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Assessing the contributions of conservation agriculture to building resilience to drought

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TABLE OF CONTENTS

List of Tables

Acronyms

CA	Conservation Agriculture
CSA	Climate Smart Agriculture
DFID	Department for International Development
SSA	Sub-Saharan Africa
FAO	Food and Agricultural Organisation of the United Nations
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
SOC	Soil Organic Carbon

Executive Summary

This literature review summarises theory and evidence of the contribution of conservation agriculture (CA) to resilience in the event of drought. A resilient agricultural system is able to continue to function and provide essential ecosystem services, such as food provisioning, following an external shock. If drought occurs, a more resilient system should offer higher productivity and food security. The review asks whether CA improves productivity and food security when rainfall is poor, and what aspects of CA contribute most to these benefits. The review will guide the design of a field study on the impacts of CA after the 2015/16 El Nino drought in southern Africa.

Conservation agriculture combines three basic sets of technologies or practices: i) minimum or reduced tillage, ii) maintenance of soil surface cover using crop residues, and iii) crop diversification using rotations. CA has been identified as a climate smart agricultural practice because it improves crop productivity, improves resilience of cropping systems to climate change, and mitigates greenhouse gases. In Southern Africa two forms of CA have recently been promoted: a manual version based on digging planting basins, and a mechanised practice based on the use of soil rippers and direct seeders or jab planters. Due, in part, to inaccessibility of CA equipment, most smallholder farmers in the region are practising manual CA techniques.

Conservation agriculture has been widely adopted around the world, especially in relatively more commercial farming systems. Most of this involves a shift from tractor ploughing to mechanical ripping linked with the maintenance of crop residues, and pursuit of rotations. South America has the largest area under CA, accounting for more than 70% of cultivated lands. The adoption is also significant in parts of the United States and Australia. The main drivers of adoption in these regions are time, labour and fuel savings contributing to a higher economic returns coupled with soil protection. CA has been widely promoted in Sub-Saharan Africa (SSA), but with much lower levels of success. This is partly because the technology conflicts with the resource demands of local farming systems. Tractor use is uncommon in most countries. Therefore, the cost savings obtainable from CA are more limited. The requirement of crop residue mulching conflicts with the use of these residues for feeding livestock. Implementing crop rotations is hampered by unavailability of legume seed, and preferences to allocate most land to staple cereals. Minimum tillage is associated with increased weed pressure. This requires farmers to perform multiple weeding putting strain on the available labour. Herbicide is either unavailable or expensive.

Partly as a consequence of these constraints, farmers in SSA have commonly adopted components of CA, rather than the full package. These may be applied with or without other critical crop management inputs such as fertiliser, or timely weed management. As a result, it is difficult to quantify true rates of adoption, or the payoffs to CA alone. This makes the evaluation of the contributions of CA to farm resilience in the event of drought much more difficult.

> **The main finding from literature is the consistency with which yields seem to be improved in the event of drier weather conditions, or in relatively more arid agro-ecologies, as a result of CA.**

Correspondingly, it is difficult to interpret some of the literature on CA adoption and performance in SSA. Debate persists regarding what constitutes a minimum definition of CA for the purposes of quantifying adoption. Evaluations of performance are commonly comparing different types of CA with different forms of 'conventional technology'. They consider CA with higher or lower levels of fertilization; or with varying levels of weed control. Measurements may be taken on the research station, on farmers' fields but under strictly controlled experimental conditions, or on farmers' fields without experimental controls. Unfortunately, these distinctions are not consistently clear in some of the literature.

This review aims to identify common sets of results most relevant to the consideration of CA performance in drought-prone environments. These include both formal experimental results, and evidence derived from household surveys of practice under farmer management. The main aim of the review is to characterize areas of agreement about the performance of these technologies. This includes agreements about what impacts CA is theoretically expected to have on crop and crop systems performance, as well as the evidence of field observations. Areas of major uncertainty, or contradictions in experimental results, are also identified.

The literature generally highlights the productivity gains offered by CA, and shows larger improvements derived from CA in conjunction with higher average levels of fertilization. This implies that fertiliser enhances the efficacy of CA, especially when applied in planting basins.

