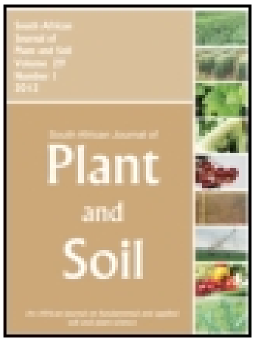

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Review Paper

A review of conservation agriculture research in South Africa

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Conservation agriculture (CA) is advocated as a sustainable farming method to improve soil health, increase crop yields and food security, while reducing input costs. In South Africa, a country with low rainfall, limited agricultural lands and a large smallholder farming community, implementing CA is imperative. To investigate the research status of CA in South Africa, a systematic review of available literature was conducted. Conservation agriculture initiatives as captured in the form of peer-reviewed publications, reports, dissertations, proceedings and projects were collected. Relevant data, such as location, type of research, CA treatments implemented, duration of interventions, main results, limitations and challenges were recorded. Most literature were in the form of peer-reviewed publications (45%). The CA interventions mostly occurred as researcher-managed field trials (60%), followed by farmer-led trials. While the interventions were fairly scattered throughout the country, there was a poor correlation between major crop-producing areas and research focus. Conservation agriculture interventions generally had a positive effect on soil properties and crop yield. Important limitations include poor reporting, short trial periods and insufficient data collection. Local research involving farmers is needed to support best-management practices for different agro-ecological zones.

Keywords: commercial agriculture, cropping systems, residue retention, smallholder agriculture, tillage systems

Introduction

South Africa is poorly endowed with agricultural resources, and much of the country is considered marginal and susceptible to degradation (Laker 2004). Soil organic matter (SOM) is naturally very low in South Africa, and it is estimated that 60% of the soils contain less than 0.5% SOM (Laker 2004; du Preez et al. 2011). Soil organic matter, or its indicator element soil organic carbon (SOC), are indicative of healthy, productive soils, while low SOM or SOC are typically associated with poor soil structure, soil crusting, low water infiltration and poor nutrient status (Mills and Fey 2003; Laker 2004). Carbon (C) is furthermore linked to climate change and agricultural production directly contributes to climate change by emitting greenhouse gases (Lal 2004; Powlson et al. 2016). However, agricultural soils not only contribute to greenhouse gas emissions, but are also the largest terrestrial sink of C with a high C sequestration and mitigation potential to reduce the impact of climate change (IPCC 2007). Conserving and increasing SOC is thus important for soil health, optimal crop production as well as climate change mitigation (Lal 2004; IPCC 2007). Poor agricultural management practices have contributed to the decline in organic C in agricultural soils (Mills and Fey 2003; Lal 2004; du Preez et al. 2011). For example, the already low SOC status of soils in South Africa is further compromised by cultivation, with an estimated average C loss of 46% (Swanepoel et al. 2016). Improving SOC in agricultural soils is considered critical for reviving and increasing productivity (Mills and Fey 2003; Lal 2004; du Preez et al. 2011).

Sustainable and regenerative agriculture practices, such as conservation agriculture (CA), that conserve or replenish SOC and improve soil health, are increasingly promoted in southern Africa as an alternative to conventional farming systems (Smith et al. 2016). The success of CA is *inter alia* attributed to higher SOM levels, resulting from the implementation of three linked CA principles: (1) continuous zero or minimum soil disturbance, (2) permanent organic soil cover and (3) crop diversification, especially with inclusion of legumes or cover crops (FAO 2007; Govaerts et al. 2009). There is general consensus among researchers that CA improves soil health by increasing SOM (Doran and Zeiss 2000; Lal et al. 2004; FAO 2007; Pittelkow et al. 2015). Increased SOC also sequestrates atmospheric carbon and thereby contributes to climate change mitigation targets (Lal 2004; Lal et al. 2004; Powlson et al. 2016). Despite its potential, CA has not yet been adopted by the majority of farmers in South Africa. In 2008/09 an area of approximately 5.2 million ha was under cultivation (DAFF 2016), of which 368 000 ha was under no-till cultivation (Derpsch et al. 2010), representing 7% of the total cultivated land.

