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Conservation Agriculture in Eastern and Southern Africa[1]

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11.1 Introduction

It is generally understood and well documented that conventional farming practices with frequent ploughing gradually degrade the physical structure of tropical soils (Brady and Weil, 2007) leading to increased soil erosion and decreased chemical quality of tropical soils. These processes are the same, but possibly somewhat slower, in subtropical areas. There have been numerous efforts, many ongoing, to develop functional Conservation Agriculture (CA) systems in eastern and southern Africa (E&S Africa) to overcome the negative effects of tillage-induced degradation, led by multiple institutions including public, commercial, religious, research and development organizations. In general, all efforts have endeavoured to implement systems based on the three principles of CA: minimal soil disturbance, soil cover with living plants or crop residues, and crop rotation (FAO; http://www.fao.org/ag/ca). However, often only one or two of these principles have been applied and the techniques, focus and methodologies employed have been as diverse as the organizations supporting the efforts. Recently some papers have suggested that CA is only applicable to small pockets of farmers in E&S Africa, and that the systems are constrained by numerous challenges that are considered insurmountable (Giller *et al*., 2009; Andersson and Giller, 2012). Those developing CA systems in the quest for sustainable agricultural production for farmers in Africa, smallholders and commercial farmers alike, have often acknowledged these same problems (e.g. Wall, 2007), and have dedicated considerable efforts to overcoming them, considering, therefore, that the challenges are surmountable. Given the confusion that these two different positions have provoked among many of those labouring to advance African agriculture, this chapter examines research results from E&S Africa in an effort to develop a clearer picture of the future of CA systems in the region.

11.1.1 Conservation Agriculture – what it is and what it is not

Conservation Agriculture is not a technology but rather a way of conducting agriculture. The term ‘conservation agriculture’ has been coined to describe the principal differences between the CA system and other (tilled) systems – not to describe all of the components of a functional CA system. In CA the degradative components are removed from conventionally tilled (ConvT) agricultural systems – tillage that damages soil structure and breaks down soil organic matter (SOM), insufficient return of organic matter to the soil and lack of protection of the soil surface, and monoculture are replaced with minimum soil disturbance, crop residue retention and crop rotation. All of the other components of productive agricultural systems, such as adequate nutrition, optimum seeding dates and plant

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populations, adequate weed control etc., are as much a part of productive CA systems as they are of tilled systems, and should be fine-tuned within the context of the new CA system based on sound agronomic decision-taking. Furthermore, CA is not a low-external-input system (Wall, 2009), as suggested by Gowing and Palmer (2008) – it is a highly productive system and functions poorly with poor management, just as, or even worse than, ConvT systems. Just removing the degradative components from unproductive tilled situations is unlikely to result in productive systems. The CA components are embedded in an overall system such as that developed by the World Agroforestry Center (ICRAF) in collaboration with several national programmes combining CA with agroforestry options, notably with *Faidherbia albida*, that reaps the benefits of both the CA for the intercrops and the trees (Garrity *et al*., 2010). The Golden Valley Research Trust (GART) and the Conservation Farming Unit (CFU) of the Zambian National Farmers Union (ZNFU) have a well-developed demonstration of *F. albida* intercropped in a CA system on the GART farm north of Lusaka (pictured in Garrity, 2011).

The principles of CA appear to have wide applicability, functioning in different continents, latitudes, soil types and with many different crops and cropping systems. However, the way in which the principles are applied depends on farmer circumstances and neighbouring farmers may use very different techniques to practise sustainable CA systems (Wall, 2007). Many of the experiences with CA in E&S Africa have used 'best bet' CA packages based on systems developed elsewhere, and then have compared these with current ConvT systems, without a phase of participatory adaptation. The confusion over the applicability of CA is also compounded by the use of different terms (Mazvimavi and Twomlow, 2009), especially Conservation Farming (CF) and Conservation Tillage (CT). Conservation Farming is a term used in southern Africa to describe 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, while CT, as strictly defined, refers to any system that maintains at least 30% soil cover with residues after seeding (Soil Science Glossary Terms Committee, 2008). As such, CT may include complete disturbance of the surface soil and therefore, depending on the level of soil disturbance, CT systems may not classify as CA systems. Unfortunately many authors use the terms CA and CT interchangeably, complicating the interpretation of results.

11.1.2 The need for a change in farming systems in eastern and southern Africa

Human beings seldom change unless there is an important reason to do so. What are the problems with current farming systems that suggest the need to embark on the difficult task of knowledge development and system change among millions of smallholder farmers in E&S Africa? Farmers in the region commonly complain of declining yields and rising costs of production although the causes of these are not always obvious or apparent to many farmers.

Excessive nutrient mining over most of Africa (Stoorvogel *et al*., 1993) is acute, and adequate plant nutrition is often cited as the most limiting factor to crop production in E&S Africa, while at the same time fertilizer use is very low (about 20 kg ha^{-1} of nutrients in 2009/10 calculated from FAOSTAT http://faostat3.fao.org/home/index.html). Fertilizer use by smallholders is not just a function of availability and affordability, but also of both production and market risk (Morris *et al*., 2007). Smallholder farmers, in particular, are averse to risk given their precarious financial situation and their poor access to credit – if fertilizer application to a crop is perceived as risky, it will not be applied (Rockström *et al*., 2002). One of the major causes of risk in E&S Africa is the risk of moisture stress, which is often more a function of inefficient use of rainfall than of insufficient or poorly distributed rainfall *per se*. Across the semi-arid tropics of sub-Saharan Africa, between 70 and 85% of rainfall is lost to surface runoff, deep drainage and evaporation rather than being used by crops for productive transpiration (Rockström *et al*., 2002) while in Zimbabwe 30% of rainfall may be lost to runoff alone (Elwell and Stocking, 1988). As a result of global warming and climate change, increased variability of seasonal distribution of rainfall is expected throughout the region coupled with a reduction in rainfall in much of the region (Lobell *et al*., 2008), factors that will aggravate the inefficiencies in rainfall use noted above.

E&S Africa tops the list of regions affected by land degradation, a long-term decline in ecosystem function measured in terms of net primary productivity (Bai *et al*., 2008) closely linked to rural household food insecurity and poverty (Malley *et al*., 2006). Elwell's comments on the causes of land degradation in Zimbabwe undoubtedly apply to the rest of the region: 'High rates of erosion and land degradation are a result of inappropriate tillage and cropping systems which have resulted in SOC (soil organic carbon) and soil structural reduction' (Elwell, 1989). Although tillage with a hand hoe accounts for 80% of the cultivated area in E&S Africa (Sims *et al*., 2012), this still results in soil structural breakdown and the formation of hard pans (Douglas *et al*., 1999 quoted by Bot and Benites,

2001) and severe hard pans are common in manually cultivated farms in Malawi and Mozambique (e.g. Materechera and Mloza-Banda, 1997).

Soil erosion and the loss of SOM are intrinsically linked to soil chemical and biological quality. Continent-wide, 5 Mg ha^{-1} of Africa's soils are lost to lakes and oceans each year (Angima *et al*., 2003). The surface soil is the most fertile and the loss of SOC from the top few centimetres of soil has a disproportionately large effect on soil infiltrability and nutrient supply (Mills and Fey, 2003). Estimated annual on-farm losses of SOC through sheet erosion in Zimbabwe were over 500 kg ha^{-1} together with approximately 50 kg ha^{-1} nitrogen and 8 kg ha^{-1} phosphorus (Elwell and Stocking, 1988).

Conventional management practices of smallholder farmers lead to organic matter decline and loss of fertility of the land (Zingore *et al*., 2005). A study of South African soils cultivated for 0–85 years showed decreased SOC content, regardless of the duration of cultivated cropping, and cultivated soils had 10–75% less SOM than uncultivated areas (Du Preez *et al*., 2011).

Agricultural systems are complex, multi-component systems adjusted and adapted to local conditions and farmer circumstances. Therefore the transfer of an agricultural system from one place to another is unlikely to be successful, but rather systems need to be tailored to local conditions (Wall, 2007). In the case of CA, tailoring technological changes to local conditions and farmer circumstances while following the principles of CA requires well-developed farmer participatory adaptive research, taking into account farmer preferences and management.

