size and input subsidies on CA adoption seem ambiguous. A study from South Africa showed that farmer adoption of CA is negatively correlated to farm size (Ntshangase et al., 2018), while a study from Zimbabwe showed farm size had a positive effect on CA adoption (Kunzekweguta et al., 2017). Lalani et al. (2017, 2016) found no evidence of an adoption bias towards the better-off and larger scale farms in Mozambique; they actually observed CA to be beneficial for extreme risk-averse poor farmers. This

seems to be confirmed by Brussow et al. (2017) who observed strongest crop income effects from mulching in the group of marginalized farmers and a decrease in this effect with increasing levels of farm output.

Conservation agriculture does not necessarily respond to common biophysical and socio-economic constraints of smallholders in SSA, such as high input prices vs low commodity prices, labour constraints, uncertain land tenure, resource limitations and high overall risks (Baudron, Andersson, et al., 2012; Giller et al., 2009; Pannell et al., 2014; Rosenstock et al., 2014). In addition, the above-mentioned benefits of CA do not necessarily motivate smallholders. First, the gains from CA may not be sufficient to compensate for the required additional costs for herbicides and labour for weed control and land preparation (Ngoma, 2018). Second, individual smallholders need to bear the costs of implementation of CA, whereas some of the benefits (such as improved ecosystem services, carbon sequestration) accrue to higher levels of society (Dallimer et al., 2018). Climate change coping measures are primarily selected by farmers based on their short-term benefits and then only when they are also compatible with local ecological, social, institutional and customary settings (Callo-Concha, 2018). A study by Brown et al. (2017) shows that an important constraint towards adoption of CA practices concerns farmers' perceived low feasibility in combination with uncertainty regarding the relevance and benefits of these practices. An example is the management of crop residues. Farmers have firm convictions about the usefulness of burning crop residues in some areas in SSA (Ngwira, Thierfelder, & Lambert, 2013), for pest control and soil fertility reasons, and it would require an important shift in farmer's mindset to change that to favour longer-term and higher-level benefits such as carbon sequestration.

5. What are the trade-offs and challenges of Conservation Agriculture and how can they be addressed?

The major challenge associated with the need for integration of multiple practices, as suggested by the Conservation Agriculture paradigm and supported by recent literature, is that it necessitates a major transformation of the established farming practices, which is not always a realistic requirement for smallholder farmers (Giller et al., 2009). Such changes embody uncertainties, which in the

absence of production surpluses or safety-nets increase the risk for farmers' livelihoods in the short-term. In addition, constraints to implementation and hence uptake of CA are imposed by trade-offs, as identified by Giller et al. (2009). Subsequent research has improved our understanding around four of these trade-offs: (1) crop residue use, (2) pest management, subdivided in weed and insect pests, (3) labour, and (4) short term yield penalties. While the number of studies confirming these trade-offs outnumber the ones that propose solutions to them (Table 2), there seems to be a growing awareness that trade-offs need to be addressed, through cropping strategy adaptations, in order to increase the likelihood of uptake of CA.

5.1. Crop residue use

The main trade-off concerns the use of crop residue biomass, which can either be used for mulching, as proposed under CA guidelines or fodder for livestock (Baudron, Delmotte, et al., 2015; Corbeels et al., 2014; Dugue et al., 2015; Naudin et al., 2015; Ndah et al., 2014; Rodriguez et al., 2017; Rusinamhodzi et al., 2015; Valbuena et al., 2012) or other uses, such as fuel (Valbuena et al., 2012) or fencing (Hove & Gweme, 2018).

For farmers that keep livestock, it is not feasible to retain all crop residues as mulch in their field

Table 2. Studies from SSA confirming or addressing the main trade-offs identified.

Main trade-offs	Confirmation	Solution
Crop residue use	(Corbeels et al., 2014; Dugue & Bassala, 2015; Hove & Gweme, 2018; Ndah et al., 2014; Rodriguez et al., 2017; Valbuena et al., 2012)	(Baudron et al., 2014; Jaleta et al., 2013; Lahmar et al., 2012; Naudin et al., 2015)
Weeds	(Camara et al., 2018; Mashingaidze et al., 2012; Thierfelder, Bunderson, et al., 2016)	(Muoni et al., 2013; Odhiambo et al., 2015)
Insect pests	(Mutsamba et al., 2016; Nyagumbo et al., 2015; Rafarasoia et al., 2016)	
Labour	(Hove & Gweme, 2018; Nana et al., 2015; Umar et al., 2012)	(Morrison, 2006; Sims et al., 2012)
Short-term yield penalty	(Bruelle et al., 2015; Droppelmann et al., 2017; Masvaya et al., 2017; Thierfelder, Matemba-Mutasa, et al., 2015)	

(Baudron, Delmotte, et al., 2015) and this trade-off is reflected in CA adoption estimates (e.g. Ndah et al., 2014). At least in the short term, it is economically more attractive to use crop residues for livestock feeding than for soil management purposes (Rusinamhodzi et al., 2015).

CA is however also considered by some to be an opportunity for mixed farms as it promotes the production of fodder crops (Mupangwa & Thierfelder, 2014), but it obviously still depends on the amount of biomass that can be produced. The level of biomass production depends highly on the productivity potential set by the local environment and the input levels that a particular farmer can apply. A study from Zimbabwe showed that the trade-off between crop residue for feed or mulch can be reduced by using a prolific biomass producing species, in this case mucuna, as a rotation crop (Tui et al., 2015). *Stylosanthes* spp. could be an alternative cover crop that produces high amounts of biomass (Rodenburg et al., 2020). Other solutions to reduce this trade-off are identifying alternative feed stocks (Jaleta et al., 2013; Valbuena et al., 2012), producing more maize biomass as feed, and introducing small-scale mechanization to further reduce the dependency on animals for traction (Baudron et al., 2014). The critical level of crop residue retention to secure the benefits and minimize the negative trade-offs thus needs to be studied for each soil and climatic environment (Paul et al., 2013).

5.2. Pest management

The most important pest management trade-off of CA is weed infestation (e.g. Camara et al., 2018; Giller et al., 2009; Lee & Thierfelder, 2017). Soils that are not tilled seasonally are prone to higher infestations of weeds, in particular perennials (Vogel, 1994). The reduced pre-season weed control of no-till systems necessitates complementary weeding during the growing season and this imposes an additional burden on available family labour in smallholder systems (Giller et al., 2009; Mashingaidze et al., 2012). Reports on changes in weed infestation between conventional tillage and minimum soil disturbance practices are however contradicting. For instance, a study from Zimbabwe observed little or no difference in weed abundance between conventional and no-till/mulch systems (Mandumbu et al., 2012). The reduced weed control resulting from minimum soil disturbance may be compensated by mulching (Sime et al., 2015), provided the mulch

sufficiently covers the soil (Giller et al., 2009; Ranaivoson et al., 2019; Randrianjafizanaka et al., 2018). An alternative is the use of herbicides (Odhiambo et al., 2015) or the combined use of mulching and herbicides. This combination has been shown to contribute to a decline in some of the dominant weed species (Odhiambo et al., 2015), overall weed density (Muoni et al., 2013) or the weed seed bank (Muoni et al., 2014). While the use of agrochemicals may counter CA-related pest problems, this may trade-off with environmental and human health (Ifejika Speranza, 2013) as well as with biodiversity. The dysfunctional pesticide markets and agricultural advisory systems in rural parts of SSA (Rodenburg et al., 2019) do also not currently provide the necessary enabling environment for safe use of agrochemicals.

Other pest management trade-offs are associated with reduced tillage and crop residue mulching attracting detrimental insects. Mulching may benefit common crop pests such as black beetles (*Heteronychus* spp. Coleoptera: Dynastidae) (Rafaraso et al., 2016) and increase termite prevalence, that subsequently damage crops (Mutsamba et al., 2016). Some of these limitations may be addressed by pest management measures or the use of resistant crop varieties.

5.3. Labour

A proposed benefit of CA is that labour demand may be decreased by shifting from conventional, seasonal tillage to practices that aim for minimum soil disturbance (e.g. Baudron, Thierfelder, et al., 2015). However, for smallholders in SSA this is often not true (Chinseu et al., 2019; Ndlovu et al., 2014; Umar et al., 2012). The labour savings obtained from not tilling the soil prior to crop establishment are often cancelled out by increased demands during later stages in the cropping season. Crop establishment may be complicated by the lack of a seedbed and the presence of crop residues, while harvesting a crop may become more laborious due to the presence of a companion crop. A modelling study focussing on farming systems in Burkina Faso, conducted to investigate the scope for CA, indeed showed that benefits of CA (e.g. diversified food, fodder and income sources) trade-off with increased labour inputs for sowing, weeding and harvesting (Nana et al., 2015). Hove and Gweme (2018) observed that such labour trade-offs can be an important reason for farmers in Zimbabwe not to adopt CA.

5.4. Short-term yield penalty

One important trade-off that potentially hampers adoption is the likelihood of a short-term yield penalty (Bruelle et al., 2015; Droppelmann et al., 2017; Masvaya et al., 2017; Thierfelder, Matemba-Mutasa, et al., 2015). While immediate benefits from CA practices, such as soil conservation, are evident (Rodenburg et al., 2020), consistent yield benefits are often only obtained after several years of implementation (Giller et al., 2009). Smallholders who need to decide whether a change of cropping practice would be a beneficial and wise decision to take may be discouraged by reduced yields in the first years following a change from conventional to conservation agriculture. Again, the production environment and agroecological conditions determine the performance of CA practices (Thierfelder, Matemba-Mutasa, et al., 2016) and the extent and direction of trade-offs around production, profits and soils (Rodriguez et al., 2017; Snapp et al., 2018).