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However, CA does not always lead to the desired improvements. This is usually the case when CA is applied incorrectly (i.e. where all the principles are not applied simultaneously and not adapted to the local situation) (Pittelkow et al. 2015). Challenges to implement CA correctly are found in all situations due to a myriad of possible socio-economic and biophysical factors and interactions (Pittelkow et al. 2015), such as under smallholder systems in the warm dry climates of southern Africa leading to yield decreases in some cases (Giller et al. 2009, 2015). One example often highlighted is the poor access to and use of appropriate rotation or cover crops by these smallholders, which is necessary to induce various benefits, such as adequate biomass for effective soil cover and increasing SOM (Giller et al. 2009, 2015; Powlson et al. 2016). However, farmers are able to transcend these challenges by successfully adopting and adapting CA in a wide range of conditions across the world (Kassam et al. 2014), raising the importance of using a systems approach when investigating and developing CA systems (Derpsch et al. 2014).

The aim of this paper was to evaluate the status quo of CA research in South Africa through a systematic review of published and unpublished literature, which include both formal researcher-managed studies, as well as community-based or farmer-centred research projects. In this review, the interventions were clustered and categorised according to different CA treatments applied (such as cropping systems and tillage practices), the temporal trend and geographical distribution of CA research. Even so, the vast range of topics and variables measured, the diverse CA treatments applied, and the different cropping systems investigated made it difficult to represent data quantitatively, and therefore a qualitative narrative approached was used. Where possible, key results were related to soil health, while gaps and future research needs were highlighted.

Materials and methods

Approach followed in the review process

Using a two-pronged approach, the following methods were applied to locate CA research outputs or interventions in South Africa: (1) a systematic literature search of peer-reviewed literature, and (2) exploiting the CA community and network to access grey literature. Only outputs published prior to March 2017 were included.

Method 1: a systematic literature search of peer-reviewed literature

This search was done using *Web of Science*™ as well as local agricultural journals, namely *South African Journal of Plant and Soil*, *South African Journal of Science* and *African Journal of Agricultural Research*. The following keywords were used in various combinations to construct research queries: 'conservation agriculture', 'cropping systems', 'crop rotation', 'cover crop', 'tillage', 'no-till', 'livestock' or 'livestock integration', 'mulch' or 'crop retention', and 'agriculture', which was geographically restricted to 'South Africa'. Each of the returned papers was screened by searching for the above-mentioned keywords in either the title or the abstract, ensuring that these keywords were used in the correct context. If the paper adequately addressed CA in South Africa, or any aspect thereof, the paper was retained for the review sample. For dissertations, South African university online libraries were searched, also using combinations of the above-mentioned keywords.

Method 2: exploitation of the CA community and network to access grey literature

Various relevant implementing agencies and institutions who have been doing research and development work on CA, including community-based or farmer-centred CA research projects, were contacted to request publications, such as reports, proceedings, presentations and/or registered project summaries. The CA network, which includes the key CA actors, such as the Agricultural Research Council (ARC), Grain SA, provincial departments of agriculture, universities, private researchers or consultants, non-governmental organisations (NGOs) and farmer groups (such as the KwaZulu-Natal No-till Club), were contacted in October 2016 and given eight weeks to respond. A second round of requests was extended in March 2017, with two weeks to respond.

It is acknowledged that not all CA research outputs that exist in South Africa were eventually captured by these two methods, but the documents and information that was received were henceforth used in the review process as a representative sample of CA research in SA.

Evaluation of study results

The CA outputs captured through the above-mentioned methods were first categorised according to their *type* and *nature*. The following *types* of outputs were obtained: (1) peer-reviewed papers, (2) reports, (3) dissertations, (4) conference proceedings or presentations, and (5) registered projects (reported by researchers from the CA community). The *nature* of the CA research initiatives was categorised as follows: (1) researcher-managed, on-farm and on-station field trials, (2) farmer-led, on-farm, field trials, (3) community-based interventions, demonstrations and surveys, (4) review publications (summary of existing research), (5) surveys (comparing contrasting treatments across large areas) and (6) other (including modelling based on laboratory trials).