Normally farmers seek other benefits rather than yield *per se* – even subsistence farmers seek to sell excess produce for economic gain to help them access food supplies that they do not produce, and so achieve food security. Neither CA alone, nor any other agricultural technology, will solve all of the problems of smallholder farmers in E&S Africa, an enabling environment of adequate input and produce markets (the U-impact pathway of Dixon *et al*., 2007), policies, research and information support are all also required (see section 11.5).

Smallholder farmers are generally not well linked to knowledge systems, and often have little access to new information and knowledge outside the community. While access to information is changing rapidly with the spread of cell phone and other information technologies, knowledge development (the application of information to understand and apply new ideas) needs more direct and constant contact. With respect to agricultural systems, farmer-participatory research followed and accompanied by farmer-to-farmer information exchange has proved to be an effective means of building knowledge in smallholder farming communities: 'farmers should be inspired to experiment, test, learn and think for themselves' (Bolliger *et al*., 2005).

11.2 History of Conservation Agriculture in Eastern and Southern Africa

Most of the cropped area of E&S Africa follows a maize mixed or a agro-pastoral millet/sorghum agricultural system (Dixon *et al*., 2001) and so much of the history of CA in the region is linked to maize-based systems.

Some of the earliest experiences in E&S Africa with CA were in the highlands of Kenya in the mid-1970s, at about the same time that farmers were starting to work with CA in southern Brazil. In an effort to conserve rainwater and to reduce production costs several large farmers began with zero tillage (ZT; Apina *et al*., 2007) and many continue to practise CA today.

At about this time (1976) the Small Grains Institute of the Agricultural Research Council of South Africa started research on CA, with trials conducted over the maize-growing areas of South Africa (Berry *et al*., 2001). Farmer-managed demonstrations were also started in the early 1970s by the extension branch of the Ministry of Agriculture of Rhodesia (now Zimbabwe) but with little success, leading to the conclusion that CA (no-till) systems were not adapted to local conditions (Oldrieve, undated).

In the 1982/83 season Oldrieve began experiments with CA on the farm he managed in north-eastern Zimbabwe and also developed systems and conducted outreach programmes for smallholder farmers in Zimbabwe (Oldrieve, 1993). The following season trials to evaluate CA were initiated at the Agricultural Research Trust (ART) farm near Harare, Zimbabwe with trials designed to evaluate CA systems (MacRobert *et al*., 1995). These trials provided important information for commercial farmers and, despite the earlier reticence, adoption of CA began, driven by rising fuel and mechanization costs (Nyagumbo, 2008) and, prior to land reform starting in 2001, approximately 20% of commercial farmers in central Zimbabwe were applying the principles of CA (Oldrieve, n.d.).

In 1988 the German Development Corporation (GTZ) initiated a research project in Zimbabwe on CA (ConTill/Agritex), a project that provided much important information to underpin future CA efforts. However, again results were not universally positive and CA was not incorporated into the agenda of the Ministry of

Agriculture. In 1995 the World Bank asked Oldrieve from Zimbabwe to attend a workshop in Zambia to plan a new CA initiative. The workshop was attended by the Zambian Minister of Agriculture, demonstrating marked political commitment, and the outcome of the workshop was the establishment of the Conservation Farming Unit of the Zambian National Farmers Union.

In 1995/96 the Planting without Ploughing project focused on smallholder farmers in KwaZulu-Natal, South Africa, installed large numbers of CA demonstration plots. The extension branch of the Ministry of Agriculture of Mozambique (DNEA) started installing demonstrations of CA together with the national research institute (INIA) in the 1996/97 season in the Manica and Nampula provinces, in a project with Sasakawa Global 2000 (SG2000) and Monsanto (Nhancale *et al*., 2006).

It was at about this time that various important donors began to show increased interest in CA, especially the German Development Corporation (GTZ), the Regional Land Management Unit of the Swedish International Development Agency (RELMA), the World Bank and the Food and Agriculture Organization of the United Nations (FAO). This interest resulted in the organization of an international workshop on 'Conservation Tillage (sic) for Sustainable Agriculture' held in Harare, Zimbabwe, 22–27 June 1998. This workshop had many outcomes, including the establishment of the African Conservation Tillage Network (ACT) – originally financed by GTZ – and the increased interest of donors and national programmes in pursuing CA projects. Following the workshop major new projects were initiated in eastern Africa, in Ethiopia, Kenya, Uganda and Tanzania.

11.3 Current Status of Conservation Agriculture in Eastern and Southern Africa

Worldwide, the adoption of CA systems by smallholder farmers has lagged well behind the adoption on large, mechanized farms: only 0.3% of the area under no-till (NT) worldwide is on smallholder farms (Derpsch *et al*., 2010). This is not unprecedented as smallholders are less able to invest in new equipment, are more risk averse than large farmers, generally have fewer links to new information systems and, importantly, manage more complex farming systems, generally mixed crop–livestock systems (Wall, 2007). In the Americas and Australia the CA movement was largely driven by farmers (Ekboir, 2002), but smallholders generally do not have the resources or linkages that enable them to take hold of the reins of development.

Recent estimates of the number of CA practitioners and the area under CA in E&S Africa are shown in Table 11.1. Much of the area in South Africa, and some of the areas in Kenya and Sudan, are likely to be on large mechanized farms, but the remainder is almost entirely on smallholder farms. It appears that well over 500,000 farmers in E&S Africa are currently using CA on at least part of their farm. The importance of this number is that the concepts of CA have reached at least half a million minds, and there are likely more farmers in E&S Africa managing CA systems today than there are CA farmers in the USA, the country with the largest area of CA in the world.

Table 11.1. Recent estimates of the use of CA practices on farms in eastern and southern Africa.

Country	Year of estimate[a]	Area ('000 ha)	No. of farmers ('000)
Sudan	2009[a]	10	
Kenya	2009[a]	15	
Tanzania	2009[a]	6	
Malawi	2012[b]	14	84
Mozambique	2009[a]	9	
Zambia	2009[c]		150
Zambia	2009[a]	40	
Zimbabwe	2009[a]	7.5	
Zimbabwe	2012[d]	141	371
South Africa	2008[e]	368	
Total	Most recent	603	

Source: [a]Derpsch *et al*., 2010; [b]J. Chisui, Lilongwe, Malawi, 2012, pers. comm.; [c]Aagard, 2009; [d]L.S. Marongwe, Zimbabwe, 2012, pers. comm.; [e]Derpsch and Friedrich, 2009.

11.4 Research Results from Eastern and Southern Africa

Seldom have all three principles of CA been part of the systems applied and reported in the literature from the region. In analysing research results we have included all reports where soil disturbance has been kept to a minimum and some residues have been left on the soil surface. Often common farmer practices have been compared to CA treatments using different fertilizer levels, causing problems in interpretation of results (Baudron *et al*., 2007; Thierfelder and Wall, 2012). While this may be valid for farmer demonstration plots we prefer to remove the fertilizer variable and apply the same fertilizer to all systems, unless one system does in fact require more fertilizer than the others. For the purposes of this chapter we have only considered results where fertilizer levels have been the same across the different systems.

11.4.1 Yield and economic benefits

There is a relative wealth of information available on the effects of CA systems on crop yields in E&S Africa, understandably especially with respect to maize. A comparison of various CA systems compared to ConvT maize systems on farmers' fields in E&S Africa shows marked yield benefits to CA in the majority of cases (Table 11.2). Results from eight different countries generally show that yields under CA are equal to or higher than ConvT. Of the six results (out of 40 shown in Table 11.2) where CA resulted in maize yields 10% or more below the yield of the ConvT treatment, two were not fertilized (Enfors *et al*., 2011), one was probably not fertilized but was after a green manure cover-crop (gmcc) (Boye and Albrecht, 2005), one received only a modest nitrogen top dressing and no other nutrients (Twomlow *et al*., 2009) and two came from the poor soils that Guto *et al*. (2012) studied in Kenya. It appears that adequate soil fertility levels are important for the successful functioning of CA systems – we hypothesize that not only are the benefits of CA restricted when crop nutrition is limiting, but also that increased biomass production is important to achieve the potential of CA systems, both through the production of sufficient residues for ground cover, as well as increased return of organic matter to the soil to improve soil physical, chemical and biological fertility.

The 23 reports of yield increases (>10% above ConvT) in farmers' fields (Table 11.2) come from a diverse set of conditions, including a range of soil types and annual rainfall (from about 500 to 1500 mm). Most were fertilized (19 of 23) and had residues retained as mulch (15 of 23) and 14 included chemical weed control, often complemented by manual weeding.