6. What is the way forward for Conservation Agriculture?

6.1. Recognizing and capitalizing the concept of partial and stepwise adoption

Recognizing that CA adoption is often partial, Thierfelder, Mombearara, et al. (2013) proposed a gradually expanding area under CA practices, as a realistic out-scaling strategy for smallholder maize farmers in SSA. As farmers adopt strategies like CA most often through a process of adaptation of the techniques to their specific needs and (resource) constraints (Dugue et al., 2015), adoption and adaptation are intertwined processes. Adoption of one CA principle can be viewed as an entry point to full adoption (Ndah et al., 2018), as part of a stepwise process. Such a pathway to adoption is schematically represented in Figure 3. The choices farmers make with respect to adoption of individual elements of innovation are based on various criteria and represent a putative compromise between (perceived) feasibility and profitability. Therefore, such partial adoption should be regarded as adaptation of CA to local conditions, needs and challenges. Ikazaki et al. (2018) showed that not all three main CA principles are always needed to achieve a certain outcome (for instance soil conservation) and a reduced number of CA practices could be equally or more beneficial to

smallholder farmers as the complete package. Therefore, in SSA, CA adoption, should not be considered in terms of a fixed technology package (Droppelmann et al., 2017; Ndah et al., 2018) but as a set of optional practices that can be adopted and adapted according to the local smallholder farming context (e.g. Descheemaeker et al., 2019; Droppelmann et al., 2017; Tessema et al., 2015; Thierfelder, Mutenje, et al., 2015; Thierfelder, Rusinamhodzi, et al., 2015).

6.2. Focusing the promotion of CA to environments where it best fits

It has been shown that in some cases the local conditions may limit the expected benefits of CA (Masvaya et al., 2017), and under such conditions CA may not be the most appropriate practice. Indeed, there is increased awareness among scholars working on Conservation Agriculture that the relevance of this crop production and soil management system depends on the local conditions and constraints (e.g. Liben et al., 2018; Mupangwa et al., 2017). Ideally CA promotion should be targeted to areas with conditions likely to be suitable for adoption (Tessema et al., 2015). Attempts have been made to profile and identify potentially suitable areas for CA in sub-Saharan Africa, for better targeted promotion (Tesfaye et al., 2015). While it is difficult to make generalizations regarding pedoclimatic conditions, some studies have indicated under which conditions CA would likely not result in benefits compared to conventional practices.

The soil texture is an important determinant with respect to CA effects on soil organic carbon. CA carbon sequestration was shown to be higher on clay than on sandy soils (Swanepoel et al., 2018). Chivenge et al. (2007) found that on clay/loam soils, SOC decomposition rate could be decreased by minimum soil disturbance practices (i.e. mulch-, clean- or tied-ripping), whereas on sandy soils, the crop residue retention (mulch) was a crucially important factor for improving SOC. Soil fertility determines the outcome of CA as well. A study in central Kenya found that only on soils of intermediate fertility minimum soil disturbance and crop residue retention increase maize yields; on the richer and poorer soils conventional practices (i.e. regular tillage and crop residue removal) were superior (Guto et al., 2012). Climate factors also have an effect. A meta-analysis showed that CA increase crop yields in drier climate zones (Pittelkow, Liang, et al., 2015). The complication is that the

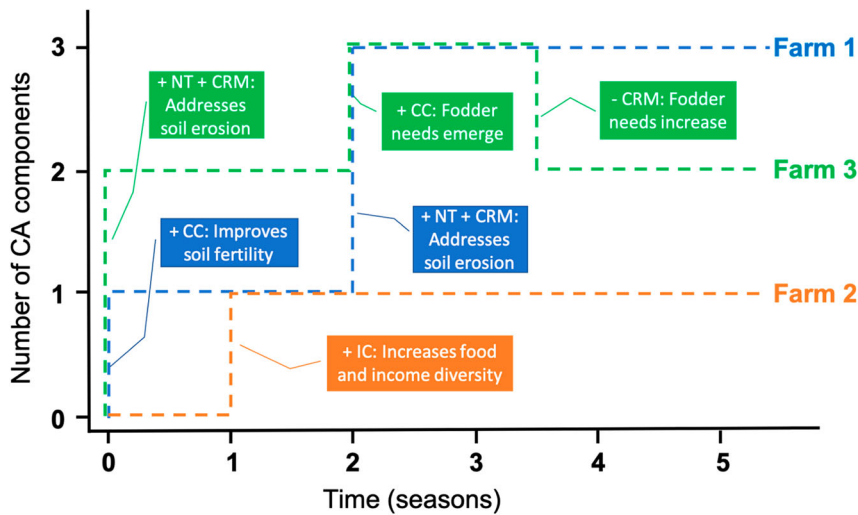


Figure 3. Examples of stepwise and farm-specific adoption and disadoption scenarios of Conservation Agriculture (CA) by smallholders in sub-Saharan Africa over time. Farm 1 (blue line): starts growing cover crops (CC) to improve soil fertility, and two seasons later add no-till (NT) and crop residue mulching (CRM) for soil conservation purposes; Farm 2 (orange line): just adopts one component, e.g. intercropping (IC) to increase food and income diversity; Farm 3 (green line): adopts two components, e.g. no-till (NT) and crop residue mulching (CRM), to reduce soil erosion and add cover crops as a third component two seasons later when fodder needs emerge because of the purchase of cattle, and later decide to drop the practice of crop residue mulching when fodder needs further increase.

above edaphic and climatic factors interact. For instance, other meta-analyses have shown that on soils with a high clay content combined with high rainfall regimes, the risks of waterlogging may be increased by no-till and mulching practices, resulting in lower yields (Steward et al., 2018), whereas on sandy soils under semi-arid conditions, these practices may not provide better crop performance than conventional practices due to the low water storage capacity (Rusinamhodzi et al., 2011).

Because of the locally specific interactions between soil, climate and management, adapting the promotion of CA to the niche environments where it best fits or where positive outcomes are most likely to appear may be a laudable but complicated approach. On top of the pedoclimatic conditions, an ‘enabling environment’ for CA is shaped by conducive institutions and innovation systems (e.g. Brown, Llewellyn, et al., 2018a; Orr, 2018; Thierfelder et al., 2018). Local capacity building and access to affordable and effective machinery and implements are seen as important enablers of CA in Africa (Thornton et al., 2018). The adoption potential of CA in sub-Saharan Africa is estimated to be substantial, but this can only be fulfilled when output and input markets improve (Corbeels et al., 2014), adapted CA technologies like machinery and seeds are developed and made available and when CA is supported by motivated service providers (Ndah et al., 2015).

6.3. Facilitating smallholders’ adaptation of CA practices to respond to local circumstances

A complementary approach would be to adapt CA practices themselves to the locally prevailing biophysical, socio-economic, cultural and institutional conditions. Following earlier suggestions (e.g. Descheemaeker et al., 2019; Giller et al., 2015; Ndah et al., 2018), for effective adaptation we propose to move from Conservation Agriculture being a fixed set of three components to Conservation Practices, as a basket of options inspired by CA. The would be implemented by: (A) identifying locally important trade-offs associated with CA and adaptations or complementary practices that help overcoming them, and then (B) identifying which combination of practices comprises a farm-specific optimal solution in terms of their complexity and feasibility and of their agroecosystem benefits.

A. Identifying Conservation Agriculture adaptations and complementary practices

It is often observed that farmers only adopt just one or two of the CA components and their choices and adaptations are not consistent among farmers (Andersson & D’Souza, 2014; Pedzisa et al., 2015). Presumably, every additional component implies an

added adoption threshold for the farmer and also the more components a farmer needs to adopt, the more trade-offs they may encounter. This may discourage the adoption of multiple components. On the other hand, CA adoption decisions are interrelated. For example, the use of crop residue mulching benefits from the additional biomass produced by a legume crop and introduces an incentive for the adoption of minimum soil disturbance practices (Ward et al., 2018). In the reality of smallholder agriculture, farmers may judge that sometimes different practices complement each other and sometimes they counteract each other (Ward et al., 2016). The preference for individual CA components and combinations of components differ across locations. For instance, in Malawi (Holden et al., 2018) and Madagascar (Penot et al., 2015), the highest adoption potential was observed for crop rotation, as farmers often continued to till their soils. In Zimbabwe, mulching seems to be the least popular of the CA practices (Cheesman et al., 2017; Kunzekweguta et al., 2017), while in Tanzania mulching was the most popular (Brussow et al., 2017).

Conservation Agriculture practices themselves could also be adapted and redesigned to match local conditions both in terms of the bio-physical and the socio-economic and cultural environment (e.g. Corbeels et al., 2014; Serraj & Siddique, 2012; Thierfelder et al., 2018), and this requires a thorough understanding of the local constraints and opportunities as well as the strengths and weaknesses of CA (Ndah et al., 2014). As shown before, the benefits of CA are highly context-specific and therefore CA practices need to be matched to the contextual reality of farmers (Brown et al., 2019; Thierfelder, Matemba-Mutasa, et al., 2015). It would require farmer participation in research and extension systems to permit a flexible and transitional promotion of CA by enabling farmers to test and adapt its components. Such adaptive management through the participation of farmers, researchers or extension services has been recommended for other complex cropping systems with long-term outcomes such as agroforestry (Brown et al., 2019; Haggard et al., 2001) and the System of Rice Intensification (Krupnik et al., 2012). A concrete example of CA adaptation is the move from no-till to different techniques of reduced tillage, such as shallow tillage or strip tillage. Other adaptations may be to add components, such as the judicious use of mineral fertilizers and other agrochemical inputs, improved varieties and small-scale

mechanization, but also the use of planting pits and the integration of livestock or farm trees, may be introduced.