The specific CA *treatments* applied, such as minimal tillage (including reduced or no-till), diversified cropping systems (including crop rotations, cover crops or livestock integration) and permanent soil cover (including mulch application or crop retention) were captured. The effects of these treatments on measured *variables* were then evaluated. The variables (such as grain yield or soil nutrient status) were categorised under five broad themes, based on factors affecting soil health, including soil biology, soil chemistry and soil physics (Doran and Zeiss 2000), as well as agronomic aspects and socio-economic impacts (FAO 2007; Knot 2014). Table 1 indicates the different topics from the publications as clustered under the five broad themes. In addition, dates of publication and/or implementation (to indicate temporal trends in CA research), location of initiatives (spatial distribution of CA research), study duration and constraints were extracted and analysed.

Table 1: Five conservation agriculture research themes with topics from publication results

Soil biology	Soil chemistry	Soil physics	Agronomy	Socio-economic
Microbial composition	Soil organic carbon	Soil water	Yield	Economic aspects
Enzyme activity	Nitrogen	Compaction	Biomass	Social acceptance
Nematodes	Phosphorus	Penetrometer resistance	Weeds	
Mycorrhizae	Nutrients	Aggregate stability	Residue	
Earthworms	Fertility		Leaf area index	
	Acidity		Seed quality	
			Planting density	

Results and discussion

A total of 147 CA research outputs were captured and analysed through the review process. The following percentages were captured under the different *types* of CA research output categories: peer-reviewed papers (45%), registered projects (24%), dissertations (14%), reports (10%) and proceedings (7%) (Figure 1). The *nature* of CA research interventions captured was ranked according to the following categories: researcher-managed field trials (61%), community-based interventions, demonstrations and surveys (18%), reviews (7%), surveys (7%) farmer-led, on-farm, field trials (5%), and other (1%) (Figure 1).

Although CA research in South Africa started in the early 1980s, the majority of the CA research outputs were produced fairly recently, with 70% of all outputs published after 2010 (Figure 2). This increase reflects a worldwide awareness regarding sustainable natural resource conservation and management. Compared with the global trends in CA research and adoption in the last few decades (Kassam et al. 2014), South African CA research has only shown a sharp increase in outputs since about 2010.

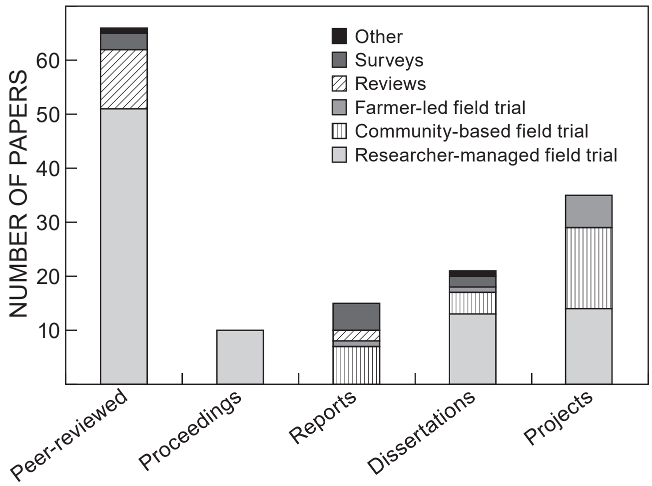

Figure 1: Number of conservation agriculture research outputs categorised under *type* and *nature*

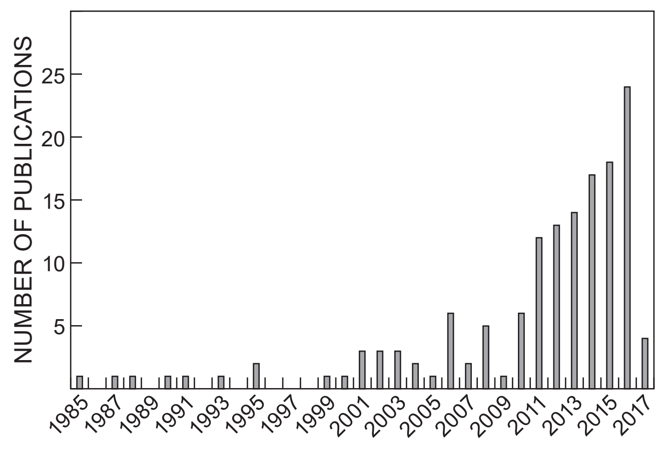

Figure 2: Trends in the number of conservation agriculture research outputs over time