One of the most consistent findings is that CA contributes to increasing average farm yields in drier conditions. This result is attributed to the contributions of planting basins, mulch, and improved soil structure to improving water infiltration, and improving water holding capacity of the fields. Over time, improvements on soil organic matter (SOM) also help. But the literature suggests this will not prevent crop loss under the most severe water stresses and drought.

The main finding from literature is the consistency with which yields seem to be improved in the event of drier weather conditions, or in relatively more arid agro-ecologies, as a result of CA. These findings justify a closer look at the contributions of CA in the context of the 2015/16 drought in southern Africa. A follow up farm survey will be conducted in some of the most drought affected areas of Zimbabwe and Zambia where CA is being practiced. The survey will seek to answer the following questions: Did farmers who adopted CA, or some parts of the CA package, achieve better yields than their neighbours who faced similar seasonal conditions, but used more conventional, non-CA crop management practices? Is the improved probability of a harvest measurably linked with the adoption of CA, or with a related practice such as higher levels of fertiliser use or better weed control? If CA clearly contributes to improved performance, why are some households continuing to apply these technologies while their neighbours are not? What are the implications for future efforts to promote the adoption of CA, or further refine the CA technology package?

“The term ‘conservation agriculture’ has been coined principally to differentiate tillage practices.

1 Introduction

Conservation agriculture (CA) is a practice that combines three basic components; i) minimum or reduced tillage, ii) maintenance of soil surface cover using crop residues, and iii) crop diversification using rotations (FAO, 2015). CA seeks to attain productivity gains while improving environmental sustainability, increase resilience to weather extremes, increase food security, alleviate poverty, conserve biodiversity and safeguard the ecosystem (FAO, 2015; Giller et al., 2009). Although CA emphasises three principles for use across different agro-ecological zones and in a wide variety of farming systems (Hobbs et al., 2008), adoption of CA has frequently been piecemeal as farmers adapt the technology to local environmental and socio-economic conditions (Pannell et al., 2014). For example, in Zimbabwe a variant of CA emphasises the digging of planting basins and application of small doses of fertiliser in order to enable early planting for smallholder farmers with limited access to draft power (Mazvimavi and Twomlow, 2009). Smallholder farmers in SSA rarely apply all the three principles together. Sometimes they add additional components to the CA system.

The term 'conservation agriculture' has been coined principally to differentiate tillage practices – between no or low-till systems and what is viewed as 'conventional' soil preparation with a plough. In CA, the degradative components are removed from conventionally tilled agricultural systems. Tillage that damages soil structure and breaks down soil organic matter (SOM), insufficient return of organic matter to the soil, the lack of protection of the soil surface, and monoculture, are replaced with minimum soil disturbance, crop residue retention and crop rotation. Rates of fertiliser application may be variable. CA is not necessarily a low-external-input system (Wall, 2009) CA is generally promoted as a highly productive system, but one that may function poorly with poor management.

Governments, with donor support, have been investing larger sums to promote the wider adoption of CA in response to the growing body of research emphasizing the positive contribution of this technology within the smallholder farming systems of SSA (Arslan et al., 2014). These initiatives cite empirical evidence suggesting that CA increases crop yields and net revenue, improves soil fertility, increases soil biodiversity and mitigates greenhouse gas emissions (Thierfelder and Wall, 2009; Pannell et al., 2014; Giller et al., 2015; Powlson et al., 2016). Correspondingly, CA has been proposed as a more sustainable farming option with the potential to address a broad set of farming constraints such as low crop productivity, vulnerability to drought, lack of draft power, increasing levels of soil degradation, and loss of fertility (Kassam et al., 2009).

1.1 CA Principles and Productivity Effects

The practice of minimum soil disturbance stabilises soil structure, and improves soil fertility, offering a more balanced ecosystem. By reducing tillage, the soil is left undisturbed which contributes to soil water storage, and helps regulate soil moisture and temperature fluctuations (Ngwira et al., 2013; Thierfelder et al., 2015b). In contrast, conventional tillage practices have been associated with increased physical, chemical and biological soil degradation (Andersson and Giller, 2012; FAO, 2015; Thierfelder and Wall, 2012).