Appropriately scaled mechanization, for instance, to slash and roll crop residues or for ripping the soil to allow sowing, could make CA feasible on a larger scale or entire farms rather than parts of the farm only (Thierfelder et al., 2018). However, many (smallholder) farmers are still facing limited access to such technologies (Baudron et al., 2019). Increasing adoption of CA would require the development of minimum tillage technologies that match a broader range of farmer types (Grabowski et al., 2016). Mechanization within CA systems would offer farmers flexibility regarding planting times (Nyagumbo et al., 2017). Small power sources such as two-wheel tractors are deemed to be compatible for CA systems (Morrison, 2006; Sims et al., 2012) and involvement of the private sector in the combined promotion of CA and adapted mechanization to smallholder farmers is proposed as a viable model in East and Southern Africa (Baudron, Sims, et al., 2015). The use of complementary agrochemicals, such as fertilizers and herbicides, is already observed among smallholders practising CA in Zambia (Westengen et al., 2018) and Kenya (Odhiambo et al., 2015). Mineral fertilizers and herbicides have been seen as important enablers of CA in Africa as they alleviate some of the important aforementioned trade-offs and challenges. Fertilizers can be a pivotal input to make CA viable, as shown by Tui et al. (2015) in Zimbabwe and further supported by Vanlauwe et al. (2014). However, the costs of these inputs form adoption barriers to farmers, while non-chemical alternatives seem to be suboptimal or not yet well adapted to CA (Thierfelder et al., 2018). Masvaya et al. (2018) investigated the best combination of sowing time, tillage, fertilizer and mulch practices for maize under semi-arid conditions in southern Africa. They found that for early planting a combination of reduced tillage, mulch and N-fertilizer reduced the risk of crop failure. CA combined with drought-tolerant varieties can constitute an effective climate change adaptation strategy in terms of crop yield (Setimela et al., 2018; Thierfelder, Rusinamhodzi, et al., 2016). Randrianjafizanaka et al. (2018), showed synergies between CA and Striga-resistant rice varieties in the control of *Striga asiatica*. When trees are integrated in CA, farm output can be further diversified and more biomass could be produced, although this may come at the expense of annual crop yields under certain conditions. Where

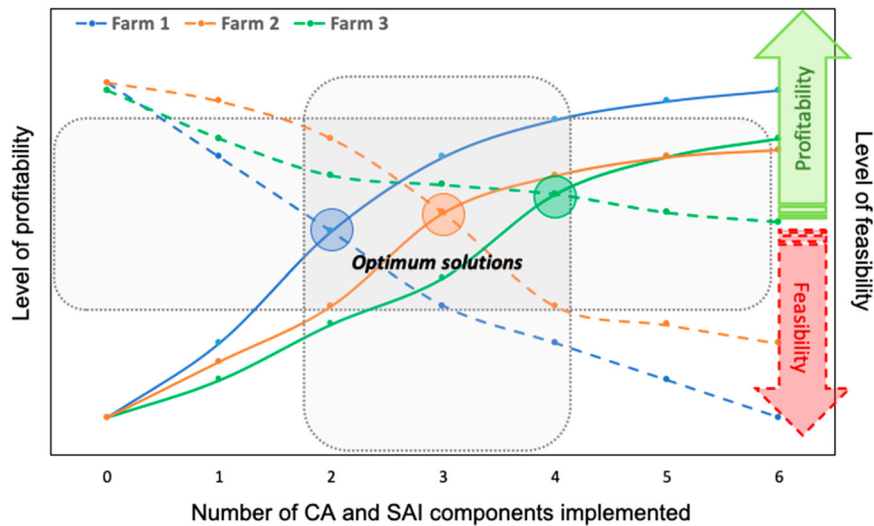


Figure 4. A theoretical representation of increasing profitability and decreasing feasibility with implementation of an increasing number of CA and other SAI components for different farms (colours blue, orange, green). Profitability is expressed in terms of agroecosystem outputs (continuous lines) and feasibility in terms of implementation by farmers (dashed lines). The overlap in shaded areas indicates the optimum profitability within feasible reach of the smallholder farmer.

and how trees may benefit smallholder farmers practicing CA, needs to be investigated (Ndoli et al., 2018).

B. Identifying and using farm-specific optimal solutions

The best number and composition of the above-mentioned Conservation Practices may vary according to the local requirements, and practices may be further adjusted to meet local conditions or overcome trade-offs. As previously shown with SRI in Senegal (Krupnik et al., 2012), such a redesign of CA would follow farmer-participatory identification of feasible solutions to smallholder farming constraints, operationalizing farm household diversity (Descheemaeker et al., 2019; Michalscheck et al., 2018), as well as determining acceptable degrees of cropping system complexity. The aim is to improve agronomic, economic, ecological and environmental returns or services (i.e. *agroecosystem outputs*) of smallholders' production systems in the most feasible and profitable way, given their social-, economic-, ecological- and physical- production environment. This may involve long-term and iterative experiments, resulting in farm-specific strategies whereby an optimal solution is found between the input required (or the number of components adopted) and the benefits reaped from them, hence between the feasibility and the profitability. A theoretical representation of this idea is provided

in Figure 4, where the overlap between the shaded areas comprises the number of component technologies representing the best compromise between feasibility and profitability.

When components of CA are combined, they tend to generate higher positive effects than when they are adopted alone (e.g. Tambo & Mockshell, 2018) and the additional combination of breeding and natural resource management technologies may create further synergies (Wainaina et al., 2018). To reach such synergies would necessitate the encouragement of farmers to test multiple components in an integrated way, with the farmer as the ultimate decision-maker in deciding which components works best in their environment. One major complication when it comes to promotion and adoption of CA in general and the above approach in particular is that many of the benefits may only become apparent on the long-term, while there is a lack of immediate income gains from CA (Corbeels et al., 2014). But we believe that this complication can also be addressed by the above stepwise approach, provided that involved stakeholders, including governments and donor agencies, embrace a long-term investment plan.

7. Conclusions

Conservation Agriculture (CA) is one of the Sustainable Agricultural Intensification (SAI) strategies that is widely

supported by international 'research for development' organizations and donor agencies to achieve sustainable agricultural development in sub-Saharan Africa. CA practices are interrelated and mutually enabling one another but also have specific trade-offs. Conservation Agriculture as a fixed package is often not adapted to the biophysical and socio-economic, cultural and institutional conditions of smallholder farms in SSA. Adoption rates of CA among smallholder farmers across SSA are therefore low, in particular when only adoption of the 'complete package' of CA is considered. Improving adoption rates would require for CA *promotion* to be better targeted, i.e. to the environments where these practices likely fit best and deliver most. Simultaneously or alternatively, it would require CA *practices* to be adapted in order to overcome trade-offs and to adjust CA to locally prevailing conditions, through a farmer-participatory process. This requires moving from Conservation Agriculture, as a fixed package of three components, to *Conservation Practices*, encompassing a basket of options for sustainable agricultural intensification.

The leading rationale of this is that, rather than promoting CA as a fixed and therefore rigid package, farmers should be exposed to a wider range of practices to enable them to consider and test them individually or combined on their own farm. Stepwise, on-farm experimentation should provide farmers with the required experiences and insights to develop the best production strategy within their own farming system. Future research and development endeavours should focus on CA adaptations that help overcoming trade-offs and adjusting the strategy to locally prevailing conditions. We believe that this will contribute to realizing the potential CA and other SAI strategies hold to sustainably intensify agriculture and improve livelihoods of smallholders in sub-Saharan Africa.

Acknowledgements

This work is an output of the Sustainable Intensification Research and Learning in Africa (SAIRLA) programme supported by the UK Department for International Development, UK Government Development (DFID).

Disclosure statement

No potential conflict of interest was reported by the author(s).

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References

- Abro, Z. A., Jaleta, M., & Teklewold, H. (2018). Does Intensive tillage enhance productivity and reduce risk Exposure? PanelData evidence from smallholders'. *Journal of Agricultural Economics*, 69 (3), 756–776. <https://doi.org/10.1111/1477-9552.12262>
- Andersson, J. A., & D'Souza, S. (2014). From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in Southern Africa. *Agriculture, Ecosystems and Environment*, 187, 116–132. <https://doi.org/10.1016/j.agee.2013.08.008>
- Andersson, J. A., Giller, K. E., Sumberg, J., & Thompson, J. (2014). Comment on "evaluating conservation agriculture for small-scale farmers in Sub-Saharan Africa and South Asia". *Agriculture, Ecosystems and Environment*, 187(2014), 1–10. *Agriculture Ecosystems & Environment* 196:21–3. <https://doi.org/10.1016/j.agee.2014.06.016>
- Baudron, F., Andersson, J. A., Corbeels, M., & Giller, K. E. (2012). Failing to yield? Ploughs, conservation agriculture and the problem of agricultural intensification: An example from the Zambezi Valley, Zimbabwe. *Journal of Development Studies*, 48(3), 393–412. <https://doi.org/10.1080/00220388.2011.587509>
- Baudron, F., Delmotte, S., Corbeels, M., Herrera, J. M., & Tittone, P. (2015). Multi-scale trade-off analysis of cereal residue use for livestock feeding vs. soil mulching in the Mid-Zambezi Valley, Zimbabwe. *Agricultural Systems*, 134, 97–106. <https://doi.org/10.1016/j.agry.2014.03.002>