Spatial distribution of CA interventions

Conservation agriculture interventions were scattered across South Africa, but the majority were clustered around established research sites linked to a few universities or research institutions, such as the ARC (Figure 3). The experimental farm of the University of Fort Hare in the Eastern Cape produced the most outputs (n = 19), followed by the Western Cape Department of Agriculture's Langgewens Research farm in the Swartland, Western Cape (n = 12) and the ARC Zeekoegat Experimental farm outside Pretoria in Gauteng (n = 10). The majority of sites (65%) produced only one output each. Most CA interventions occurred in the Eastern Cape (22%) and Western Cape (19%) provinces, mostly through community-based projects and demonstrations (Figure 3). Since 1997, national and provincial governments, in partnership with research institutions such as the ARC, launched a number of CA interventions under the banner of community-based natural resource management programmes, such as LandCare (under the Department of Agriculture, Forestry and Fisheries; DAFF), Conservation Agriculture Technologies (CATs; under the Department of Rural Development and Land Reform) and Eco-Technologies (under DAFF and provincial departments of agriculture), primarily to empower smallholder farmers (Smith 2006; Smith et al. 2016). Since 2010 CA research was increasingly supported and funded by the grain industry (mostly through the Maize Trust [MT] and Winter Cereal Trust [WCT]). In 2014 the CA Farmer Innovation Programme (FIP) was launched jointly by Grain SA, the MT and the WCT, to facilitate and coordinate CA research projects among commercial and smallholder grain farmers (Smith et al. 2016). A significant percentage of all the CA interventions has thus been focused on smallholder farmers, mostly in provinces with large communal areas, such as the

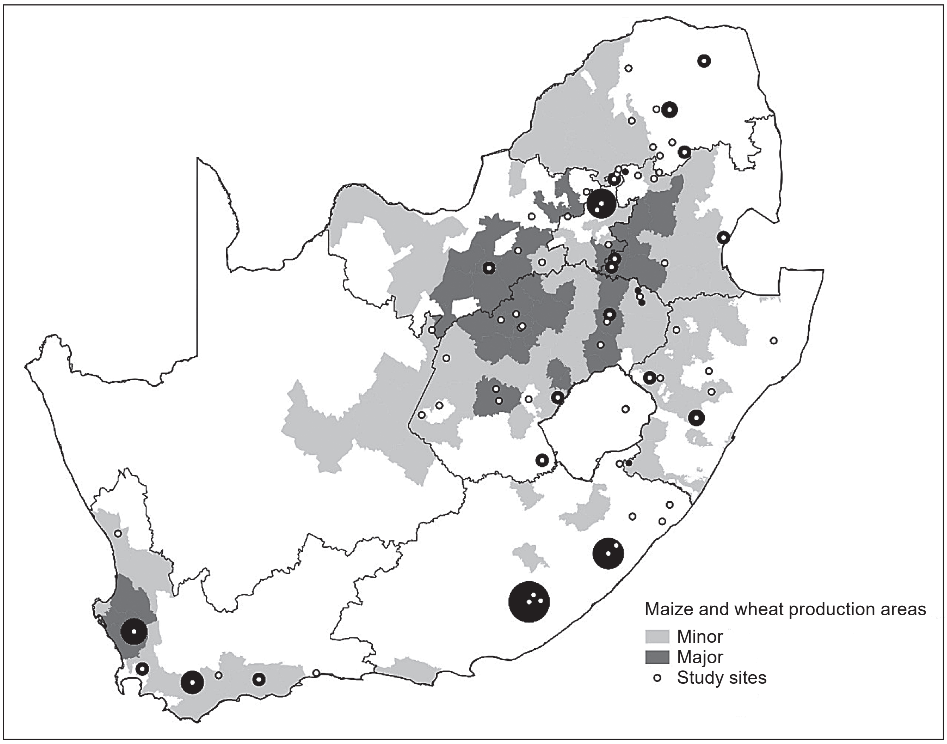

Figure 3: Distribution of research sites for review outputs. Bubble size indicates effort where the larger bubbles represent more outputs per site

Eastern Cape, KwaZulu-Natal and Limpopo, resulting in a poor correlation with the major grain production areas.