Overall the effects of CA on yield in trials from research stations (Table 11.3) have been positive and only in five of the cases shown were yields under CA >10% less than under ConvT. In general, yield benefits of CA systems from on-farm trials (Table 11.2) were, however, clearer as compared to the ones from research stations (Table 11.3).

There is not as much information about the management of other crops under CA in E&S Africa as there is for maize. However, results (Table 11.4) suggest that cotton, cowpea, sorghum, wheat and even teff, can yield just as well under CA as they can with tillage. Achieving acceptable plant stands was a problem on some of the reported cowpea and sorghum work, highlighting the need for adequate equipment and understanding of the management of the CA system before embarking on comparative studies.

Table 11.2. Effects of CA practices on maize yields in eastern and southern Africa. Results from trials on farmers' fields, mostly farmer managed. Plots were fertilized and surface residues were retained unless otherwise indicated.

Country	Place	Soil type	Seasons of data	Fertilized[a]	Surface residues	Weed control[b]	Mean rainfall	Mean yield	CA treatment[e]	% yield increase[f]	Reference	Notes
South	Thukela Basin, KZN	Sandy loam	1		Prob none	H+M	710	1900	Rip line	140	Kosgei *et al*., 2007	
Tanzania	Arusha and Arumeru	Various	4		No	Manual	1100	2800	Rip line	54	Rockström *et al*., 2009	46 sites
Zimbabw	Zimuto	Ferralic arenosol	6			H+M	620	1250	DS	54	Thierfelder and Wall,	
Zambia	Malende, Monze	Sandy loam	3			H+M	758	6400	DS	51	Thierfelder *et al*., 2013	Second
Kenya	Masai farm,	Ferralic arenosol	1	Prob	No	Manual	1800	1850	NT	47	Boye and Albrecht,	
Malawi	Ntonda section	Fluvisol	3			H+M	800	4100	DS	42	Ngwira *et al*., 2012a	
Malawi	Balaka market	Fluvisol, 80% sand	3			H+M	800	4200	DS	40	Ngwira *et al*., 2012a	
Tanzania	Arusha and Arumeru	Various	4		No	Manual	1100	2600	Basins	39	Rockström *et al*., 2009	46 sites
Zambia	Malende, Monze	Sandy loam	3			H+M	758	6400	Rip line	38	Thierfelder *et al*., 2013	Second
Zimbabw	11 Districts		1	Manure	Prob none	Manual			Basins	36	Twomlow *et al*., 2009	
Zimbabw	Zimuto	Ferralic arenosol	6			H+M	620	1250	Rip line	29	Thierfelder and Wall,	
Malawi	Lemu	Luvisol – sandy	5			H+M	935	5200	DS	26	Ngwira *et al*., 2012c	
Tanzania	Arusha and Arumeru	Various	4	No	No	Manual	1100	1750	Rip line	25	Rockström *et al*., 2009	46 sites
Malawi	Ntonda section	Fluvisol	3			H+M	800	3800	DS	23	Ngwira *et al*., 2012a	
Malawi	Balaka market	Fluvisol, 80% sand	3			H+M	800	3850	DS	22	Ngwira *et al*., 2012a	
Malawi	Zidyana	Luvisol – sandy clay	5			H+M	1375	5200	DS	19	Ngwira *et al*., 2012c	
Tanzania	NE – Makanya	Ferralsols – infertile	3	Manure		M	562	600	Rip line	18	Enfors *et al*., 2011	Three
Zambia	Kayowozi, Chipata	Acrisol	4			H+M	950	3200	Dibble	15	Thierfelder *et al*., 2013	
Tanzania	NE – Makanya	Ferralsols – infertile	2	Manure		M	562	2100	Rip line	14	Enfors *et al*., 2011	Two
Ethiopia	708 farms in		5		30% rec.	H+M		4700	NT	12	Ito *et al*., 2007	708
Zimbabw	Hereford	Chromic luvisol	5			H+M	850	5150	DS	11	Thierfelder and Wall,	
Kenya	Leuro farm, W Kenya	Nito-humic Ferralsol	1	Prob	No	M	1800	2100	NT	10	Boye and Albrecht,	
Zimbabw	11 Districts		1	No	Prob none	M			Basins	10	Twomlow *et al*., 2009	
Zimbabw	11 Districts		1	Man+2	Prob none	M			Basins	9	Twomlow *et al*., 2009	
Uganda	753 demonstrations		1			H+M		4800	Hoe	9	Findlay *et al*., 2001	
Kenya	Meru South, Central	Humic nitisols	3			H+M	1500	3235	Hoe holes?	7	Guto *et al*., 2012	Mediu
Ethiopia	Tigray, 3 sites	Various	5		No	M	500	1500	Rip+Ss	6	Rockström *et al*., 2009	25 sites
Zambia	Malende, Monze	Sandy loam	3			H+M	758	3650	DS	3	Thierfelder *et al*., 2013	First 3
Kenya	Meru South, Central	Humic nitisols	3			H+M	1500	4000	Hoe holes	2	Guto *et al*., 2012	Good
Kenya	Masai farm, W	Ferralic arenosol	1	Prob	Only gmcc	M	1800	2800	NT	2	Boye and Albrecht,	
Ethiopia	Tigray, 3 sites	Various	5	No	No	M	500	1250	Rip+Ss	1	Rockström *et al*., 2009	19sites
Kenya	Meru South, Central	Humic nitisols	3		No	H+M	1500	4000	Hoe holes	1	Guto *et al*., 2012	Good
Zimbabw	Hereford	Chromic luvisol	5			H+M		5150	Rip line	−1	Thierfelder and Wall,	
Kenya	Meru South, Central	Humic nitisols	3		No	H+M	1500	3235	Hoe holes	−5	Guto *et al*., 2012	Mediu
Zambia	Malende, Monze	Sandy loam	3			H+M	758	3650	Rip line	−5	Thierfelder *et al*., 2013	First 3
Kenya	Leuro farm, W Kenya	Nito-humic Ferralsol	1	Prob	gmcc	M	1800	7250	NT	−20	Guto *et al*., 2012	
Tanzania	NE – Makanya	Ferralsols – infertile	2	No	No	M	562	2100	Rip line	−20	Enfors *et al*., 2011	Two
Zimbabw	11 Districts		1	28N TD	Prob none	M			Basins	−22	Twomlow *et al*., 2009	
Tanzania	NE – Makanya	Ferralsols – infertile	3	No	No	M	562	400	Rip line	−24	Enfors *et al*., 2011	Three
Kenya	Meru South, Central	Humic nitisols	3			H+M	1500	2160	Hoe holes	−26	Guto *et al*., 2012	Poor
Kenya	Meru South, Central	Humic nitisols	3		No	H+M	1500	2160	Hoe holes	−33	Guto *et al*., 2012	Poor

[a]Man, manure; [b]H, herbicide; M, manual weeding; [c]approximate average annual rainfall (mm); [d]approximate mean yield of trial kg ha^{-1}; [e]DS, mechanical direct seeder; NT, no-tillage; rip line, seeded in rip line; Ss, sub-soiled; [f]Effect of CA treatment on yield (%) compared to ConvT with same fertilizer.

Table 11.3. Effects of CA practices on maize yields in eastern and southern Africa. Results from researcher managed trials on research stations. Plots were fertilized and surface residues were retained unless otherwise indicated.