- Baudron, F., Jaleta, M., Okitoi, O., & Tegegn, A. (2014). Conservation agriculture in African mixed crop-livestock systems: Expanding the niche. *Agriculture Ecosystems & Environment*, 187, 171–182. <https://doi.org/10.1016/j.agee.2013.08.020>
- Baudron, F., Misiko, M., Getnet, B., Nazare, R., Sariah, J., & Kaumbutho, P. (2019). A farm-level assessment of labor and mechanization in eastern and Southern Africa. *Agronomy for Sustainable Development*, 39(2), 2. <https://doi.org/10.1007/s13593-019-0563-5>
- Baudron, F., Sims, B., Justice, S., Kahan, D. G., Rose, R., Mkomwa, S., Kaumbutho, P., Sariah, J., Nazare, R., Moges, G., & Gérard, B. (2015). Re-examining appropriate mechanization in eastern and Southern Africa: Two-wheel tractors, conservation agriculture, and private sector involvement. *Food Security*, 7(4), 889–904. <https://doi.org/10.1007/s12571-015-0476-3>
- Baudron, F., Thierfelder, C., Nyagumbo, I., & Gerard, B. (2015). Where to target conservation agriculture for African smallholders? How to overcome challenges associated with its implementation? Experience from eastern and Southern Africa. *Environments*, 2(3), 338–357. <https://doi.org/10.3390/environments2030338>
- Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., & Giller, K. E. (2012). Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. *Field Crops Research*, 132, 117–128. <https://doi.org/10.1016/j.fcr.2011.09.008>
- Bell, A. R., Cheek, J. Z., Mataya, F., & Ward, P. S. (2018). Do as they did: Peer effects explain adoption of conservation agriculture in Malawi. *Water*, 10(1), <https://doi.org/10.3390/w10010051>
- Brevault, T., Bikay, S., Maldes, J. M., & Naudin, K. (2007). Impact of a no-till with mulch soil management strategy on soil macrofauna communities in a cotton cropping system. *Soil and Tillage Research*, 97(2), 140–149. <https://doi.org/10.1016/j.still.2007.09.006>
- Brown, B., Llewellyn, R., & Nuberg, I. (2018a). Global learnings to inform the local adaptation of conservation agriculture in eastern and Southern Africa. *Global Food Security*, 17, 213–220. <https://doi.org/10.1016/j.gfs.2017.10.002>
- Brown, B., Llewellyn, R., & Nuberg, I. (2018b). Why do information gaps persist in African smallholder agriculture? Perspectives from farmers lacking exposure to conservation agriculture. *The Journal of Agricultural Education and Extension*, 24(2), 191–208. <https://doi.org/10.1080/1389224x.2018.1429283>
- Brown, B., Nuberg, I., & Llewellyn, R. (2017). Negative evaluation of conservation agriculture: Perspectives from African smallholder farmers. *International Journal of Agricultural Sustainability*, 15(4), 467–481. <https://doi.org/10.1080/14735903.2017.1336051>
- Brown, B., Nuberg, I., & Llewellyn, R. (2018a). Constraints to the utilisation of conservation agriculture in Africa as perceived by agricultural extension service providers. *Land Use Policy*, 73, 331–340. <https://doi.org/10.1016/j.landusepol.2018.02.009>
- Brown, B., Nuberg, I., & Llewellyn, R. (2018b). Further participatory adaptation is required for community leaders to champion conservation agriculture in Africa. *International Journal of Agricultural Sustainability*, 16(3), 286–296. <https://doi.org/10.1080/14735903.2018.1472410>
- Brown, B., Nuberg, I., & Llewellyn, R. (2019). From interest to implementation: Exploring farmer progression of conservation agriculture in eastern and Southern Africa. *Environment, Development and Sustainability*, <https://doi.org/10.1007/s10668-019-00340-5>
- Bruelle, G., Naudin, K., Scopel, E., Domas, R., Rabeharisoa, L., & Tittonell, P. (2015). Short- to mid-term impact of conservation agriculture on yield variability of upland rice: Evidence from farmer's fields in Madagascar. *Experimental Agriculture*, 51(1), 66–84. <https://doi.org/10.1017/s0014479714000155>
- Brussow, K., Fasse, A., & Grote, U. (2017). Is sustainable intensification pro-poor? Evidence from small-scale farmers in rural Tanzania. *Resources*, 6(3), <https://doi.org/10.3390/resources6030047>
- Callo-Concha, D. (2018). Farmer perceptions and climate change adaptation in the West Africa Sudan Savannah: Reality Check in Dassari, Benin, and Dano, Burkina Faso. *Climate*, 6(2), 44. <https://doi.org/10.3390/cli6020044>
- Camara, A., Dieng, A., Diaw, M. T., Mergeai, G., & Bindelle, J. (2018). Effect of management practices for *Stylosanthes hamata* (L.) Taub. Biomass cover on the weed species in different direct-seeding, mulch-based cropping systems. *Weed Biology and Management*, 18(4), 184–196. <https://doi.org/10.1111/wbm.12158>
- Cheesman, S., Andersson, J. A., & Frossard, E. (2017). Does closing knowledge gaps close yield gaps? On-farm conservation agriculture trials and adoption dynamics in three smallholder farming areas in Zimbabwe. *The Journal of Agricultural Science*, 155(1), 81–100. <https://doi.org/10.1017/s0021859616000095>
- Cheesman, S., Thierfelder, C., Eash, N. S., Kassie, G. T., & Frossard, E. (2016). Soil carbon stocks in conservation agriculture systems of Southern Africa. *Soil and Tillage Research*, 156, 99–109. <https://doi.org/10.1016/j.still.2015.09.018>
- Chinseu, E., Dougill, N., & Stringer, L. (2019). Why do smallholder farmers dis-adopt conservation agriculture? Insights from Malawi. *Land Degradation & Development*, 30(5), 533–543. <https://doi.org/10.1002/ldr.3190>
- Chivenge, P. P., Murwira, H. K., Giller, K. E., Mapfumo, P., & Six, J. (2007). Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. *Soil and Tillage Research*, 94(2), 328–337. <https://doi.org/10.1016/j.still.2006.08.006>
- Corbeels, M., Cardinael, R., Naudin, K., Guibert, H., & Torquebiau, E. (2019). The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-Saharan Africa. *Soil and Tillage Research*, 188, 16–26. <https://doi.org/10.1016/j.still.2018.02.015>
- Corbeels, M., de Graaff, J., Ndah, T. H., Penot, E., Baudron, F., Naudin, K., Andrieu, N., Chirat, G., Schuler, J., Nyagumbo, I., Rusinamhodzi, L., Traore, K., Mzoba, H. D., & Adolwa, I. S. (2014). Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. *Agriculture Ecosystems & Environment*, 187, 155–170. <https://doi.org/10.1016/j.agee.2013.10.011>
- Dallimer, M., Stringer, L. C., Orchard, S. E., Osano, P., Njoroge, G., Wen, C., & Gicheru, P. (2018). Who uses sustainable land management practices and what are the costs and benefits? Insights from Kenya. *Land Degradation & Development*, 29(9), 2822–2835. <https://doi.org/10.1002/ldr.3001>
- Descheemaeker, K., Ronner, E., Ollenburger, M., Franke, A. C., Klapwijk, C. J., Falconnier, G. N., Wichern, J., & Giller, K. E.