Permanent organic soil cover protects the soil surface from erosion, and creates a stable and favourable micro-climate for plant growth. Spreading of available crop residues as surface mulch prevents soil losses from the physical impact of rain and wind, conserves soil moisture by reducing evaporation, and enriches the soil nutrients by increasing soil microorganisms added in the decomposition of organic matter ((FAO, 2015; García-Torres et al., 2003; Giller et al., 2009; Erenstein, 2003; Andersson and Giller, 2012). Mulching with crop residues has been shown to reduce early weed growth, reducing labour demand early in the season. However, due to competing demands for crop residues for animal feed and thatching, smallholder farmers may be unwilling to leave enough quantities of crop residues in the field to effectively reduce weed pressure (Valbuena et al., 2012).

Crop rotation calls for farmers to alternate legumes with their cereal crops which improves soil fertility by fixing nitrogen and enhancing biodiversity (Andersson and Giller, 2012; Andersson and D'Souza, 2014; FAO, 2015). One of the main reasons for crop rotation in CA systems is to avoid problems of pests and diseases harboured in the residue (Thierfelder and Wall, 2010b). Crop rotation can suppress the development of weeds, arthropod pests and soil-borne diseases by reducing their population levels in the soil. Crop diversification with legumes and cover crops, instead of a fallow period, leads to improved productivity through fertiliser use efficiency and water use efficiency (FAO, 2012; FAO, 2015; Andersson and D'Souza, 2014).

1.2 CA Practices in Sub-Saharan Africa

There are two primary methods for implementing CA in SSA: manual and mechanised. The distinguishing feature of manual CA is achieving the principle of minimum soil disturbance through the digging of planting basins (Mazvimavi and Twomlow, 2009; Andersson and D'Souza, 2014). The basin tillage system, similar to the *Zai* system that originated in West Africa, consists of simple planting pits made by hand hoes. Farmers are expected to plant their seed, and apply any fertiliser by hand each year in the same pit (Andersson and D'Souza, 2014; Mazvimavi and Twomlow, 2009; Giller et al., 2009). Mechanised CA involves the use of ox or tractor-drawn 'rippers' and seeders for achieving reduced tillage. Alternatively, these farmers may use oxen to rip their fields and then use a jab planter to plant their fields by hand. The hand-jab planter is a simple and relatively low cost implement for penetrating surface mulch and depositing seed and fertiliser at the required soil depth.

In parts of Southern Africa, the term CA is sometimes used interchangeably with the term Conservation Farming (CF) or the term Conservation Tillage (CT) (Mazvimavi and Twomlow, 2009). CF describes a particular form of CA with small basins (covering 8–15% of the field surface) dug in the same place each year, and inputs and seed concentrated in these basins. CT refers to any system that maintains at least 30% soil cover with residues after seeding (Soil Science Glossary Terms Committee, 2008).

1.3 Areas Planted to CA

The global area under CA systems is estimated at 125 million hectares (ha) or about 9% of the world's crop land (Friedrich et al., 2012). The countries in the world with the largest areas under "CA" are actually under no-tillage, which incorporates two of the CA components; minimum tillage and residue retention. These are the USA with 19.3 million ha, followed by Brazil with 11.2 million ha, Argentina with 7.3 million ha, Canada with about 4.1 million ha, Australia with 1 million ha, and Paraguay with 790.000 ha. Though the USA has the largest area under no-tillage, the technology is only applied on 16% of total cultivated area. The largest share of land under no-tillage cultivation is in South America, where Argentina, Brazil, Paraguay and Uruguay are using the system on about 70% of the total cultivated area (Jat et al., 2014). Table 1 shows that South America has the biggest share of land under no-tillage compared to the other continents. Increased yield has not been the main driver for no-tillage adoption in countries with high adoption rates. Instead, these farmers are adopting no-tillage in order to save time, labor, and tractor fuel. They expect to achieve higher economic returns along with soil protection (Jat et al., 2014).

Table 1: Area planted to CA in the World

Country	CA area (million ha)
South America	55,464
North America	39,981
Australia and New Zealand	17,162
Russia and Ukraine	5,100
Asia	4,723
Europe	1,351
Africa	1,013

Source: Adapted from Friedrich et al. (2012).

Conservation agriculture is believed to be increasing in SSA, particularly in Eastern and Southern Africa (Andersson and Giller, 2012; Andersson and D'Souza, 2014). Table 2 shows the area planted to CA in Sub-Saharan Africa as calculated by Friedrich et al. (2012). Adoption rates in SSA are highest in areas where mechanised agriculture is common, such as South Africa. However, available data also suggest significant adoption of manual CA by smallholders, especially in

Zambia, where an estimated 200 000 smallholders have adopted CA (Arslan et al., 2014), and in Zimbabwe, where an estimated 130 000 smallholder farmers have adopted CA (Mazvimavi, 2011).