The Highveld region in South Africa produces 70% of the country's cereal crops and 90% of the commercially grown maize, rendering this a very important agricultural region, and critical for national food security (Walker and Schulze 2008). However, less than 20% (16% in Free State and 3% in North West) of the research output was produced in this area.

Most data generated was from researcher-managed field trials (as opposed to farmer-led trials or review publications), which included all of the long-term results (implemented for 10 years and longer) collected from on-station research facilities linked to universities, provincial government departments or research institutions such as the ARC or the South African Sugarcane Research Institute. This illustrates the importance of formal research.

CA field trials

Since field trials, either researcher-managed or farmer-led, on-station or on-farm, have been the dominant nature of CA interventions captured, the results of the field trials were evaluated under 'duration' and 'CA treatments implemented'.

Duration of CA field trials

The majority of CA field trial projects (78%) lasted less than 5 years, 17% were implemented between 10 and 15 years, and only 5% reported on results from CA implementation that exceeds 15 years (including Graham et al. 2002; Kotze and du Preez 2007; Loke et al. 2012, 2013). Short-term studies often don't induce or detect significant changes in soil health, especially build-up of SOC, and changes in yield. The latter, is however, largely influenced by climatic conditions. However, resource-use efficiency (especially of water) could be improved through CA, especially by sufficient crop residue retention, and could have had positive impacts on yield in some cases (Govaerts et al. 2009; Rusinamhodzi et al. 2011). To adequately observe and quantify the impact of CA on soil, other ecosystem functions and services, and yields, long-term field trials are ideally needed.

CA treatments implemented in field trials

The main aim of most CA field trials was either to test the effects of, or to adapt the three basic principles of CA (minimal soil disturbance, diversified cropping systems and permanent organic soil cover or mulch) in different study areas, either individually or in various treatment combinations. The following treatment categories were analysed: (1) tillage, (2) cropping systems and (3) mulch. Under the tillage category the following practices were implemented: no-till, reduced tillage, rainwater harvesting or rip-on-row. Under cropping systems, various cash crops, cover crops, legumes or grass crops were identified. These crops were planted as intercropping, strip-cropping or crop rotation systems. In some rotation systems only two rotation crops were used, whereas others implemented a four-rotation system or included a fallow year. Some trials implemented a summer–winter rotation, and others integrated grains with livestock and pastures.

There was considerable variation on how the three basic CA principles were implemented and tested. Only 4% of the studies included all three CA principles. However, soil

cover was not always added as a specific treatment, and it could be argued that reduced tillage implies soil cover by default, in which case 35% of all interventions investigated a combination of cropping systems and tillage which could be representative of all three CA principles. Most studies only evaluated one CA principle, such as cropping systems (30%) or tillage practices (17%).

Research themes and topics

The soil themes and topics listed in Table 1 were used as a framework to further analyse the research data captured through the review process.

Research theme: soil chemical properties

Soil organic carbon

Several studies (18%) confirmed the positive effect of various CA treatments on SOM or SOC and soil fertility (Graham et al. 2002). Increases in SOC resulted from the following CA treatments: reduced or no-tillage (van der Watt 1987; Agenbag and Stander 1988; Kotze and du Preez 2007; Mchunu et al. 2011; Cheesman et al. 2016; Beukes and Swanepoel 2017; Sosibo et al. 2017), soil cover or mulch (Graham and Haynes 2006; Muzangwa 2016) and diversified cropping (du Preez et al. 2011; Njaimwe et al. 2016). Reduced or no-till had the greatest effect on increased SOM or SOC (Kotze and du Preez 2007; Esmeraldo 2017) compared with other CA treatments. Despite the positive impacts of CA treatments on SOC, some studies reported that these increases were small (Cheesman et al. 2016), slow (du Preez et al. 2011), or not significant compared with conventional systems (Njaimwe et al. 2016).