- (2019). Which options fit best? Operationalizing the socio-ecological niche concept. *Experimental Agriculture*, 55(S1), 169–190. <https://doi.org/10.1017/s001447971600048x>
- Droppelmann, K. J., Snapp, S. S., & Waddington, S. R. (2017). Sustainable intensification options for smallholder maize-based farming systems in sub-Saharan Africa. *Food Security*, 9(1), 133–150. <https://doi.org/10.1007/s12571-016-0636-0>
- Dube, T., Mlilo, C., Moyo, P., Ncube, C., & Phiri, K. (2018). Will adaptation carry the future? Questioning the long-term capacity of smallholder farmers' adaptation strategies against climate change in Gwanda District, Zimbabwe. *Journal of Human Ecology*, 61(1–3), 20–30. <https://doi.org/10.1080/09709274.2018.1452866>
- Dugue, P., & Bassala, J. P. O. (2015). Technological innovation and land management: The effects of direct seeding mulch-based cropping systems. *Cahiers Agricultures*, 24(2), 93–101. <https://doi.org/10.1684/agr.2015.0738>
- Dugue, P., Nana, P. D., Faure, G., & Le Gal, P. Y. (2015). Dynamics of adopting conservation agriculture in family farms: From technique to innovative process. *Cahiers Agricultures*, 24(2), 60–68. <https://doi.org/10.1684/agr.2015.0748>
- FAO. *Conservation agriculture* FAO. Accessed 10/06/2020. <http://www.fao.org/ag/ca/index.html>
- Fisher, M., Holden, S. T., Thierfelder, C., & Katengeza, S. P. (2018). Awareness and adoption of conservation agriculture in Malawi: What difference can farmer-to-farmer extension make? *International Journal of Agricultural Sustainability*, 16(3), 310–325. <https://doi.org/10.1080/14735903.2018.1472411>
- Giller, K. E., Andersson, J. A., Corbeels, M., Kirkegaard, J., Mortensen, D., Erenstein, O., & Vanlauwe, B. (2015). Beyond conservation agriculture. *Frontiers in Plant Science*, 6. <https://doi.org/10.3389/fpls.2015.00870>
- Giller, K. E., Witter, E., Corbeels, M., & Tittonell, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, 114(1), 23–34. <https://doi.org/10.1016/j.fcr.2009.06.017>
- Gonzalez-Sanchez, E. J., Veroz-Gonzalez, O., Conway, G., Moreno-García, M., Kassam, A., Mkomwa, S., Ordoñez-Fernandez, R., Triviño-Tarradas, P., & Carbonell-Bojollo, R. (2019). Meta-analysis on carbon sequestration through conservation agriculture in Africa. *Soil and Tillage Research*, 190, 22–30. <https://doi.org/10.1016/j.still.2019.02.020>
- Grabowski, P. P., & Kerr, J. M. (2014). Resource constraints and partial adoption of conservation agriculture by hand-hoe farmers in Mozambique. *International Journal of Agricultural Sustainability*, 12(1), 37–53. <https://doi.org/10.1080/14735903.2013.782703>
- Grabowski, P. P., Kerr, J. M., Haggblade, S., & Kabw, S. (2016). Determinants of adoption and disadoption of minimum tillage by cotton farmers in eastern Zambia. *Agriculture Ecosystems & Environment*, 231, 54–67. <https://doi.org/10.1016/j.agee.2016.06.027>
- Guto, S. N., Pypers, P., Vanlauwe, B., de Ridder, N., & Giller, K. E. (2012). Socio-ecological Niches for minimum tillage and crop-residue retention in continuous maize cropping systems in smallholder farms of central Kenya. *Agronomy Journal*, 104(1), 188–198. <https://doi.org/10.2134/agronj2010.0359>
- Haggard, J., Ayala, A., Díaz, B., & Reyes, C. U. (2001). Participatory design of agroforestry systems: Developing farmer participatory research methods in Mexico. *Development in Practice*, 11(4), 417–424. <https://doi.org/10.1080/09614520120066701>
- Holden, S. T., Fisher, M., Katengeza, S. P., & Thierfelder, C. (2018). Can lead farmers reveal the adoption potential of conservation agriculture? The case of Malawi. *Land Use Policy*, 76, 113–123. <https://doi.org/10.1016/j.landusepol.2018.04.048>
- Hove, M., & Gweme, T. (2018). Women's food security and conservation farming in Zaka District-Zimbabwe. *Journal of Arid Environments*, 149, 18–29. <https://doi.org/10.1016/j.jaridenv.2017.10.010>
- Ifejika Speranza, C. (2013). Buffer capacity: Capturing a dimension of resilience to climate change in African smallholder agriculture. *Regional Environmental Change*, 13(3), 521–535. <https://doi.org/10.1007/s10113-012-0391-5>
- Ikazaki, K., Nagumo, F., Simporé, S., & Barro, A. (2018). Are all three components of conservation agriculture necessary for soil conservation in the Sudan Savanna? *Soil Science and Plant Nutrition*, 64(2), 230–237. <https://doi.org/10.1080/00380768.2017.1422393>
- Iverson, A. L., Marin, L. E., Ennis, K. K., Gonthier, D. J., Connor-Barrie, B. T., Remfert, J. L., Cardinale, B. J., & Perfecto, I. (2014). Do polycultures promote win-wins or trade-offs in agricultural ecosystem services? A meta-analysis. *Journal of Applied Ecology*, 51(6), 1593–1602. <https://doi.org/10.1111/1365-2664.12334>
- Jaleta, M., Kassie, M., & Shiferaw, B. (2013). Tradeoffs in crop residue utilization in mixed crop-livestock systems and implications for conservation agriculture. *Agricultural Systems*, 121, 96–105. <https://doi.org/10.1016/j.agsy.2013.05.006>
- Kassam, A., Friedrich, T., Shaxson, F., & Pretty, J. (2009). The spread of conservation Agriculture: Justification, sustainability and uptake. *International Journal of Agricultural Sustainability*, 7(4), 292–320. <https://doi.org/10.3763/ijas.2009.0477>
- Kaweesa, S., Mkomwa, S., & Loiskandl, W. (2018). Adoption of conservation agriculture in Uganda: A case study of the Lango Subregion. *Sustainability*, 10(10), <https://doi.org/10.3390/su10103375>
- Khataza, R. R. B., Doole, G. J., Kragt, M. E., & Hailu, A. (2018). Information acquisition, learning and the adoption of conservation agriculture in Malawi: A discrete-time duration analysis. *Technological Forecasting and Social Change*, 132, 299–307. <https://doi.org/10.1016/j.techfore.2018.02.015>
- Khataza, R. R. B., Hailu, A., Kragt, M. E., & Doole, G. J. (2017). Estimating shadow price for symbiotic nitrogen and technical efficiency for legume-based conservation agriculture in Malawi. *Australian Journal of Agricultural and Resource Economics*, 61(3), 462–480. <https://doi.org/10.1111/1467-8489.12212>
- Kimaro, A. A., Mpanda, M., Rioux, J., Aynekulu, E., Shaba, S., Thiong'o, M., Mutuo, P., Abwanda, S., Shepherd, K., Neufeldt, H., & Rosenstock, T. S. (2016). Is conservation agriculture 'climate-smart' for maize farmers in the highlands of Tanzania? *Nutrient Cycling in Agroecosystems*, 105(3), 217–228. <https://doi.org/10.1007/s10705-015-9711-8>
- Kitonyo, O. M., Sadras, V. O., Zhou, Y., & Denton, M. D. (2018). Nitrogen fertilization modifies maize yield response to tillage and stubble in a sub-humid tropical environment. *Field Crops Research*, 223, 113–124. <https://doi.org/10.1016/j.fcr.2018.03.024>

- Krupnik, T. J., Shennan, C., Settle, W. H., Demont, M., Ndiaye, A. B., & Rodenburg, J. (2012). Improving irrigated rice production in the Senegal River Valley through experiential learning and innovation. *Agricultural Systems*, 109, 101–112. <https://doi.org/10.1016/j.agsy.2012.01.008>
- Kunzekweguta, M., Rich, K. M., & Lyne, M. C. (2017). Factors affecting adoption and intensity of conservation agriculture techniques applied by smallholders in Masvingo district. *Zimbabwe. Agrekon*, 56(4), 330–346. <https://doi.org/10.1080/03031853.2017.1371616>
- Lahmar, R., Bationo, B. A., Dan Lamso, N., Guéro, Y., & Tittonell, P. (2012). Tailoring conservation agriculture technologies to West Africa semi-arid zones: Building on traditional local practices for soil restoration. *Field Crops Research*, 132, 158–167. <https://doi.org/10.1016/j.fcr.2011.09.013>
- Lalani, B., Dorward, P., & Holloway, G. (2017). Farm-level economic analysis - Is Conservation Agriculture Helping the poor? *Ecological Economics*, 141, 144–153. <https://doi.org/10.1016/j.ecolecon.2017.05.033>
- Lalani, B., Dorward, P., Holloway, G., & Wauters, E. (2016). Smallholder farmers' motivations for using Conservation Agriculture and the roles of yield, labour and soil fertility in decision making. *Agricultural Systems*, 146, 80–90. <https://doi.org/10.1016/j.agsy.2016.04.002>
- Lee, N., & Thierfelder, C. (2017). Weed control under conservation agriculture in dryland smallholder farming systems of Southern Africa. A review. *Agronomy for Sustainable Development*, 37(5), <https://doi.org/10.1007/s13593-017-0453-7>
- Liben, F. M., Hassen, S. J., Weyesa, B. T., Wortmann, C. S., Kim, H. K., Kidane, M. S., Yeda, G. G., & Beshir, B. (2017). Conservation agriculture for maize and bean production in the central Rift Valley of Ethiopia. *Agronomy Journal*, 109(6), 2988–2997. <https://doi.org/10.2134/agronj2017.02.0072>
- Liben, F. M., Tadesse, B., Tola, Y. T., Wortmann, C. S., Kim, H. K., & Mupangwa, W. (2018). Conservation agriculture effects on crop productivity and soil properties in Ethiopia. *Agronomy Journal*, 110(2), 758–767. <https://doi.org/10.2134/agronj2017.07.0384>
- Manda, J., Alene, A. D., Gardebroek, C., Kassie, M., & Tembo, G. (2016). Adoption and impacts of sustainable agricultural practices on maize yields and incomes: Evidence from rural Zambia. *Journal of Agricultural Economics*, 67(1), 130–153. <https://doi.org/10.1111/1477-9552.12127>
- Mandumbu, R., Twomlow, S. J., Jowah, P., Mashingaidze, N., Hove, L., & Karavina, C. (2012). Weed seed bank response to tillage and residue management in semi-arid Zimbabwe. *Archives of Phytopathology and Plant Protection*, 45(18), 2165–2176. <https://doi.org/10.1080/03235408.2012.722842>
- Marenya, P. P., Kassie, M., Jaleta, M., Rahut, D. B., & Erenstein, O. (2017). Predicting minimum tillage adoption among smallholder farmers using micro-level and policy variables. *Agricultural and Food Economics*, 5(1), 1. <https://doi.org/10.1186/s40100-017-0081-1>
- Mashingaidze, N., Madakadze, C., Twomlow, S., Nyamangara, J., & Hove, L. (2012). Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe. *Soil and Tillage Research*, 124, 102–110. <https://doi.org/10.1016/j.still.2012.05.008>
- Masvaya, E. N., Nyamangara, J., Descheemaeker, K., & Giller, K. E. (2017). Tillage, mulch and fertiliser impacts on soil nitrogen availability and maize production in semi-arid Zimbabwe. *Soil and Tillage Research*, 168, 125–132. <https://doi.org/10.1016/j.still.2016.12.007>
- Masvaya, E. N., Nyamangara, J., Giller, K. E., & Descheemaeker, K. (2018). Risk management options in maize cropping systems in semi-arid areas of Southern Africa. *Field Crops Research*, 228, 110–121. <https://doi.org/10.1016/j.fcr.2018.09.002>
- Michalscheck, M., Groot, J. C. J., Kotu, B., Hoeschle-Zeledon, I., Kuivainen, K., Descheemaeker, K., & Tittonell, P. (2018). Model results versus farmer realities. Operationalizing diversity within and among smallholder farm systems for a nuanced impact assessment of technology packages. *Agricultural Systems*, 162, 164–178. <https://doi.org/10.1016/j.agsy.2018.01.028>
- Micheni, A. N., Kanampiu, F., Kitonyo, O., Mburu, D. M., Mugai, E. N., Makumbi, D., & Kassie, M. (2016). On-farm experimentation on Conservation Agriculture in maize-legume based cropping systems in Kenya: Water use efficiency and economic impacts. *Experimental Agriculture*, 52(1), 51–68. <https://doi.org/10.1017/s0014479714000556>
- Morrison, J. (2006). Conservation agriculture in Africa: Is there a role for two-wheel tractors? *Appropriate Technology*, 33(4), 43–45.
- Muoni, T., Rusinamhodzi, L., Rugare, J. T., Mabasa, S., Mangosho, E., Mupangwa, W., & Thierfelder, C. (2014). Effect of herbicide application on weed flora under conservation agriculture in Zimbabwe. *Crop Protection*, 66, 1–7. <https://doi.org/10.1016/j.cropro.2014.08.008>
- Muoni, T., Rusinamhodzi, L., & Thierfelder, C. (2013). Weed control in conservation agriculture systems of Zimbabwe: Identifying economical best strategies. *Crop Protection*, 53, 23–28. <https://doi.org/10.1016/j.cropro.2013.06.002>
- Mupangwa, W., Mutenje, M., Thierfelder, C., & Nyagumbo, I. (2017). Are conservation agriculture (CA) systems productive and profitable options for smallholder farmers in different agro-ecoregions of Zimbabwe? *Renewable Agriculture and Food Systems*, 32(1), 87–103. <https://doi.org/10.1017/s1742170516000041>
- Mupangwa, W., Nyagumbo, I., & Mutsamba, E. (2016). Effect of different mulching materials on maize growth and yield in conservation agriculture systems of sub-humid Zimbabwe. *Aims Agriculture and Food*, 1(2), 239–253. <https://doi.org/10.3934/agrfood.2016.2.239>
- Mupangwa, W., & Thierfelder, C. (2014). Intensification of conservation agriculture systems for increased livestock feed and maize production in Zimbabwe. *International Journal of Agricultural Sustainability*, 12(4), 425–439. <https://doi.org/10.1080/14735903.2013.859836>
- Mupangwa, W., Thierfelder, C., Cheesman, S., Nyagumbo, I., Muoni, T., Mhlanga, B., Mwila, M., Sida, T. S., & Ngwira, A. (2019). Effects of maize residue and mineral nitrogen applications on maize yield in conservation-agriculture-based cropping systems of Southern Africa. *Renewable Agriculture and Food Systems*, <https://doi.org/10.1017/S174217051900005X>
- Mupangwa, W., Twomlow, S., Walker, S., & Hove, L. (2007). Effect of minimum tillage and mulching on maize (*Zea mays* L.) yield and water content of clayey and sandy soils. *Physics and Chemistry of the Earth, Parts A/B/C*, 32(15–18), 1127–1134. <https://doi.org/10.1016/j.pce.2007.07.030>