Country	Place[a]	Soil type	Seasons of data	Fertilized[b]	Surface residues	Weed control[c]	Average rainfall[d]	Mean yield[e]	CA treatment[f]	% Yield increase[g]	Reference	Notes
Zimbabwe	Henderson RS	Arenosol	2			H+M	880	4300	Rip line	41	Thierfelder *et al*., 2012a	
	Matopos RS	Arenosol	2	Man+50N		M	590	900	Rip line	40	Mupangwa *et al*., 2007	
	Henderson RS	Arenosol	2			H+M	880	4300	Basins	39	Thierfelder *et al*., 2012a	
	Makoholi RS	Ferralic arenosol	2	?		?	620	1600	Mulch-rip	37	Moyo, 1998	
	Henderson RS	Arenosol	2			H+M	880	4300	DS	32	Thierfelder *et al*., 2012a	
	Matopos RS	Arenosol	2	Man+50N		M	590	900	Basins	30	Mupangwa *et al*., 2007	
	Henderson RS	Arenosol	6			H+M	880	2600	Basins	25	Thierfelder pers. comm.	Harare, December
	Henderson RS	Arenosol	6			H+M	880	2600	Rip line	22	Thierfelder and Wall, 2012	
	Henderson RS	Arenosol	6			H+M	880	2600	DS	11	Thierfelder and Wall, 2012	
	Makoholi RS	Ferralic arenosol	3			?	620	1600	Mulch-rip	10	Munodawafa and Zhou, 2008	Marked seasonal
	Matopos RS	Cambisol	2	Man+50N		M	590	1400	Rip line	8	Mupangwa *et al*., 2012	1st year maize in
	Domboshawa FTC	Sand	8	?	?	?	750	3600	Mulch-rip	6	Munyati, 1997	CA better in 5 of 8
	Matopos RS	Cambisol	1	Man+50N		M	590	2100	Basins	4	Mupangwa *et al*., 2012	Mean of
	Henderson RS	Arenosol	2			H+M	880	3800	Basins	4	Thierfelder and Wall, 2009	Marked seasonal
	Matopos RS	Cambisol	2	Man+50N		M	590	2600	Basins	3	Mupangwa *et al*., 2007	
	Henderson RS	Arenosol	2			H+M	880	3800	DS	1	Thierfelder and Wall, 2009	Marked seasonal
	Henderson RS	Arenosol	2			H+M	880	3800	Rip+Ss	0	Thierfelder and Wall, 2009	
	Makoholi RS	Ferralic arenosol	6			Prob M	475	2800	Mulch-rip	−1	Chuma and Hagmann, 1995	
	Matopos RS	Cambisol	2	Man+50N		M	590	2600	Rip line	−5	Mupangwa *et al*., 2007	
	Matopos RS	Cambisol	1	Man+50N		M	590	2100	Rip line	−11	Mupangwa *et al*., 2012	Mean of
	Matopos RS	Cambisol	2	Man+50N		M	590	1400	Basins	−13	Mupangwa *et al*., 2012	1st year maize in
	Domboshawa FTC	Granite sands	1			M	438	650	Mulch-rip	−71	Vogel *et al*., 1994	Severe drought
Zambia	Monze FTC	Lixisol	2			H+M	660	5000	Basins	26	Thierfelder and Wall, 2009	
	Monze FTC	Lixisol	4			H+M	750	4000	DS	25	Thierfelder *et al*., 2012a	
	Monze FTC	Lixisol	2			H+M	660	5000	DS	18	Thierfelder and Wall, 2009	
	GART Farm	Humic Eutrustox	2			M	850	4900	Hoe holes	0	Gill *et al*., 1992	
Mozambique	Susendenga RS	Haplic luvisol	5			H+M	1085	2500	DS	−2	Thierfelder *et al*., 2012b	
Malawi	Chitedze RS	Chromic luvisol	4			H+M	960	5250	Hoe holes	2	Thierfelder *et al*., 2012b	
	Bunda College	Oxic Rhodustalf	3			M	857	4600	Hoe holes?	−7	Materechera and Mloza-Banda, 1997	Wide spacing: 0.91

[a]RS, Research Station; FTC, Farmer Training Centre; [b]Man, manure; [c]H, herbicide; M, manual weeding; [d]approximate average annual rainfall (mm); [e]approximate mean yield of trial in kg ha^{-1}; [f]DS, mechanical direct seeder; NT, no-tillage; Rip line, seeded in rip line; Ss, sub-soiled; [g]effect of CA treatment on yield (%) compared to ConvT with same fertilizer.

Table 11.4. Effects of CA practices on yields of crops other than maize in eastern and southern Africa. Surface residues were retained unless indicated.

Crop	Country	Place[a]	Soil type	Seasons of data	Fertilized[b]	Surface residues	Weed control[c]	Average rainfall[d]	Mean yield[e]	CA Treatment[f]	% yield increase[g]	Type of trial[h]	Reference
Cotton	Zimbabwe	North-east	Sandy loam	3[i]	No		M	550	700	Hoe holes	−1	OF-FM	Baudron *et al*., 2012a
		Save Valley	Cambisol	6	High		M	Irrigated	3070	Hoe holes?	−14	OS	Gwenzi *et al*., 2008
Cowpea	Zimbabwe	Matopos RS	Cambisol	2	Man+50N		M	590	800	Basins	7	OS	Mupangwa *et al*., 2012
										Rip line	6	OS	
				1	No		M	580	300	Rip line	−34	OS	Mashingaidze *et al*., 2012
										Basins	−45	OS	
Sorghum	Zimbabwe	North-east	Sandy loam	3[j]	No		M	550	1070	Hoe holes	−1	OF-FM	Baudron *et al*., 2012a
		Matopos RS	Cambisol	1	Manure		M	580	3500	Basins	−37	OS	Mashingaidze *et al*., 2012
										Rip line	−12		
					Man+50N		M	590	1900	Basins	−21	OS	Mupangwa *et al*., 2012
										Rip line	9		
Soybean	Zimbabwe	Harare	Sandy clay	4	Yes	+ and –[k]	Yes	Suppl. irrig.	3800	DS	1	OS	MacRobert *et al*., 1995
Teff	Ethiopia	Different sites	Various	4	Yes	30%?[l]	H+M		1180	?	11	PP-FM	Ito *et al*., 2007
		Tigray	Various	1	?		H	500–800	800	PB	−35	OF-FM	Nyssen *et al*., 2010
Wheat	Ethiopia	Different sites	Various	4	Yes	30%?	H+M		2380	Rip line	9	PP-FM	Ito *et al*., 2007
	Ethiopia	Tigray	Various	2	?		H	500–800	1250	PB	90	OF-FM	Nyssen *et al*., 2010
	Zimbabwe	Harare	Sandy clay	5	Yes	+ and −	H+M	Irrigated	6300	DS	2	OS	MacRobert *et al*., 1995
	South Africa	SW Cape	Sand	6	Yes	Burned	H	411		DS	0	OS	Agenbag and Maree, 1991
	Zimbabwe	Save Valley	Cambisol	6	High		M	Irrigated	4400	Hoe holes?	−4	OS	Gwenzi *et al*., 2008
	South Africa	Near Bethlehem	Plinthosol	9	Yes	+ and −	Mech+H	650	2000	Conv. drill	−6	OS	Du Preez *et al*., 2001

[a]RS, Research Station; [b]Man, manure; [c]H, herbicide; M, manual weeding; Mech, mechanical weeding; [d]approximate average annual rainfall (mm); [e]approximate mean yield of trial in kg ha^{-1}; [f]DS, mechanical direct seeder; NT, no-tillage; Rip line, seeded in rip line; Ss = sub-soiled; Conv. drill, conventional seed drill; [g]effect of CA treatment on yield (%) compared to ConvT with same fertilizer; [h]OF-FM, on-farm, farmer managed; OS, on-station; PP-FM, paired plots, farmer managed; [i]18, 28 and 23 farms in the 3 years; [j]FTC = Farmer Training Centre; on 18, 28 and 23 farms in the 3 years, respectively; [k]mean of burned and unburned plots; [l]farmers were recommended to leave at least 30% of the residues, but residue cover was not evaluated.

Increased yield is not necessarily a prerequisite for CA adoption: cost and labour reductions may be just as important and in the final analysis it is the balance of benefits as perceived by the farmer that will define adoption. Economic analysis is probably not only important but also the best analysis for comparisons of systems where several components vary. Economic analysis is able to integrate results where systems have different seeding dates, fertilizer levels, use different equipment etc.

The three main components of comparisons of the economics of ConvT and CA systems in E&S Africa are the cost of tillage, the cost of weed control and crop yield. The first two of these are also the factors that have the biggest impact on labour demands. Where herbicides have been used in Malawi, labour costs were lower in CA systems than the normal farmer production practices (Table 11.5) by between 28 (Ngwira *et al*., 2012a) and 63% (Ito *et al*., 2007). These labour savings were partially offset by increased input costs, but because of increased yields net returns per hectare were increased by US$130–370 (Ito *et al*., 2007; Ngwira *et al*., 2012a, c)resulting in a mean 60% increase in net benefits, while returns to labour (US$ day^{-1}) were increased by 100% in CA systems with continuous maize and by 92% in CA maize systems intercropped with legumes (mean data from Ngwira *et al*., 2012a, c).