Other nutrients and pH

Even though there was a paucity of studies investigating the effect of CA on soil fertility and nutrient status (n = 13), several of these studies reported a positive effect of CA on soil nutrients. Dube et al. (2013a, 2013b) and Loke et al. (2013) found increased build-up of phosphorus (P), sulphur (S) and zinc (Zn) in surface soil layers, as well as improved P uptake (under reduced or no-till). Similarly, an increase in SOC was generally accompanied by an increase in other nutrients, such as calcium (Ca), potassium (K) and P (Graham et al. 2002). Soil nitrogen (N) content was also positively linked to CA (Loke et al. 2012; Swanepoel et al. 2014). While tillage practices were not reported to result in significant changes in soil N (Maali 2003), cropping systems, especially those that included legumes, were strongly linked to positive N contributions (Maali and Agenbag 2004; Dube et al. 2012a; Muzangwa et al. 2013; Swanepoel et al. 2014). Overall, improved soil fertility was associated with no-till (Kutu 2012), residue retention (Muzangwa 2016) or CA practices in general (Wiltshire and du Preez 1993). However, these changes did not always significantly affect yields (Loke et al. 2013; Nciizah et al. 2015a, 2015b).

Changes in soil pH as a result of CA were reported in three studies. Higher levels of SOC was linked to increased soil acidification (Graham et al. 2002; Sosibo et al. 2017). On the other hand, CA management practices, such as no-till and stubble mulch, were reported to increase soil pH (Loke et al. 2013).

Soil physical properties

Soil compaction and aggregate stability

In this review, several studies (n = 13) reported on soil strength (measured as penetrometer resistance; PR), soil compaction or aggregate stability. Soil strength or PR increased under reduced or no-till (Agenbag and Stander 1988; Steyn et al. 1995; Taylor et al. 2012; Swanepoel et al. 2014). These increases were associated with compacted layers and mostly occurred in the upper soil layers (Steyn et al. 1995; Swanepoel et al. 2014). The results concur with other studies that found an increase in bulk density and compacted layers under no-till soils, often due to the absence of ploughing that could alleviate topsoil compaction. These compacted layers are linked to insufficient biomass production and low SOC (Lampurlanés and Cantero-Martínez 2003). Increased PR results in reduced root elongation, which reduces crop production and grain yield and thus negatively impacts on the success of CA (Agenbag and Stander 1988; Swanepoel et al. 2014).

Improvements in soil aggregate stability are usually positively linked to improvements in soil structure, water infiltration, water-holding capacity, root penetration and a reduction in soil erosion (Lampurlanés and Cantero-Martínez 2003). In one study, grazing vetch increased aggregate stability, whereas oats reduced aggregate stability (Mupambwa and Wakindiki 2012). In various studies aggregate stability increased under reduced and no-till systems (Kidson 2014; Beukes and Swanepoel 2017; Esmeraldo 2017) and as a result of cover crops (Graham et al. 2002; Graham and Haynes 2006; Njaimwe et al. 2016).

Soil water content

Plant-available water was higher under no-till (Kongo and Jewitt 2006; Kosgei et al. 2007; Mupambwa and Wakindiki 2012; Taylor et al. 2012; Kidson 2014) and intercropping systems (Mzezewa et al. 2011), with an increase in runoff under conventional tillage (Kosgei et al. 2007). Similarly, Knot (2014) observed that cover crops increased infiltration and soil water content (Myburgh 2013; Knot 2014) and decreased runoff (Bennie and Hensley 2001; Tesfhuney et al. 2013) and associated soil loss (Russel 1991; Mchunu et al. 2011).

Soil biological properties

Increased SOM is beneficial to soil biology, supporting a larger population and diversity of soil organisms (Graham and Haynes 2006). Soil disturbance (such as tillage practices) and chemical treatments have a negative impact on soil biology (Badenhorst 2016). These negative impacts could be immediate and could persist for well over a year (Swanepoel et al. 2015b). Biological changes were strongly linked to changes in SOM. Conservation agriculture treatments that affected SOM, subsequently also affected soil biology (Mukumbareza et al. 2015). For example, reduced or no-till linked to increased SOM, also increased glomalin levels (Koch 2017), earthworm abundance (Mcinga et al. 2017) and nematode populations (Swanepoel et al. 2014; Swart et al. 2014). Cropping systems, especially cover crops and residue retention, resulted in higher microbial biomass and enzyme activity (Mukumbareza et al. 2015). However, not all soil biology changes were positive.