- Mutsamba, E. F., Nyagumbo, I., & Mafongoya, P. (2016). Termite prevalence and crop lodging under conservation agriculture in sub-humid Zimbabwe. *Crop Protection*, 82, 60–64. <https://doi.org/10.1016/j.cropro.2016.01.004>
- Muzangwa, L., Mkeni, P. N. S., & Chiduzo, C. (2017). Assessment of Conservation Agriculture practices by smallholder farmers in the eastern Cape Province of South Africa. *Agronomy*, 7(3), <https://doi.org/10.3390/agronomy7030046>
- Muzangwa, L., Mkeni, P. N. S., & Chiduzo, C. (2019). The Use of residue retention and Inclusion of legumes to improve soil biological activity in maize-based No-till systems of the eastern Cape Province, South Africa. *Agricultural Research*, <https://doi.org/10.1007/s40003-019-00402-0>
- Naab, J. B., Mahama, G. Y., Yahaya, I., & Prasad, P. V. V. (2017). Conservation Agriculture Improves soil quality, crop yield, and incomes of smallholder farmers in North Western Ghana. *Frontiers in Plant Science*, 8. <https://doi.org/10.3389/fpls.2017.00996>
- Nana, P. D., Andrieu, N., Zerbo, I., Ouedraogo, Y., & Le Gal, P. Y. (2015). Conservation agriculture and performance of farms in West Africa. *Cahiers Agricultures*, 24(2), 113–122. <https://doi.org/10.1684/agr.2015.0743>
- Naudin, K., Bruelle, G., Salgado, P., Penot, E., Scopel, E., Lubbers, M., de Ridder, N., & Giller, K. E. (2015). Trade-offs around the use of biomass for livestock feed and soil cover in dairy farms in the Alaotra lake region of Madagascar. *Agricultural Systems*, 134, 36–47. <https://doi.org/10.1016/j.agry.2014.03.003>
- Ndah, H. T., Schuler, J., Diehl, K., Bateki, C., Sieber, S., & Knierim, A. (2018). From dogmatic views on conservation agriculture adoption in Zambia towards adapting to context. *International Journal of Agricultural Sustainability*, 16(2), 228–242. <https://doi.org/10.1080/14735903.2018.1447227>
- Ndah, H. T., Schuler, J., Uthes, S., Zander, P., Traore, K., Gama, M. S., Nyagumbo, I., Triomphe, B., Sieber, S., & Corbeels, M. (2014). Adoption potential of conservation agriculture practices in Sub-Saharan Africa: Results from five case studies. *Environmental Management*, 53(3), 620–635. <https://doi.org/10.1007/s00267-013-0215-5>
- Ndah, H. T., Schuler, J., Uthes, S., Zander, P., Triomphe, B., Mkomwa, S., & Corbeels, M. (2015). Adoption potential for Conservation Agriculture in Africa: A newly developed assessment approach (QAToCA) applied in Kenya and Tanzania. *Land Degradation & Development*, 26(2), 133–141. <https://doi.org/10.1002/ldr.2191>
- Ndlovu, P. V., Mazvimavi, K., An, H., & Murendo, C. (2014). Productivity and efficiency analysis of maize under conservation agriculture in Zimbabwe. *Agricultural Systems*, 124, 21–31. <https://doi.org/10.1016/j.agry.2013.10.004>
- Ndoli, A., Baudron, F., Sida, T. S., Schut, A. G. T., van Heerwaarden, J., & Giller, K. E. (2018). Conservation agriculture with trees amplifies negative effects of reduced tillage on maize performance in East Africa. *Field Crops Research*, 221, 238–244. <https://doi.org/10.1016/j.fcr.2018.03.003>
- Ngoma, H. (2018). Does minimum tillage improve the livelihood outcomes of smallholder farmers in Zambia? *Food Security*, 10(2), 381–396. <https://doi.org/10.1007/s12571-018-0777-4>
- Ngwira, A. R., Aune, J. B., & Thierfelder, C. (2014). On-farm evaluation of the effects of the principles and components of Conservation Agriculture on maize yield and weed biomass in Malawi. *Experimental Agriculture*, 50(4), 591–610. <https://doi.org/10.1017/s001447971400009x>
- Ngwira, A., Sleutel, S., & De Neve, S. (2012). Soil carbon dynamics as influenced by tillage and crop residue management in loamy sand and sandy loam soils under smallholder farmers' conditions in Malawi. *Nutrient Cycling in Agroecosystems*, 92(3), 315–328. <https://doi.org/10.1007/s10705-012-9492-2>
- Ngwira, A. R., Thierfelder, C., Eash, N., & Lambert, D. M. (2013). Risk and maize-based cropping systems for smallholder Malawi farmers using Conservation Agriculture technologies. *Experimental Agriculture*, 49(4), 483–503. <https://doi.org/10.1017/s0014479713000306>
- Ngwira, A. R., Thierfelder, C., & Lambert, D. M. (2013). Conservation agriculture systems for Malawian smallholder farmers: Long-term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems*, 28(4), 350–363. <https://doi.org/10.1017/s1742170512000257>
- Njaimwe, A. N., Mkeni, P. N. S., Muchaonyerwa, P., Chiduzo, C., & Wakindiki, I. I. C. (2018). Sensitivity of selected chemical and biological soil quality parameters to tillage and rotational cover cropping at the Zanyokwe Irrigation Scheme, South Africa. *South African Journal of Plant and Soil*, 35(5), 321–328. <https://doi.org/10.1080/02571862.2018.1446225>
- Ntshangase, N. L., Muroyiwa, B., & Sibanda, M. (2018). Farmers' perceptions and factors influencing the adoption of no-till conservation agriculture by small-scale farmers in Zashuke, KwaZulu-Natal province. *Sustainability (Switzerland)*, 10(2), <https://doi.org/10.3390/su10020555>
- Nyagumbo, I., Mkuhlani, S., Mupangwa, W., & Rodriguez, D. (2017). Planting date and yield benefits from conservation agriculture practices across Southern Africa. *Agricultural Systems*, 150, 21–33. <https://doi.org/10.1016/j.agry.2016.09.016>
- Nyagumbo, I., Munamati, M., Mutsamba, E. F., Thierfelder, C., Cumbane, A., & Dias, D. (2015). The effects of tillage, mulching and termite control strategies on termite activity and maize yield under conservation agriculture in Mozambique. *Crop Protection*, 78, 54–62. <https://doi.org/10.1016/j.cropro.2015.08.017>
- Nyamadzawo, G., Nyamugafata, P., Wuta, M., Nyamangara, J., & Chikowo, R. (2012). Infiltration and runoff losses under fallowing and conservation agriculture practices on contrasting soils, Zimbabwe. *Water Sa*, 38(2), 233–240. <https://doi.org/10.4314/wsa.v38i2.8>
- Odhiambo, J. A., Norton, U., Ashilenje, D., Omondi, E. C., & Norton, J. B. (2015). Weed Dynamics during Transition to Conservation Agriculture in Western Kenya maize production. *Plos One*, 10(8), <https://doi.org/10.1371/journal.pone.0133976>
- Okeyo, J. M., Norton, J., Koala, S., Waswa, B., Kihara, J., & Bationo, A. (2016). Impact of reduced tillage and crop residue management on soil properties and crop yields in a long-term trial in western Kenya. *Soil Research*, 54(6), 719–729. <https://doi.org/10.1071/sr15074>
- Orr, A. (2018). Markets, institutions and policies: A perspective on the adoption of agricultural innovations. *Outlook on Agriculture*, 47(2), 81–86. <https://doi.org/10.1177/0030272018776433>
- Pannell, D. J., Llewellyn, R. S., & Corbeels, M. (2014). The farm-level economics of conservation agriculture for resource-poor