Where herbicides are not used, labour savings from land preparation may be offset by labour requirements for weeding (Jat *et al*., 2012a, b). In Zimbabwe, labour for weeding a mulch-rip treatment was similar to that used in the tilled plots at two sandy soil sites (Vogel, 1994), but 10–25% more labour was used in two ‘best bet’ CA treatments on sandy soils previously abandoned due to degradation (Siziba, 2007). However, even in the latter case net benefits were higher in CA systems once tillage costs were included.

In northern Tanzania work with gmcc intercropped with maize (Mariki, 2004) without fertilizer and using glyphosate herbicide only in the first three seasons, weed pressure declined with time due principally to the competition of the gmcc, probably largely the increased ground cover. In the first season of this work, 11% more labour (178 person days ha^{-1}) was used in the no-till plots with gmcc (*Mucuna pruriens* and *Lablab purpureus*) than in the tilled plots (160 person days ha^{-1}) but four seasons later labour use was 45% lower in the CA plots than in the tilled plots (90 person days ha^{-1} and 162 person days ha^{-1}, respectively).

Table 11.5. Comparison of labour use (person days ha^{-1}) in CA and ConvT maize systems in eastern and southern Africa. All plots fertilized unless otherwise indicated.

					Land prep., planting. fertilizer application		Weed control		Total			
Country	Site(s)	Fertilizer	Weed control	CA treatment[a]	ConvT	CA	ConvT	CA	ConvT	CA	Reference	Notes
Malawi	Various		Glyphosate,	Hoe holes	39	14	19	0	68	25	Ito *et al*.,	Assume
	Balaka +		Glyphosate,	Hoe holes					65	44	Ngwira *et al*.,	
	Lemu +		Glyphosate	Hoe holes					62	49	Ngwira *et al*.,	Legume
			Glyphosate,						62	40		
Tanzania	Karatu	No	Glyphosate	DS					161	114	Mariki, 2004;	GMCC
Zimbabw	ART, Harare		Herbicides	DS					22	13	MacRobert *et*	
	Shamva		Glyphosate	DS`	8	2	29	32	61	62	Siziba, 2007	
				Rip line		5		27		55		
Zambia	Various	Variable	Manual	Basins	97	113	58	81	176	211	Haggblade	
				Rip line	14	26	27	35	48	77		
	Magoye			Dibble			12	57			Muliokela *et*	
				Basins			12	46				
Zimbabw	Various			Basins	29	46	26	52	77	116	Mazvimavi	
	Zimuto			DS	8	2	19	31	38	47	Siziba, 2007	
				Rip line		5		25		41		
	Domboshaw			Mulch-rip			55	61			Vogel, 1994	
	Makoholi						29	24				

More efficient machinery use has been one of the drivers of CA adoption on mechanized farms in the Americas. There are little published data on machinery use in CA in E&S Africa, but on the ART farm near Harare, machinery costs for land preparation in CA as compared to ConvT were reduced by 97% (Steiner, 2002) and over the whole crop season by 66% (MacRobert *et al*., 1995).

Labour is an important component of the CF system in Zambia, Zimbabwe and Malawi. Farmers are advised to dig basins during the dry season to reduce labour requirements and ensure that the basins are ready when the first planting rains arrive. However, digging basins involves considerable labour (28–34 person days ha^{-1}) in the first year (Mazvimavi and Twomlow, 2009; Umar *et al*., 2012) although as the basins are dug in exactly the same place each year the difficulty and time for digging is reduced in subsequent years (Baudron *et al*., 2007). In areas where the basins have not given large returns this results in disadoption (Baudron *et al*., 2007) and leads to complaints about the labour requirements (Haggblade and Tembo, 2003), and even referring to the basin system as 'dig and die' (Andersson and Giller, 2012). Although digging of basins involves about 2.5 times more labour than building ridges for planting (34 versus 13 person days ha^{-1}), because of the increased maize yield the returns to labour ($ day^{-1} worked) in Zambia were five times higher in the basin system than with ConvT (Umar *et al*., 2012).

11.4.2 The importance of mulch and crop rotation

There is little consistent information of the importance of mulch and crop rotation in CA systems in E&S Africa. In central Kenya residues generally had positive effects on yield of minimum tillage (CA) plots, although this effect was small (0.6 t ha^{-1} extra grain yield), seldom significant and only marginally economic on good and medium soils and uneconomic on poor soils (Guto *et al*., 2012). In the drier conditions of south-western Zimbabwe (Mupangwa *et al*., 2012) the effects of mulch were variable, but there was a significant yield response to mulch levels up to 4 t ha^{-1} in rip-line seeded maize, sorghum and cowpea. A survey of farmer trials with planting basins in Zimbabwe (Mazvimavi and Twomlow, 2009) showed major positive effects of residues on crop yield both under CA (74%; 1.7 t ha^{-1} increase over yields without residues) and ConvT (92%; 1.4 t ha^{-1} yield increase). Given that the issue of residues is such a central one to the adaptation and adoption of CA systems it appears that the quantification of the benefits of the residues under different conditions needs to be addressed more by research.

Crop rotation is one of the three pillars of CA, but is often the last to be incorporated into the system by farmers, often because of a lack of adequate markets for alternative crops (Thierfelder and Wall, 2010a). Although one of the main reasons for crop rotation in CA systems is to avoid problems of pests and diseases harboured on the residues (Baudron *et al*., 2012b), there may also be marked yield benefits associated with crop rotation under CA conditions (Fig. 11.1). Only maize grain yield in the maize phase of the rotation is shown in Fig. 11.1, and a full economic analysis is necessary to ascertain the profitability of the rotations. Legumes are often preferred for rotations because of the benefits of biological nitrogen fixation, but non-legume crops may also benefit the following maize crop as evidenced by the 10% yield increase in yield of maize in a maize–cotton rotation in Monze FTC (Fig. 11.1).

In areas where there is intense land pressure, farmers may prefer to intercrop rather than rotate their crops. Some results from farm trials in Zimbabwe (Thierfelder *et al*., 2012a) and Malawi (Ngwira *et al*., 2012a) show intermediate yield benefits (less than the effect of rotation) in maize due to intercropping, but more information on the effects of intercrops is needed, including information on their effects on diseases and pests.

In some parts gmcc are an integral part of productive CA systems. The feasibility of gmcc is closely linked to water availability. If there is sufficient moisture for an economic crop it is unlikely that farmers will sow a gmcc unless it can be demonstrated that profits are greater with the gmcc than with only economic crops. In northern Tanzania, which has a bimodal rainfall pattern, in a comparison of ConvT monoculture maize, a NT maize–gmcc rotation and a no-till maize–gmcc intercrop (where the legume gmcc continued to grow during the unreliable short rains), all without fertilizer application, maize yields with the intercrop (1.7 t ha^{-1}) were 350% higher than with the ConvT monocrop (0.5 t ha^{-1}) (Mariki, 2004). A large part of the yield response was undoubtedly due to N fixation by the gmcc. Rotation only increased yields by another 11% over the maize yields with the intercrop, unlikely therefore to be of interest to farmers.