Table 2: Area planted to CA in Sub-Saharan Africa

Country	CA Area (ha)
South Africa	368,000
Zambia	200,000
Mozambique	152,000
Zimbabwe	139,300
Kenya	33,000
Ghana	30,000
Tanzania	25,000
Malawi	16,000
Sudan	10,000
Madagascar	60,000
Lesotho	2,000
Namibia	340
Total	981,640

Source: Adapted from Friedrich et al. (2012).

1.3.1 What is CA adoption

The relative accuracy of these estimates of adoption, however, is subject to debate. Much depends on the definition of CA considered. Adoption studies do not consistently define the CA package being applied. Nor do they clearly account for the ambiguities of partial adoption (Andersson and D'Souza, 2014; Giller et al., 2015).

'CA adopters' commonly redesign the CA package to fit their own environmental and socio-economic conditions (Mazvimavi and Twomlow, 2009; Andersson and D'Souza, 2014). The majority of smallholder farmers reported to be practising CA in southern Africa are in fact practising minimum tillage with improved fertility management (Baudron, 2007; Mazvimavi and Twomlow, 2009). Rotation may be partial. The use of crop residues may be limited. In effect, these farmers are evaluating the technology and adopting those components of the package believed most useful(Mazvimavi and Twomlow, 2009). Even so, this may only be applied on a limited portion of their land. Furthermore, adoption rates vary by crop (maize and cotton), gender, and length of experience with CA.

1.4 Challenges in CA Adoption

The adoption of any technology will only occur when the perceived benefits of the technology exceed the perceived costs (Erenstein 2003). The benefits and costs of CA vary substantially depending on the constituent elements of the technology being applied and the characteristics of the farming environment. While some studies of CA demonstrate large yield gains under CA (Fowler and Rockstrom, 2001), these results may be contingent on the adoption of all three

CA practices. Similarly, claims that CA is labor saving may only apply to mechanised CA. Giller et al. (2009) discuss these issues and argue that CA may not be profitable for all categories of farmers. Farm resource and environmental constraints often limit adoption to just one or two of the three components that constitute CA.

One of the major constraints to adoption of the entire CA package is the perception that CA requires a high level of knowledge and skill (Wall et al., 2014). Many farmers question the feasibility of merely planting without first ploughing. and this practice contradicts traditional beliefs (Kassam et al., 2009). In addition, uptake of CA technologies is more complicated than the application of conventional tillage systems because of the multiple components of the technology, and the expected evolution of rotations over multiple years (Pannell et al., 2006).

The higher adoption rates in many developed countries have been attributed to both the commercial orientation of these farms, and the immediate cost savings obtained in these mechanised systems (Kassam et al., 2009). Farmers in developing countries may find that CA initially increases their costs due to the need to purchase new farming equipment or inputs (e.g. rippers, small-scale seeders, or herbicides). Some of this equipment may not be readily available.

The requirement for continuous soil cover with crop residues, as a mulch, has been identified as a major obstacle to smallholder CA compliance (Giller et al., 2015; Erenstein, 2003). Numerous studies have pointed to the fact that implementing CA requires a trade-off between different uses of crop residues in crop-livestock farming systems (Valbuena et al., 2012; Erenstein, 2003; Rusinamhodzi et al., 2013). In smallholder farm settings where communal grazing lands provide the bulk of dry season feed, using crop residues for mulch in CA imposes an opportunity cost in the form of livestock feed (Erenstein, 2003; Valbuena et al., 2012). In most regions of SSA, crop residues become a communal resource after harvest for free-range feeding of livestock. Therefore protecting the crop residues from free grazing through fencing of plots may require renegotiation of traditional rules or local by-laws (Erenstein, 2003).