- farmers. *Agriculture Ecosystems & Environment*, 187, 52–64. <https://doi.org/10.1016/j.agee.2013.10.014>
- Paul, B. K., Vanlauwe, B., Ayuke, F., Gassner, A., Hoogmoed, M., Hurisso, T. T., Koala, S., Lelei, D., Ndabamenye, T., Six, J., & Pulleman, M. M. (2013). Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. *Agriculture Ecosystems & Environment*, 164, 14–22. <https://doi.org/10.1016/j.agee.2012.10.003>
- Pedzisa, T., Rugube, L., Winter-Nelson, A., Baylis, K., & Mazvimavi, K. (2015). The intensity of adoption of Conservation agriculture by smallholder farmers in Zimbabwe. *Agrekon*, 54(3), 1–22. <https://doi.org/10.1080/03031853.2015.1084939>
- Penot, E., Domas, R., Fabre, J., Poletti, S., Macdowall, C., Dugue, P., & Le Gal, P. Y. (2015). The technician proposes, the farmer disposes. The adoption of Conservation Agriculture (CA) in the lake Alaotra region, Madagascar. *Cahiers Agricultures*, 24(2), 84–92. <https://doi.org/10.1684/agr.2015.0745>
- Penot, E., Fevre, V., Flodrops, P., & Razafimahatratra, H. M. (2018). Conservation Agriculture to buffer and alleviate the impact of climatic variations in Madagascar: Farmers' perception. *Cahiers Agricultures*, 27(2), <https://doi.org/10.1051/cagri/2018009>
- Pittelkow, C. M., Liang, X. Q., Linquist, B. A., van Groenigen, K. J., Lee, J., Lundy, M. E., van Gestel, N., Six, J., Venterea, R. T., & van Kessel, C. (2015). Productivity limits and potentials of the principles of conservation agriculture. *Nature*, 517(7534), 365–U482. <https://doi.org/10.1038/nature13809>
- Pittelkow, C. M., Linquist, B. A., Lundy, M. E., Liang, X. Q., van Groenigen, K. J., Lee, J., van Gestel, N., Six, J., Venterea, R. T., & van Kessel, C. (2015). When does no-till yield more? A global meta-analysis. *Field Crops Research*, 183, 156–168. <https://doi.org/10.1016/j.fcr.2015.07.020>
- Rafaraso, L. S., Letourmy, P., Naudin, K., Andrianantoandro, A., Rajaonera, T. E., Randriamanantsoa, R., & Ratnadass, A. (2016). Effect of cover crop residues on White Grubs and Adults of *Heteronychus bituberculatus* (Coleoptera: Dynastidae) and on the damage they Cause to Upland rice. *African Entomology*, 24(1), 75–79. <https://doi.org/10.4001/003.024.0075>
- Ranaivoson, L., Naudin, K., Ripoche, A., Rabeharisoa, L., & Corbeels, M. (2019). Effectiveness of conservation agriculture in increasing crop productivity in low-input rainfed rice cropping systems under humid subtropical climate. *Field Crops Research*, 239, 104–113. <https://doi.org/10.1016/j.fcr.2019.05.002>
- Randrianjafizanaka, M. T., Autfray, P., Andrianaivo, A. P., Ramonta, I. R., & Rodenburg, J. (2018). Combined effects of cover crops, mulch, zero-tillage and resistant varieties on *Striga asiatica* (L.) Kuntze in rice-maize rotation systems. *Agriculture Ecosystems & Environment*, 256, 23–33. <https://doi.org/10.1016/j.agee.2017.12.005>
- Rodenburg, J., Johnson, J. M., Dieng, I., Senthilkumar, K., Vandamme, E., Akakpo, C., Allarangaye, M. D., Baggie, I., Bakare, S. O., Bam, R. K., Bassoro, I., Abera, B. B., Cisse, M., Dogbe, W., Gbakatchetche, H., Jaiteh, F., Kajiru, G. J., Kalisa, A., Kamissoko, N., ... Saito, K. (2019). Status quo of chemical weed control in rice in sub-Saharan Africa. *Food Security*, 11(1), 69–92. <https://doi.org/10.1007/s12571-018-0878-0>
- Rodenburg, J., Randrianjafizanaka, M. T., Büchi, L., Dieng, I., Andrianaivo, A. P., Raveloson Ravaomanarivo, L. H., & Autfray, P. (2020). Mixed outcomes from conservation practices on soils and *Striga*-affected yields of a low input, rice-maize system in Madagascar. *Agronomy for Sustainable Development*, 40(8), <https://doi.org/10.1007/s13593-020-0612-0>
- Rodriguez, D., de Voil, P., Rufino, M. C., Odeno, M., & van Wijk, M. T. (2017). To mulch or to munch? Big modelling of big data. *Agricultural Systems*, 153, 32–42. <https://doi.org/10.1016/j.agsy.2017.01.010>
- Rosenstock, T. S., Mpanda, M., Rioux, J., Aynekulu, E., Kimaro, A. A., Neufeldt, H., Shepherd, K. D., & Luedeling, E. (2014). Targeting conservation agriculture in the context of livelihoods and landscapes. *Agriculture Ecosystems & Environment*, 187, 47–51. <https://doi.org/10.1016/j.agee.2013.11.011>
- Rusinamhodzi, L., Corbeels, M., van Wijk, M. T., Rufino, M. C., Nyamangara, J., & Giller, K. E. (2011). A meta-analysis of long-term effects of conservation agriculture on maize grain yield under rain-fed conditions. *Agronomy for Sustainable Development*, 31(4), 657–673. <https://doi.org/10.1007/s13593-011-0040-2>
- Rusinamhodzi, L., van Wijk, M. T., Corbeels, M., Rufino, M. C., & Giller, K. E. (2015). Maize crop residue uses and trade-offs on smallholder crop-livestock farms in Zimbabwe: Economic implications of intensification. *Agriculture Ecosystems & Environment*, 214, 31–45. <https://doi.org/10.1016/j.agee.2015.08.012>
- Schaafsma, M., Utila, H., & Hiron, M. A. (2018). Understanding trade-offs in upscaling and integrating climate-smart agriculture and sustainable river basin management in Malawi. *Environmental Science & Policy*, 80, 117–124. <https://doi.org/10.1016/j.envsci.2017.11.007>
- Senyolo, M. P., Long, T. B., Blok, V., & Omta, O. (2018). How the characteristics of innovations impact their adoption: An exploration of climate-smart agricultural innovations in South Africa. *Journal of Cleaner Production*, 172, 3825–3840. <https://doi.org/10.1016/j.jclepro.2017.06.019>
- Serraj, R., & Siddique, K. H. M. (2012). Conservation agriculture in dry areas. *Field Crops Research*, 132, 1–6. <https://doi.org/10.1016/j.fcr.2012.03.002>
- Setimela, P., Gasura, E., Thierfelder, C., Zaman-Allah, M., Cairns, J. E., & Boddupalli, P. M. (2018). When the going gets tough: Performance of stress tolerant maize during the 2015/16 (El Nino) and 2016/17 (La Nina) season in Southern Africa. *Agriculture Ecosystems & Environment*, 268, 79–89. <https://doi.org/10.1016/j.agee.2018.09.006>
- Sime, G., Aune, J. B., & Mohammed, H. (2015). Agronomic and economic response of tillage and water conservation management in maize, central rift valley in Ethiopia. *Soil and Tillage Research*, 148, 20–30. <https://doi.org/10.1016/j.still.2014.12.001>
- Sims, B. G., Thierfelder, C., Kienzie, J., Friedrich, T., & Kassam, A. (2012). Development of the conservation agriculture equipment industry in sub-Saharan Africa. *Applied Engineering in Agriculture*, 28(6), 813–823. <https://doi.org/10.13031/2013.42472>
- Sithole, N. J., Magwaza, L. S., & Thibaud, G. R. (2019). Long-term impact of no-till conservation agriculture and N-fertilizer on soil aggregate stability, infiltration and distribution of C in different size fractions. *Soil and Tillage Research*, 190, 147–156. <https://doi.org/10.1016/j.still.2019.03.004>
- Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-Kerr, R., & Kanyama-Phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences*, 107(48), 20840–20845. <https://doi.org/10.1073/pnas.1007199107>