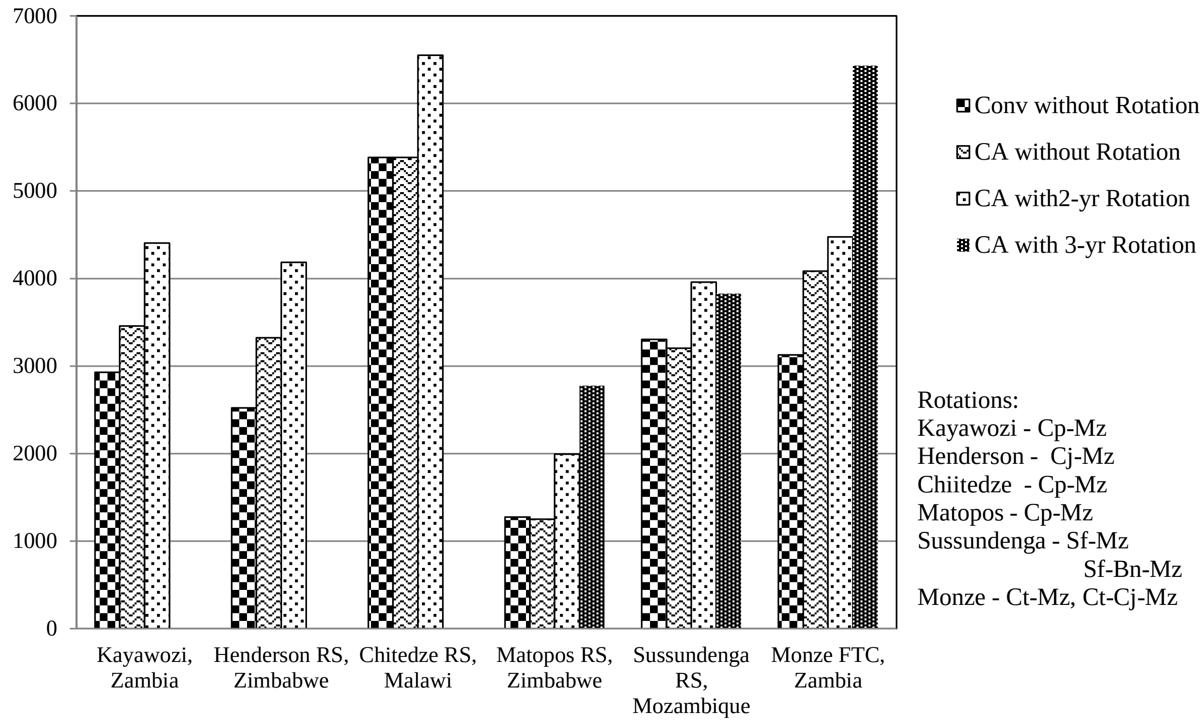

Fig. 11.1. The effect of CA and crop rotation on maize yield on farmers' fields (Kayawozi) and five research stations in southern Africa (Adapted from Thierfelder *et al*., 2012a, 2013 and Mupangwa *et al*., 2012). Mz = Maize; Cp = Cowpea; Cj = *Crotalaria juncea* (sunnhemp); Sf = sunflower; Bn = common bean; Ct = cotton.

11.4.3 Effect of Conservation Agriculture on soil quality (physical, chemical and biological)

A meta-analysis of the effects of CA on SOC in the developing world, including Africa (Govaerts *et al*., 2009), found little evidence of increases in SOC under CA. However, in the published reports we have analysed from E&S Africa CA has increased SOC compared to ConvT in practically all cases (Chuma and Hagmann, 1995; Haynes *et al*., 2003; Boye and Albrecht, 2005; Chivenge *et al*., 2007; Nyamadzawo *et al*., 2007; Oicha *et al*., 2010; Du Preez *et al*., 2011; Mchuru *et al*., 2011; Guto *et al*., 2012; Ngwira *et al*., 2012b, c; Thierfelder and Wall, 2012; Thierfelder *et al*., 2012 a, b, 2013) although differences are relatively seldom statistically significant. Only two instances were found in the literature where CA treatments had lower SOC than the cultivated soils: the 0–10 cm horizon of the Zidyana soils in Nkhotakhota Province of Malawi after 6 years of CA (Ngwira *et al*., 2012c) (SOC was higher under CA in these soils in the 10–30 cm horizon) and the 0–5 cm horizon of the sandy soils at the Masai farm site in western Kenya after 5 years of NT (Boye and Albrecht, 2005). However, recent studies comparing SOC under CA and ConvT in southern Africa have shown little difference in SOC despite several years under CA conditions (Thierfelder, unpublished data). Obviously further work is required to better understand SOC dynamics after a change to CA.

Importantly, many of the published reports have compared CA and ConvT effects on SOC over the whole tillage horizon (top 20 cm for animal traction tillage and top 30 cm for mechanical traction tillage) or more, thus permitting a valid comparison as ConvT systems may distribute SOC over this horizon, whereas in CA, surface accumulation of SOC is common. Most reports that have considered the whole tillage horizon have found significant increases in total SOC under CA compared to ConvT once the CA system had been practised for several years. In Zimbabwe there were significant increases in SOC after 10 years of mulch-ripping (15% on clay soil, 62% on a sandy soil) (Chivenge *et al*., 2007), while in CA systems established with an animal traction direct seeder there were significant increases in SOC in the 0–30 cm horizon after only 3–4 years of CA at three diverse sites in Zimbabwe: 17% higher on a sandy soil at Henderson Research Station, 13% higher on farmers' fields on a clay loam at Hereford Farm near Shamva and a huge 93% increase on the extremely sandy soils (>90% sand) around Chikato Village near Masvingo (Thierfelder and Wall, 2012). In Malawi, a survey of the fields of 48 farmers managing CA systems showed higher SOC levels in the 0–20 cm horizon of CA plots compared to ConvT plots, but only after 4 (44% higher SOC) or 5 (74% higher SOC) years of CA were the differences statistically significant (Ngwira *et al*., 2012b).

As expected from the generally higher levels of SOC under CA systems, the proportion of water-stable aggregates is also usually higher in CA systems in E&S Africa (Chuma, 1993; Boye and Albrecht, 2005; Thierfelder and Wall, 2010b), although there were no differences in aggregate stability between CA and ConvT systems in farmers' fields in Malawi (Ngwira *et al*., 2012c) and Ethiopia after 1 year of permanent beds (Oicha *et al*., 2010). Differences in aggregate stability of sandy soils may not be apparent using the aggressive wet sieving technique (e.g. Boye and Albrecht, 2005) and may require less aggressive tests, such as the dispersion test, to show differences in aggregation (Thierfelder and Wall, 2012).

11.4.4 Conservation Agriculture and soil water balance

One of the major benefits of CA is the effects on water balance, through effects on infiltration, evaporation, soil water-holding capacity, soil compaction and crop rooting characteristics. Changes in these components will also affect drainage, and possibly nutrient losses, as well as runoff and soil erosion. There are now considerable data on many of these processes under conditions of E&S Africa.

Thirty-nine sets of data from Kenya (3), Malawi (6), Zambia (12), Zimbabwe (17) and South Africa (1) show an overall increase in infiltration rate of 67% under CA conditions, although data obviously include different numbers of sites, years of results etc. Of all these results the only three that do not show a positive effect of CA on infiltration rates are the results of Guto *et al.* (2012) from Meru South in central Kenya, obtained with ring infiltrometers that were pushed into the soil. We suggest that this method is not appropriate for comparing infiltration rates between treatments that have different effects on the structure of the soil surface, as infiltration is affected greatly by conditions in the surface layer (0–1 cm) and if this layer is disturbed by inserting infiltration rings results will be questionable. Comparisons of the effects of CA and tillage on infiltration rates can best be achieved with (small, portable) rainfall simulators (e.g. Thierfelder *et al*., 2005) or with the simple 'time to pond' procedure (Govaerts *et al*., 2006) without soil surface disturbance. With these methods CA systems have universally shown greater water infiltration rates than tilled systems in southern Africa. Residues on the soil surface protect the soil from the impact of raindrops and reduce soil sealing and crust formation. In the absence of crop residues, untilled (CA) soils, especially degraded soils, can have lower infiltration rates and be less productive than tilled soils (Wall, 1999; Govaerts *et al*., 2005) and so it is not surprising that where little mulch is kept infiltration will be reduced and tillage to break the soil crust can give beneficial effects (Baudron *et al*., 2012a).

Soil water-holding capacity is a function of soil texture, porosity and SOC content. As SOC content increases the soil will hold more water (Hudson, 1994). Water that cannot be held by the soil should drain if there is no dense layer that impedes water flow. Although drainage may also take nutrients from the root zone it is a positive process in that it allows aeration of the root zone. As water infiltration is increased by CA, drainage is likely to increase during periods of excess rainfall above the soil water-holding capacity (Moyo and Hagmann, 1994; Nyagumbo, 2002; Munodawafa and Zhou, 2008; Thierfelder and Wall, 2009). However, where drainage is restricted, CA may lead to excess moisture in the profile, waterlogging and anoxia (Rusinamhodzi *et al*., 2011). Adaptation of CA practices for these conditions, including the possibility of permanent raised beds, is required.

Little work has been done to directly measure water evaporation from the soil surface under conditions of E&S Africa. However, between 60 and 75% of precipitation in semi-arid South Africa may be lost to unproductive evaporation (Bennie and Hensley, 2001), while across semi-arid sub-Saharan Africa losses to evaporation of 30–50% of precipitation have been calculated (Rockström *et al*., 2002). Obviously any reduction in evaporation could play a major role in increasing rainfall-use-efficiency (RUE), but we have found no reports of consistent benefits of CA in reducing evaporation (see Bennie and Hensley, 2001). The fact that soil is generally moist under a cover of crop residues suggests that evaporation is reduced but this needs confirmation and quantification in order to prioritize actions to enhance RUE.