The key challenge to adoption of crop rotations is the preference of farmers to plant the largest portion of their land to a staple cereal like maize in order to assure household food security. Virtually all farmers practice a limited amount of rotation on a small portion of their fields. Farmers also recognize the value of rotating cereal crops with legumes. But if the legume only accounts for 10 to 15 percent of cropped area, the opportunity to rotate is limited. Furthermore, if the legume is targeted toward lighter textured soils, this rotation may be viewed as inappropriate in some parts of the farm. Decisions to plant legumes, and their use in rotation are also influenced by limited markets for legume grains. Additionally, rotations are sometimes limited by the unavailability of seed (Mazvimavi and Twomlow, 2009; Pannell et al., 2014).

In rotations with commonly grown legumes such as groundnut or bambaranut, the CA principle of minimum soil disturbance is essentially compromised by the fact that harvesting requires the crop to be pulled from the soil (Thierfelder et al., 2013b). Farmers are also hesitant to plant legumes in permanent planting basins because the recommended spacing differs from that commonly used for cereal crops (Baudron, 2007). According to Andersson and D'Souza (2014), legume production is also likely to compromise the CA principle of permanent soil cover, as legume residues are often preferred as animal feed or, when retained, they disintegrate very quickly.

Andersson and Giller (2012) view weed pressure as a limiting factor in the adoption of CA. Minimum tillage has a tendency to increase labor requirements for weeding and land preparation, at least in the first two or three seasons (Andersson and D'Souza, 2014; Friedrich et al., 2012; Mashingaidze et al., 2012; Rusinamhodzi, 2015). The reallocation of labour, especially to weeding, often implies more work for women. One of the primary motivations for conventional tillage is weed control (Baudron, 2007). One of the challenges of CA adoption is finding alternatives for weed management. One alternative for weed control with CA is the increased use of herbicides. However, smallholder farmers often lack the cash to invest in these agrochemicals (Mashingaidze et al., 2012). The accessibility of herbicides and other key inputs is also limited in many areas where CA is being promoted.

Some agencies in Asia and Africa have sought to speed the adoption of CA by providing promotional incentives to smallholder farmers such as subsidised fertiliser support (Andersson and D'Souza, 2014). Assessment studies then need to consider whether any gains derived from CA result from the component CA technologies themselves or the fertiliser.

In general, observers have concluded that the uptake of CA as a package in Africa has been disappointing. Many challenges remain for targeting and adapting these systems to the diverse needs of different groups of smallholders (Erenstein et al., 2012; Giller et al., 2015; Giller et al., 2009; Friedrich et al., 2012). Ultimately, some researchers have simply questioned the suitability of CA for smallholder farmers in most of SSA (Giller et al., 2009; Gowing and Palmer, 2008; Baudron et al., 2012). Debates about the future of CA continue among researchers and development practitioners.

2 Contribution of CA to Crop Resilience

High priority needs to be placed on improving the resilience of smallholder farming systems to climate shocks given the dependence of these communities on agriculture for the provision of food, feed, fodder, fuel and income (Frelat et al., 2016). Climate-related farming risks are particularly high in SSA's predominantly rainfed farming systems (Cooper et al., 2008). As climate changes, the risks associated with rising temperatures, rainfall variability (change in patterns, onset and amounts), and extreme weather events such as droughts and floods are expected to worsen (Thornton et al., 2009).

CA has been widely promoted in smallholder farming systems in SSA as a practice for building resilience against climate change and variability. Recognizing that what is promoted as CA is often not what has been adopted, we will first discuss agronomic theory behind CA's contribution to crop resilience. We then discuss the broad evidence of CA's contribution to crop resilience available from studies of farming practices.

2.1 Theoretical Contribution of CA to Crop Resilience

CA is a composite technology; however, given the proclivity of smallholder farmers to adopt parts of this package it is important to understand the expected contribution from each component of the technology. In general, agronomic theory suggests that CA should improve adaptive capacity and reduce crop vulnerability to extreme climatic events (Friedrich et al., 2012). While CA may not be able to overcome the most severe droughts, agronomic theory suggests that it can help to reduce crop water deficits during mid-season dry spells, particularly during critical phonological stages such as flowering.

The lack of soil disturbance and the presence of surface mulch improve moisture storage in soil while reducing evaporation (Klocke et al., 2009; Bescansa et al., 2006). In water scarce conditions, the improvement of soil moisture storage facilitates deeper rooting of crops (Giller et al., 2015; Giller et al., 2009; FAO, 2012; Rusinamhodzi et al., 2011). This allows plants to take advantage of larger areas of soil moisture. This is expected to enable crops lacking supplemental irrigation to bridge severe mid-season dry spells (Rockström et al., 2010; Rockström et al., 2003; Thierfelder and Wall, 2010a).