Chiduza and Dube (2013) reported increased pests, such as cutworm, snail and slug infestations, under certain CA treatments, resulting in an increased need for integrated pest management strategies.

Agronomic aspects

Productivity and yields

Varied results were documented regarding productivity. Yields were strongly related to soil conditions (Maali and Agenbag 2003) and climatic conditions (Bennie et al. 1995), and thus significantly affected by seasonal rainfall, tillage and cropping system as well as fertiliser interaction with CA. Reduced or no-till has been associated with yield increases due to increased water infiltration (Kosgei et al. 2007; Elleboudt 2012; Kutu 2012), although not always significantly (Kutu 2012). Some studies reported a lower yield under reduced or no-till due to poor crop establishment in such soils (Russel 1991), reduced nutrient uptake due to accumulation of immobile nutrients such as P in the surface soil (Loke et al. 2013), soil compaction (Swanepoel et al. 2014), or unknown reasons (Bennie et al. 1995), whereas others reported higher yields in some years, and lower yields in others (Jansen van Rensburg 2002; Trytsman 2008; Swanepoel et al. 2014). The effect of different cropping systems on yield varied (Trytsman 2008). Certain crops showed potential to improve soil properties and yield, especially rotation systems that include legume crops, such as cowpea or grazing vetch. Cover crops that produced high biomass, such as grazing vetch (Dube et al. 2012b), lablab (Trytsman 2008) or pastures (Swanepoel et al. 2015b; Le Roux et al. 2017), had positive effects on grain yield the following year, supported livestock integration (Trytsman 2008) and effectively increased SOM (Swanepoel et al. 2015b).

Weeds

Reports on weed dynamics under CA varied. Some studies reported high biomass and effective soil cover under CA systems, resulting in effective weed suppression (Thobatsi 2009; Murungu et al. 2010; Dube et al. 2012c, 2014). Crops that produced high biomass were effective in weed control, whereas treatments with low biomass production (Murungu et al. 2010) or fallow conditions (Murungu et al. 2011b) were less effective. Even though some studies reported that mulch could reduce problematic weed species over time (Dube et al. 2012c), others reported that mulch had no effect on certain weed species (such as narrow leaf weeds) (Chiduza and Dube 2013). In one study, reduced tillage was associated with an increase in weed species diversity and biomass during three cropping seasons (Swanepoel et al. 2015a).

Economic and social aspects

Few studies included an economic assessment of CA (n = 9). Crop rotations under CA improved profitability of wheat production (Visser 2014; Knott 2015). De Wit et al. (2015) applied models to estimate profitability of CA, and observed, similar to Lawrence et al. (1999), that CA was more profitable and less risky than conventional tillage practices in maize production in the long term. Elleboudt (2012) reported that while yields increased under CA in smallholder farming systems, these improvements were not enough to offset the additional costs. Swanepoel et al. (2014) reported that some CA treatments (such as maize/vetch intercropping) were more profitable than maize monoculture, while at the same time other CA treatments (such as maize/soybean rotation) were less profitable than maize monoculture. Conservation agriculture profitability will always be a function of various factors, such as market trends, climatic conditions, farmer’s attitude, knowledge and skills, but improved soil health and eco-efficiency under CA systems could play a critical role to maximise agronomic production and profitability, while enhancing ecosystem services (Lal 2010).

In the review sample, the community-based interventions were mostly captured through reports, dissertations or proceedings. It is clear that these types of CA interventions have been implemented quite widely, resulting in higher levels of awareness, knowledge and skills among participating communities. However, these reports are not very accessible and contain little quantitative technical information and supporting data.

In our sample, a number of studies were captured aiming to assess the impact of CA among participating farmers, which primarily included farmer-led, on-farm trials and community-based interventions (Smith et al. 2005). Overall, the farmers’ attitudes toward CA were positive (Jansen van Rensburg 2002; Lange and Ellis 2010). Farmers indicated that crop rotation increased yields, but that weeds can pose a problem (Matlou et al. 2015), especially in smallholder farming systems where manual labour is used. In some cases, farmers had to rely heavily on pesticides (du Toit 2012). However, some farmers reported no improvements in yields after implementing CA, which is often ascribed to incorrect or incomplete implementation of CA principles (Smith et al. 2005; Smith 2006; Muzangwa 2016).