Increased water infiltration results in reduced runoff. Studies from Ethiopia (Gebreegziabher *et al*., 2009; Nyssen *et al*., 2010), sandy soils in Kenya (Boye and Albrecht, 2005), Zimbabwe (Vogel, 1992; Moyo and Hagmann, 1994; Vogel *et al*., 1994; Moyo, 1998; Nyagumbo, 1998, 2002; Munodawafa and Zhou, 2008; Thierfelder and Wall, 2009) and South Africa (Kosgei *et al*., 2007; Mallet quoted by Bennie and Hensley, 2001) show an average 51% reduction in runoff with CA (range 14–95%). However, runoff was higher with NT treatments on a heavy soil in central Kenya (Boye and Albrecht, 2005) (although runoff plots were very small (1 m^{-2}) and only gmcc residues were left on the surface) and on sandy soils with less than a 2% slope in a semi-arid environment in South Africa (Bennie *et al*., 1994 quoted by Bennie and Hensley, 2001) where over 4 years 12.1% of the rainfall was lost to runoff from the NT plots with residue retention, while only 7.1% was lost from the ploughed plots.

Runoff water leads to erosion, with the amount of erosion depending on the erodability of the soil and the velocity of water running across it (erosivity). Data on the effect of CA treatments on erosion are shown in Table 11.6. On average 12.6 Mg ha^{-1} soil was lost from tilled treatments compared to 2.9 Mg ha^{-1} from CA treatments – a 77% reduction in erosion with CA. Not only is runoff reduced by CA, but residues on the soil surface reduce the velocity of water flow, allowing suspended solids to be deposited. On a very sandy site in Zimbabwe erosion was reduced by 99% by CA, and the distribution of textural classes in the sediment was changed. Silt+clay concentration in the sediment from the CA plots (47%) was higher than from the tilled plots (30%) because the larger sand particles had more time to settle. This is of course relative and a lot less clay and silt was lost overall from the CA plots (0.09 Mg ha^{-1}) than from the tilled plots (10.29 Mg ha^{-1}) (Moyo, 1998).

Table 11.6. Soil loss (Mg ha^{-1}) from CA and ConvT systems in eastern and southern Africa. Surface residues were kept unless otherwise indicated.

Country	Place	Soil type	Treatment description	Years of data	Average rainfall[a]	Soil loss Mg ha^{-1} ConvT	CA	Reference
Ethiopia	Near	Vertisol	CA = permanent	1	466	19.5	4.7	Gebreegziabher *et al*., 2009
	Tigray, Gum	Vertisol	CA = Derdero +	2	500–800	14.6	3.0	Nyssen *et al*., 2010
	Tigray, May	Vertisol		1	500–800	10.4	8.2	
Kenya	Leuro farm	Nito-	Continuous	1	1800	2.1	1.9	Boye and Albrecht, 2005
			Improved fallow			0.3	0.2	
	Masai farm	Ferralic	Continuous	1	1800	2.0	2.9	
			Improved fallow			0.7	0.9	
Zimbabw	Makoholi RS	Ferralic	CA = no-till tied	3	547	2.6	0.7	Vogel, 1992
	Domboshawa	Sand		3	858	4.1	1.7	
	MakoholiRS	Ferralic		1	483	34.3	0.2	Moyo, 1998
				3	547	33.0	2.0	Munodawafa and Zhou, 2008
	Domboshawa	Sand		8	858	41.0	8.0	Munyati, 1997
	Henderson	Arenoso	CA= Animal	2	880	7.2	4.5	Thierfelder and Wall, 2009
			CA = Rip line				4.1	
Mean						12.8	3.1	

[a]Approximate average annual rainfall (mm); [b]not clear whether residues were retained.

11.4.5 Conservation Agriculture and soil biological activity

Because of the lack of disturbance by tillage coupled with a more constant food supply from the residues, soil biological activity may be increased by CA. Earthworms are one of the indicators of enhanced soil biological activity and play an important role in incorporating organic matter and in increasing porosity and root channels. Data from South Africa (Haynes *et al*., 2003), Zambia (Thierfelder and Wall, 2010b), Malawi (Ngwira *et al*., 2012c) and Tanzania (Mariki, 2004: Steiner, 2013, unpublished data) all show significant increases in earthworm populations under conditions of CA with residue retention. On average across all sites there was a five-fold increase, with 22 earthworms m^{-2} (range 2–48) under ConvT and 113 earthworms m^{-2} (range 40–400) under CA. In the Zambian data the eight-fold increase in earthworm populations was after only 3 years in a CA system.

Generally CA systems increase soil microbial biomass. In results from KwaZulu-Natal, South Africa, soil microbial biomass (C) was 40% higher than ploughed fields after 3 years of CA (Chaplot *et al*., 2012) and 50% higher after 25 years. In Malawi, there were significant reductions in soil microbial biomass (C and N) on farmers' fields after 2–3 years of CA, but then significantly higher soil microbial biomass after 4 and 5 years of CA (Ngwira *et al*., 2012b). Farmers often talk about a transition period of 2–3 years after initiating CA, after which the system starts to improve, which can probably be attributed to the gradual increase in soil biological activity.

11.4.6 Conservation Agriculture and weeds, pests and diseases

There is little published information on the effects of CA on weeds, pests and diseases. One of the principal reasons for tillage is to control weeds, and so a move to CA systems obviously leads to weed problems. Earlier we highlighted this aspect in the discussion of herbicide and labour use. Some results from South America suggest that weed pressure declines with time as long as weed control is good (Skóra Neto, 1993) and Baudron *et al.* (2007) report that GART in Zambia holds to a 50% reduction in weed pressure after 5 years of CA practice with good weed control. There are also reports that residue cover helps control weeds but the results shown in Fig. 11.2 suggest that the levels of residue cover for any reasonable weed control would be excessively high. Mulch may also affect the weed spectrum, and in Tanzania the populations of problematic weeds such as *Digitaria* spp. and *Cyperus* sp. were markedly reduced by CA with gmcc (Steiner, 2013, unpublished).

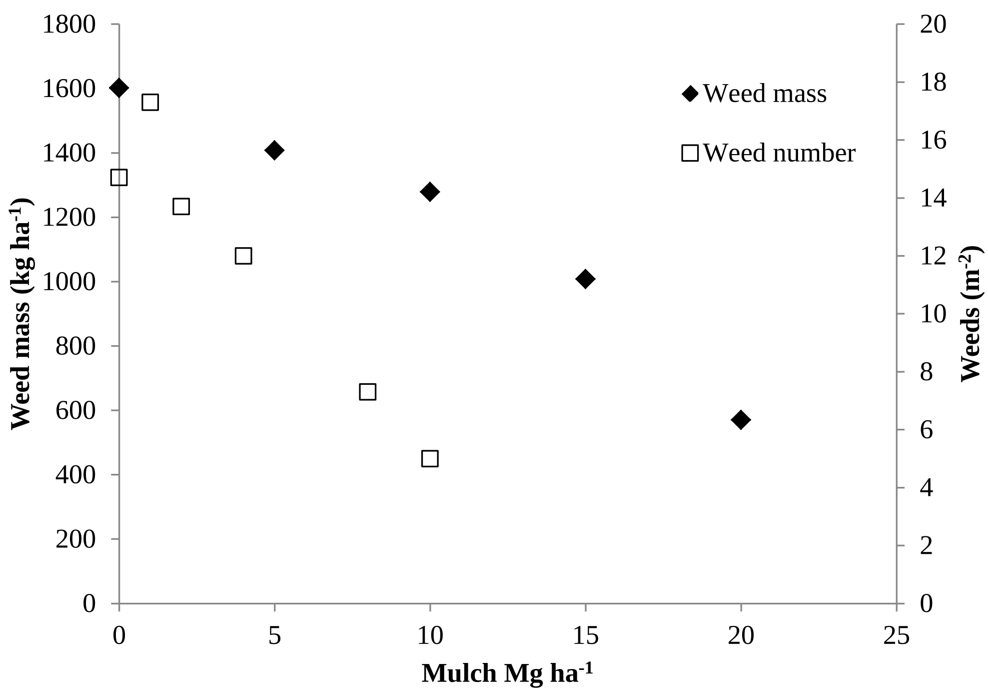

Fig. 11.2. Effect of mulch quantity on weed numbers at Matopos Research Station, Zimbabwe (adapted from Twomlow *et al*., 2009) and weed mass at the GART Research Farm in Zambia (adapted from Gill *et al*., 1992).