The increased soil moisture conservation is also associated with regulation of heat stress, which is prevalent with the changing climate (Cairns et al., 2013, Lobell et al., 2008). In many warmer environments, cooler soils improve seedling establishment and crop growth. These also further reduce water evaporation.

Semi-arid areas of southern Africa commonly experience flash floods and long mid-season dry spells. The combined use of planting basins and soil cover in the CA package helps , capture the limited rainwater arriving in high-intensity storms helps reduce soil erosion (Mupangwa et al., 2007; Thierfelder and Wall, 2009). Soil losses of up to 50 Mg ha year have been reported under conventional agricultural systems in Zimbabwe (Elwell and Stocking, 1988). Again, the combination of low-till systems and mulch reduces both wind and water erosion of soils (Rosenstock et al., 2014; Mupangwa et al., 2008) and can reverse soil degradation associated with soil erosion (Hobbs, 2007; Knowler and Bradshaw, 2007) of the CA practice of minimum soil disturbance improves water-retention and enables more efficient use of rainwater in the soil which considerably reduces the risk of crop failure due to drought (Kassam et al., 2009; Erenstein, 2003). Planting basins reduce the risks of crop failure by improving the concentration of water and available soil fertility amendments within the basin with the seed or young plant. This appears particularly valuable under drought conditions.

Hussain et al. (1999) observed that the combination of tillage and mulch management has potential to substantially improve crop yields and soil conditions in the semi-arid tropics. Corbeels et al. (2014) concluded that mulch is a major factor in influencing the performance of CA systems. Hobbs and Govaerts (2010) identify CA as a climate change adaptation strategy because improved soil quality and improved nutrient cycling are expected to strengthen crop growth, and therefore increase the resilience of crops to variable rainfall and higher temperatures.

One of the main objectives of climate smart agriculture is the reduction of greenhouse gas emissions. Reduced tillage systems are expected to improve carbon sequestration by raising the levels of soil organic matter, also known as soil organic carbon (SOC). The principal benefit to smallholder farming systems is found in the contributions of higher levels of organic carbon to improving water holding capacity of the soil and soil structure (Sanchez 2002). Since these gains take many years to be achieved, few smallholder place priority on these objectives. Instead, they prioritize more immediate gains in productivity, production and food security(Govaerts et al., 2009; Lal, 2004). Nonetheless, the secondary benefits obtained from improving soil quality, and SOC specifically, are expected to increase the resilience of these cropping systems to drought in the future.

Crop diversification through crop rotations or intercropping with legumes such as cowpea, groundnut, pigeon pea, and common bean, or with cash crops such as cotton have been promoted as a component of CA (Rusinamhodzi et al., 2012; Thierfelder et al., 2013a). The greater biodiversity in ecosystems is associated with greater resilience because of the ability to break the pest and disease cycles that are likely to increase with climate change (Lin, 2011). The legumes also fix nitrogen, which improves soil fertility, nutrient cycling and SOC, thus increasing crop productivity (Smith et al., 2008Drinkwater et al., 1998).

2.2 Evidence of CA's Effects on Drought

Farmers commonly perceive CA as a technology appropriate to dry areas because it allows them to improve their productivity and profitability while conserving and even improving the natural resource base and the environment (Gowing and Palmer, 2008). A study by Lalani et al. (2016) found that farmers perceived that CA performs better in a drought year. The perception of farmers is that CA reduces the risk of crop failure associated with moisture deficit. Similarly, Arslan et al. (2014) found that households in districts with high rainfall variability are more likely to adopt CA because of its ability to conserve soil moisture and improve crop yield. This supports the hypothesis that farmers perceive CA as a technology that can mitigate the effects of variable rainfall and improve the efficiency of soil water management. The finding that adoption is significantly higher in areas of high rainfall variability provides suggestive evidence for potential benefits of CA for adaptation to climate variability (Arslan et al., 2014).