In a study focused on a smallholder community-based (LandCare) CA intervention, Smith (2006) found that farmer-centred innovation systems, which include approaches such as farmer field schools and action research, could effectively be used to mainstream CA in South Africa.

Limitations and gaps

The studies sampled showed slow changes in SOM, so the positive effects resulting from a build-up of SOM affecting yields and profitability were not always detected. Adequate biomass could not be generated in many situations due to climatic conditions or use of suitable rotation or cover crops (Murungu et al. 2011a; du Toit 2012; Cheesman et al. 2016). Study periods were often too short and did not allow for sufficient time to adequately build up SOM (Dube et al. 2013b), leading to inconclusive results (Murungu et al. 2011b; Elleboudt 2012).

Diversified cropping systems with at least three crops in rotation are advocated in CA, with legumes an integral element due to their positive impact on soil N content. However, it was found that this effect is diluted with no measurable advantage if the rotation interval period is too long (Maali and Agenbag 2003; Murungu et al. 2011b). Management changes, such as alternative cropping systems and associated improved soil nutrient status (Murungu et al. 2011b), did not always result in any measureable yield

changes. Often the positive effects of CA principles *per se* were over-shadowed by other management aspects, such as fertiliser practices (Maali and Agenbag 2003; Kutu 2012), effective weed control, planting date (Fourie et al. 2001), or environmental factors such as temperature and rainfall (Maali and Agenbag 2003; Sithole et al. 2016) and inherent soil properties (Swanepoel et al 2015b; Sosibo et al. 2017).

While CA was generally associated with positive results, some researchers reported unintended drawbacks. In some cases, reduced or no-tillage practices were associated with compaction layers (Steyn et al. 1995; Bennie and Hensley 2001; Taylor et al. 2012) or changes in weed dynamics (Murungu et al. 2010; Dube et al. 2012c; Swanepoel et al. 2015a), which in turn led to increased labour or chemical inputs (Giller et al. 2009).

Limited research has been done (or published) on crop residues or soil cover, cover crops, soil biology, soil water, livestock integration, economics, greenhouse gas emissions and C fractions, including particulate organic matter. More emphasis should be placed on recommending and using appropriate CA approaches and technologies across diverse agro-ecosystems and communities (Smith 2006; Thierfelder et al. 2016), supportive government policies (Aghdasi and Lange 2011; Nkala et al. 2011), farmer support (du Toit 2012) and funding (Jansen van Rensburg 2002), and reporting and data capturing.

Conclusions and recommendations

A collection of peer-reviewed papers, dissertations, reports, proceedings and projects were captured and reviewed as a representative sample of CA initiatives across South Africa. Although these initiatives were reasonably scattered throughout South Africa, most occurred at on-station field trials and in communal areas in the form of farmer-led trials. Very few CA initiatives were implemented in the key commercial grain-producing areas, where they were mostly driven by farmers themselves. The following recommendations can be made:

- Long-term research: in view of the pressing major threats of land and water degradation, biodiversity loss, climate change and economical decline of conventional farming practices, research conducted in various agro-ecological zones needs to focus on immediate impacts, but with a long-term view of continuous adaptation of CA principles in local farming conditions through systems research approaches.
- Formal research approaches should complement CA studies where possible. Formal research studies lead to peer-reviewed publications or dissertations, which are easily available and accessible through libraries and online databases. Most of the useable data extracted for this review was captured from formal research.
- Prioritising and funding long-term CA systems research in various regions of South Africa should be supported. These efforts would help to identify and adapt best management practices and quantify the immediate to long-term effects of CA practices, either through farmer-led or on-station trials.
- Facilitating scaling-out/up: creating and strengthening CA farmer-centred innovation systems through research initiatives could be an important platform to scale-out/up CA across South African agro-ecosystems.
- Reporting and data sharing: infrequent or inadequate data collection, reporting and unavailability or difficulty to access information render many of the CA initiatives worthless in terms of knowledge sharing. Appropriate platforms and mechanisms are needed to share data, results and experiences with a wider audience.

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