- Snapp, S. S., Grabowski, P., Chikowo, R., Smith, A., Anders, E., Sirrine, D., Chimonyo, V., & Bekunda, M. (2018). Maize yield and profitability tradeoffs with social, human and environmental performance: Is sustainable intensification feasible? *Agricultural Systems*, 162, 77–88. <https://doi.org/10.1016/j.agsy.2018.01.012>
- Steward, P. R., Dougill, A. J., Thierfelder, C., Pittelkow, C. M., Stringer, L. C., Kudzala, M., & Shackelford, G. E. (2018). The adaptive capacity of maize-based conservation agriculture systems to climate stress in tropical and subtropical environments: A meta-regression of yields. *Agriculture Ecosystems & Environment*, 251, 194–202. <https://doi.org/10.1016/j.agee.2017.09.019>
- Sumberg, J., Andersson, J., Giller, K., & Thompson, J. (2013). Response to 'combining sustainable agricultural production with economic and environmental benefits'. *The Geographical Journal*, 179(2), 183–185. <https://doi.org/10.1111/j.1475-4959.2012.00472.x>
- Swanepoel, C. M., Rotter, R. P., van der Laan, M., Annandale, J. G., Beukes, D. J., du Preez, C. C., Swanepoel, L. H., van der Merwe, A., & Hoffmann, M. P. (2018). The benefits of conservation agriculture on soil organic carbon and yield in Southern Africa are site-specific. *Soil and Tillage Research*, 183, 72–82. <https://doi.org/10.1016/j.still.2018.05.016>
- Tambo, J. A., & Mockshell, J. (2018). Differential impacts of Conservation Agriculture technology options on household income in Sub-Saharan Africa. *Ecological Economics*, 151, 95–105. <https://doi.org/10.1016/j.ecolecon.2018.05.005>
- Tesfaye, K., Jaleta, M., Jena, P., & Mutenje, M. (2015). Identifying potential Recommendation Domains for Conservation Agriculture in Ethiopia, Kenya, and Malawi. *Environmental Management*, 55(2), 330–346. <https://doi.org/10.1007/s00267-014-0386-8>
- Tessema, Y., Asafu-Adjaye, J., Rodriguez, D., Mallawaarachchi, T., & Shiferaw, B. (2015). A bio-economic analysis of the benefits of conservation agriculture: The case of smallholder farmers in Adami Tulu district, Ethiopia. *Ecological Economics*, 120, 164–174. <https://doi.org/10.1016/j.ecolecon.2015.10.020>
- Thierfelder, C., Baudron, F., Setimela, P., Nyagumbo, I., Mupangwa, W., Mhlanga, B., Lee, N., & Gérard, B. (2018). Complementary practices supporting conservation agriculture in Southern Africa. A review. *Agronomy for Sustainable Development*, 38(2), <https://doi.org/10.1007/s13593-018-0492-8>
- Thierfelder, C., Bunderson, W. T., Jere, Z. D., Mutenje, M., & Ngwira, A. (2016). Development of Conservation Agriculture (CA) systems in Malawi: Lessons learned from 2005 to 2014. *Experimental Agriculture*, 52(4), 579–604. doi: 10.1017/s0014479715000265
- Thierfelder, C., Chisui, J. L., Gama, M., Cheesman, S., Jere, Z. D., Trent Bunderson, W., Eash, N. S., & Rusinamhodzi, L. (2013). Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. *Field Crops Research*, 142, 47–57. doi: 10.1016/j.fcr.2012.11.010
- Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T. S., Lamanna, C., & Eyre, J. X. (2017). How climate-smart is conservation agriculture (CA)? - its potential to deliver on adaptation, mitigation and productivity on smallholder farms in Southern Africa. *Food Security*, 9(3), 537–560. <https://doi.org/10.1007/s12571-017-0665-3>
- Thierfelder, C., Matemba-Mutasa, R., Bunderson, W. T., Mutenje, M., Nyagumbo, I., & Mupangwa, W. (2016). Evaluating manual conservation agriculture systems in Southern Africa. *Agriculture Ecosystems & Environment*, 222, 112–124. <https://doi.org/10.1016/j.agee.2016.02.009>
- Thierfelder, C., Matemba-Mutasa, R., & Rusinamhodzi, L. (2015). Yield response of maize (*Zea mays* L.) to conservation agriculture cropping system in Southern Africa. *Soil and Tillage Research*, 146(PB), 230–242. <https://doi.org/10.1016/j.still.2014.10.015>
- Thierfelder, C., Mombeyara, T., Mango, N., & Rusinamhodzi, L. (2013). Integration of conservation agriculture in smallholder farming systems of Southern Africa: Identification of key entry points. *International Journal of Agricultural Sustainability*, 11(4), 317–330. <https://doi.org/10.1080/14735903.2013.764222>
- Thierfelder, C., Mutenje, M., Mujeyi, A., & Mupangwa, W. (2015). Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal area, Zimbabwe. *Food Security*, 7(1), 15–31. <https://doi.org/10.1007/s12571-014-0404-y>
- Thierfelder, C., Mwila, M., & Rusinamhodzi, L. (2013). Conservation agriculture in eastern and southern provinces of Zambia: Long-term effects on soil quality and maize productivity. *Soil & Tillage Research*, 126, 246–258. <https://doi.org/10.1016/j.still.2012.09.002>
- Thierfelder, C., Rusinamhodzi, L., Ngwira, A. R., Mupangwa, W., Nyagumbo, I., Kassie, G. T., & Cairns, J. E. (2015). Conservation agriculture in Southern Africa: Advances in knowledge. *Renewable Agriculture and Food Systems*, 30(4), 328–348. <https://doi.org/10.1017/S1742170513000550>
- Thierfelder, C., Rusinamhodzi, L., Setimela, P., Walker, F., & Eash, N. S. (2016). Conservation agriculture and drought-tolerant germplasm: Reaping the benefits of climate-smart agriculture technologies in central Mozambique. *Renewable Agriculture and Food Systems*, 31(5), 414–428. <https://doi.org/10.1017/S1742170515000332>
- Thierfelder, C., & Wall, P. C. (2012). Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. *Soil Use and Management*, 28(2), 209–220. <https://doi.org/10.1111/j.1475-2743.2012.00406.x>
- Thornton, P. K., Whitbread, A., Baedeker, T., Cairns, J., Claessens, L., Baethgen, W., Bunn, C., Friedmann, M., Giller, K. E., Herrero, M., Howden, M., Kilcline, K., Nangia, V., Ramirez-Villegas, J., Kumar, S., West, P. C., & Keating, B. (2018). A framework for priority-setting in climate smart agriculture research. *Agricultural Systems*, 167, 161–175. <https://doi.org/10.1016/j.agsy.2018.09.009>
- Tsegaye, W., LaRovere, R., Mwabu, G., & Kassie, G. T. (2017). Adoption and farm-level impact of conservation agriculture in central Ethiopia. *Environment, Development and Sustainability*, 19(6), 2517–2533. <https://doi.org/10.1007/s10668-016-9869-5>
- Tui, S. H. K., Valbuena, D., Masikati, P., Descheemaeker, K., Nyamangara, J., Claessens, L., Erenstein, O., van Rooyen, A., & Nkomboni, D. (2015). Economic trade-offs of biomass use in crop-livestock systems: Exploring more sustainable options in semi-arid Zimbabwe. *Agricultural Systems*, 134, 48–60. <https://doi.org/10.1016/j.agsy.2014.06.009>
- Umar, B. B., Aune, J. B., Johnsen, F. H., & Lungu, I. O. (2012). Are smallholder Zambian farmers Economists? A Dual-analysis of farmers' Expenditure in Conservation and conventional

- Agriculture systems. *Journal of Sustainable Agriculture*, 36(8), 908–929. <https://doi.org/10.1080/10440046.2012.661700>
- Valbuena, D., Erenstein, O., Tui, S. H. K., Abdoulaye, T., Claessens, L., Duncan, A. J., Gerard, B., Rufino, M. C., Teufel, N., van Rooyen, A., & van Wijk, M. T. (2012). Conservation Agriculture in mixed crop-livestock systems: Scoping crop residue trade-offs in Sub-Saharan Africa and South Asia. *Field Crops Research*, 132, 175–184. <https://doi.org/10.1016/j.fcr.2012.02.022>
- Van Hulst, F. J., & Posthumus, H. (2016). Understanding (non-) adoption of Conservation Agriculture in Kenya using the Reasoned Action approach. *Land Use Policy*, 56, 303–314. <https://doi.org/10.1016/j.landusepol.2016.03.002>
- Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B., & Nolte, C. (2014). A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, 155, 10–13. <https://doi.org/10.1016/j.fcr.2013.10.002>
- Vogel, H. (1994). Weeds in single-crop conservation farming in Zimbabwe. *Soil and Tillage Research*, 31(2-3), 169–185. [https://doi.org/10.1016/0167-1987\(94\)90078-7](https://doi.org/10.1016/0167-1987(94)90078-7)
- Wainaina, P., Tongruksawattana, S., & Qaim, M. (2018). Synergies between different types of agricultural technologies in the Kenyan small farm sector. *The Journal of Development Studies*, 54(11), 1974–1990. <https://doi.org/10.1080/00220388.2017.1342818>
- Ward, P. S., Bell, A. R., Droppelmann, K., & Benton, T. G. (2018). Early adoption of conservation agriculture practices: Understanding partial compliance in programs with multiple adoption decisions. *Land Use Policy*, 70, 27–37. <https://doi.org/10.1016/j.landusepol.2017.10.001>
- Ward, P. S., Bell, A. R., Parkhurst, G. M., Droppelmann, K., & Mapemba, L. (2016). Heterogeneous preferences and the effects of incentives in promoting conservation agriculture in Malawi. *Agriculture Ecosystems & Environment*, 222, 67–79. <https://doi.org/10.1016/j.agee.2016.02.005>
- Westengen, O. T., Nyanga, P., Chibamba, D., Guillen-Royo, M., & Banik, D. (2018). A climate for commerce: The political agronomy of conservation agriculture in Zambia. *Agriculture and Human Values*, 35(1), 255–268. <https://doi.org/10.1007/s10460-017-9820-x>