A number of scientific studies highlight the justifications for these perceptions. These indicate that the water harvesting properties of CA practice are more beneficial under low rainfall conditions (see Table 3). However, these studies also suggest that under high rainfall conditions, CA may reduce water drainage and the use of mulch can lead to water logging which results in decreased yields. While a few studies find that yields under CA decrease during arid spells (Baudron et al., 2012; Corbeels et al., 2014b, Ndlovu et al., 2014), the majority of studies demonstrate that CA can outperform conventional methods in semi-arid and arid climates. Several studies highlight that CA increases crop yields only in arid climates (Mafongoya et al., 2016; Nyamangara et al., 2014; Ngoma et al., 2015).

Table 3: Evidence of the effect of yield on CA compared to conventional agriculture under low rainfall conditions

Author	Study country	Crop	Main finding	Comment
(Gatere et al., 2013)	Zambia	Maize	Positive yield effects are experienced in the drier agro-ecological zones below 1000mm mean annual rainfall	Benefits of CA through water harvesting by the basins and water logging effects depressed yield under high rainfall regimes.
(Ngoma et al., 2015)	Zambia	Maize	CA has greater yield impact in the drier areas compared to the wetter areas	Ripping and planting basins can raise maize yields if tillage is done early.
(Nyagumbo et al., 2016)	Malawi Mozambique	Maize, Legume	Yield stability analysis showed that CA basins were superior in dry and unfavourable rainfall conditions compared to farmer practice	Water harvesting effect
(Farooq et al., 2011)	Various	Various	CA yields mostly higher than conventional systems where annual rainfall was below 560 mm.	CA can compete with convectional tillage on a purely crop production basis and also has well-established environmental benefits
(Rusinamhodzi et al., 2011)	Various	Various	Maize yield was higher with CA practices when mean annual precipitation was below 600mm (dry conditions)	Moisture conservation effects in low rainfall areas under CA and compromised drainage in high rainfall areas
(Rockström et al., 2009)	Kenya, Ethiopia, Tanzania, Zambia	Maize, Tef in Ethiopia	Higher yields were obtained for CA plus fertiliser treatments over conventional treatments in most locations.	CA constitutes a water harvesting strategy.
(Nyamangara et al., 2014)	Zimbabwe	Maize	Yield benefits of CA were observed in the drier parts of the country receiving less than 650 mm annual rainfall. A higher weighted mean difference under CA for the lower rainfall range and this was notably so when basins were used	Better water availability under CA because of water harvesting in the basins, particularly at the beginning of the season enhances crop establishment.
(Baudron et al., 2012)	Zimbabwe	Cotton	Cotton yields under CA were significantly lower in the drier season compared to conventional tillage	The physiology of the crop could explain the low yields in dry areas
(Corbeels et al., 2014b)	SSA	Variety of crops	Lower crop yields observed under drier regimes for CA systems. CA yield benefits relatively low under dry climates	High level of variability in rainfall during the growing season with occurrence of dry spells Strong mulching effects on soil – water balance.
(Erenstein, 2003)	Mexico	Maize	Difference in yield was more remarkable in the marginal rainfall zone, where the grain yield from CA is 930 kg / ha.	Water availability under CA contributing to improved productivity in marginal rainfall areas
(Zheng et al., 2014)	China	Maize, Rice Wheat	Crop yield increased under CA practices with increase in aridity index.	Water retention properties of CA aiding crop growth under moisture stress

Author	Study country	Crop	Main finding	Comment
(Ndlovu et al., 2014)	Zimbabwe	Maize	Less yield benefits are realised from using CA in the drier areas but the net incremental effect on yield is above 100%	Crop production is constrained by very dry conditions despite application of CA.
(Hussain et al., 1999)	USA	Maize Soybeans	Yields under CA practices were 10–100% higher in relatively dry year than under conventional tillage practices.	Water retention properties of CA aiding crop growth under moisture stress
(Thierfelder and Wall, 2009)	Zambia Zimbabwe	Maize	Results suggest that CA has the potential to increase the productivity of rainfall water and therefore reduce the risk of crop failure	Full potential of CA in mitigating drought were not evident as there was no significant drought period in either season.
(Thierfelder and Wall, 2010b)	Zambia	Maize	CA plots had higher infiltration rates leading to higher soil moisture levels that were found to improve yields in a poor season.	CA is primarily a water harvesting and conservation strategy
(Thierfelder and Wall, 2012)	Zimbabwe	Maize	In CA system, yield reductions were observed in very wet seasons.	Water-logging effects especially in the short term

One problem is that the research methods and sources of data underlying these studies are not consistently or thoroughly described. Some of the studies rely on data from agronomic field trials, under varying levels of farmer management, and some cite data from household surveys. The results are derived from different levels of CA adoption. In many cases only a subset of the three CA components are applied. While fertiliser is commonly applied in these trial conditions, the rates of application vary considerably, and may thus confound these results. The control treatments underlying the various studies differ. In some cases, this is a simple comparison of CA performance in wet and dry zones. In others, CA is being compared with conventional tillage treatments in one agro-ecology. Differences in results are also expected depending on the experience of the farmer and the number of years that CA has been applied. A portion of the benefits from CA, particularly those related with improvements in SOC and soil structure may only be realised in the longer term (Mando et al., 2005). Giller et. al. (2009) note that it can take between five to fifteen years for the full benefits of CA to manifest themselves.

2.3 Evidence Gaps on the Question of Whether CA Builds Resilience to Drought

There is a general consensus regarding the definition of CA based on the three principles laid out by FAO (2015). However, there is much less clarity on the definition of CA as practiced by farmers. The primary element of the CA package and basis for field classifications seems to be the tillage practice. If a farmer is applying reduced tillage, either with a mechanical ripper or a planting basin, they tend to be classified as a CA adopter. They may or may not maintain a significant level of crop residues. More likely than not the level and consistency of crop rotations will be limited. Yet much of the theory, and a large portion of the research evidence, tracks the advantages of the full CA package. In further field investigations, it is important to be more exact about the definitions of CA being measured. Given variable adoption rates, it is also important to measure the contributions of partial adoption of only a sub-set of CA components on productivity and resilience. Is adoption of all three CA components required or can farmers significantly benefit by only adopt one or two of these components? How much do adoption benefits depend on the use of complementary inputs like fertiliser, and on the levels of fertiliser applied?

The adoption data for CA are highly variable. While many farmers seem to identify the value of CA, or at least parts of the CA package, adoption rates remain generally low. Neighbouring farmers view the package differently. Farmers with the same apparent resources and opportunities adopt and do not adopt. Some farmers adopt and later disadopt part or all of the CA package. A closer review of adoption in a single environment can help characterize the main drivers of adoption and possibly explain why neighbouring farmers make different decisions.

Related to this issue, there is a need to better understand what drives farmers to adopt one CA component but not the others. There is evidence that many farmers are continuing to use planting basins across wide stretches of the semi-arid agro-ecologies of Zimbabwe. Both mechanical ripping and planting basins continue to be widely applied in Zambia. Yet only a portion of these farmers are maintaining their crop residues and practising consistent crop rotations. Again, there is a need to know what differentiates these farmers, and whether the partial adoption strategies are justified.

Finally, data measuring the benefits of CA under non-experimental conditions, under the farmer's own management, are limited. Data drawn from the experiment station or from closely managed on-farm trials may reveal different results from the much more variable results of farmer practice. The fact that many farmers continue to apply at least basic elements of the CA package suggests they see value in the technology. Field surveys highlight the fact that many farmers see advantages in low rainfall environments. The level and source of these advantages need to be better understood in order to identify how CA should best be promoted as a contribution to climate resilience.

3 Conclusion

Based on evidence generated from the literature, especially from research in SSA, CA seems to provide improved resilience to climate change, and to drought in particular. Higher productivity and production levels are made possible by the combination of moisture conservation, improved water storage, lower evaporation, lower soil temperatures, and the concentration of water in the root zone. Gains are recognised even if only a portion of the CA package is adopted.

Paradoxically, however, despite the high risks of drought in southern Africa, the rates of adoption of CA have remained unexpectedly low. While many early adopters continue to the low or no till technologies, others have dropped the package. There is little information to explain why.

This literature review justifies a closer look at the performance of CA, in its multiple variants, and the determinants of variable adoption in the field. These results highlight the particular value of examining whether CA contributed to improving the likelihood and level of a harvest despite the relatively severe 2015/16 drought in Zimbabwe and Zambia. Which component practices contributed most to improving the resilience of the cropping system? Do neighbouring farmers, some adopting, and others not adopting, see these differences. Could non-adopters become adopters as a result of these experiences? What are the implications for future drought relief programs?

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