In the 1986/87 season in South Africa, just as adoption of CA was beginning to take hold in KwaZulu-Natal, a diplodia maize cob rot epidemic (caused by *Stenocarpella maydis*) was worse on CA fields and caused a set-back to the adoption of CA (Fowler, 1999). This can be expected from necrotrophic diseases (that survive on dead tissue – the residues) and stresses the importance of crop rotation in CA systems to guard against disease. The maize varieties at that time were not resistant to the diplodia, but since then maize varieties resistant to the disease, and also to grey leaf spot (GLS), another residue-borne disease, have become available.

There are few consistent reports of increased insect damage in CA systems in E&S Africa. Termites are often cited as a problem because they consume the residues but at the same time they open up channels that aid in water infiltration. Reports of damage to the maize crop are very variable, probably because termite species differ greatly from place to place. Although there are reports of increased damage with CA, our observations in Malawi show clearly more damage to the maize crop in conventionally ridged plots without residues.

White grubs (Scarabidae larvae) are a sporadic pest that can do considerable damage by killing young plants. There are reports that damage due to white grubs may be worse in CA than in conventional systems, e.g. the report in Giller *et al*. (2009) based on field observations in a few fields in Mozambique. We have seen similar situations in Malawi, but it appears that crop rotation with legumes overcomes the problem (Thierfelder, forthcoming).

11.5 Problems Encountered in Scaling-out Conservation Agriculture in Eastern and Southern Africa

Numerous problems have been encountered in scaling-out even simple, single component technological innovations (e.g. new maize varieties) in E&S Africa and therefore it is not surprising that the adoption of a complex system change such as CA has been slow. While the principal technological challenges of CA involve weed control, adequate equipment for seeding, residue and nutrient management, these are surmountable problems that have technical solutions. However, the practical limitations to widespread adoption, described by Wall (2007), are principally economic, organizational, social and legal:

- Mind-set;
- Knowledge of the CA system;
- Residue retention, and competition for scarce residues;
- Physical and financial access to inputs;
- Availability of adapted equipment;
- Capacity building among farmers, researchers and extension agents;
- Development of innovation systems around CA;
- Land tenure;
- Support to farmers for environmental services.

Overcoming these problems will require concerted efforts in resolving the weak links in the value chains surrounding maize and accompanying crops in E&S Africa. A major step in this direction is the development of local innovation systems involving multiple agents representing all major stakeholders in the value chains (including agents involved in both input and output markets – the U-impact pathway), and especially farmers (Ekboir, 2002; Wall *et al*., 2002). Moving away from the common linear model of agricultural technology development and dissemination to a farmer participatory model within a local innovation system will help overcome many of the limitations noted above. However, innovation systems do not normally develop spontaneously, they need to be catalysed (Wall *et al*., 2002), and in the absence of other catalysts the capacity of extension agents and researchers to catalyse, build and nurture local innovation systems will be extremely important. As CA becomes more widespread there should be an important change in the focus of adaptive CA research embedded in these innovation systems, moving away from comparisons between ConvT and CA systems, and rather concentrating on the identification and resolution of problems within the developing CA systems, while strategic research to understand the processes underpinning the successful application of CA systems is needed to aid in the development of adapted systems. At the same time the focus of extension agents should change from being conduits of information to farmers, to rather becoming catalysts of local innovation systems and facilitators of farmer-to-farmer information exchange – farmers believe information they get from other farmers far more readily than they do from those that do not rely on farming for their livelihoods.

Maintaining crop residues on the soil surface is an issue in smallholder systems worldwide, as smallholders generally manage complex mixed crop/livestock systems. The need for understanding and demonstrating the importance of crop residues for soil cover in E&S Africa was noted above. However, in other environments, especially on degraded soils with a tendency to form a surface crust, direct seeding of crops into untilled soil without surface mulch leads to reduced yields compared to tilled systems (Wall, 1999; Govaerts *et al*., 2005; Enfors *et al*., 2011; Baudron *et al*., 2012a); soil crusts need to be broken by tillage or their development reduced by the surface protection offered by mulch cover. However, leaving mulch on the soil surface implies direct competition for residues with different household enterprises, especially livestock. Residues of cereal crops are at best a low quality maintenance feed, meaning that draught animals are weak after the dry season and tillage with animal traction is a slow and lengthy process. Options for system intensification under CA include possibilities of producing higher quality feed on part of the land (as allowed by the increased staple crop productivity in CA systems), thus allowing some of the low-quality cereal crop residues to be retained for mulch (Thierfelder and Wall, 2011), although smallholder farmers generally do not like to grow fodder crops (K. Steiner, 2013, pers. comm.). However, as with many other smallholder systems worldwide, communal grazing is the norm in E&S Africa (e.g. Mtambanengwe and Mapfumo, 2005 in Zimbabwe), meaning that an individual farmer cannot protect the residues on his or her own fields without considerable cost of both capital and goodwill (Erenstein, 2002). Residue retention becomes a social issue and needs to be dealt with through the innovation system at the community level. This will not be easy, not least of all because in many parts it is the richer and more powerful members of the community who own more cattle and benefit most from communal grazing rights. However, there are some examples from Tanzania and Zimbabwe of community action that has resulted in restrictions to communal grazing in E&S Africa (Wall, 2007) – these need to be multiplied.

Equipment for manual CA systems is not a major issue as the ubiquitous hoe is a functional tool for seeding in CA systems, as is the pointed (or dibble) stick (Ngwira *et al*., 2012c). However, improved versions of these basic tools such as the Chaka hoe for more effective digging of planting basins (Conservation Farming Unit, 2007) facilitate more efficient crop establishment under CA. Punch planters made in Brazil, Tanzania and China have as yet not been widely accepted in E&S Africa, although tests continue. Animal traction equipment, largely from Brazil, has been introduced into many countries and functions well, but price restricts their greater use. Government and international support is needed to stimulate local production in the region and to adapt the equipment to local 'materials, conditions, economic circumstances and skill levels' (Sims *et al*., 2012) and to ensure local capacity for maintenance, repair and the supply of spare parts. Four-wheel tractors are used on the relatively few large commercial farms in the region, and imported equipment has generally been used for CA experiences. Some service provision to smallholders has also occurred. However, more recently interest has grown, especially in eastern Africa, for two-wheel tractors and prototype equipment for CA using two-wheel tractors is being manufactured in both Kenya and Tanzania.

Once adapted equipment is available, markets for the equipment and other inputs needed for productive agricultural systems, together with functional credit markets, are required. Markets in many smallholder farming areas are weak due to large seasonal variation in demand and supply; stabilizing demand through more productive, lower risk (more stable) production systems will help make input supply and produce purchase enterprises more attractive to small entrepreneurs, but systematic support to fair and competitive market development and maintenance will be required. Although the public sector should take a lead and monitor this process, non-governmental and aid programmes have an opportunity to play a leading role in stimulating development through support to market development for inputs, outputs and credit.

11.6 Prospects for the Widespread Adoption of Conservation Agriculture in Eastern and Southern Africa

The combined effects of advancing soil degradation, climate change and rising prices of inputs, will increase the pressure on farmers, researchers and development agencies in E&S Africa to develop and practise more efficient and sustainable farming systems. To think that this change will be easy would be illusionary, but nevertheless it is inevitable. Although agricultural technology, based on the principles of CA, can address many of the challenges, without changes in infrastructure and markets, both for inputs and produce, widespread adoption of these technologies is unlikely. The Zambian example of political support and the involvement of all of the major stakeholders (policy makers, donors, input suppliers, trainers) in an innovation system to develop and support CA (Baudron *et al*., 2007) is an example of a functional, albeit imperfect, U-impact pathway. Increased efforts are needed to develop local innovation systems around CA, focusing on the efforts of innovative farmers and the bottle-necks in the value chains surrounding the principal farm enterprises. We have shown in this chapter that CA systems do function acceptably in many situations in E&S Africa, although there is still considerable scope for improvement and local adaptation, necessarily with farmer involvement. However, more effort is now needed on the other components of the value chains to ensure widespread adoption.

11.7 Concluding Remarks – Is the Glass Half-Full or Half-Empty?

There is a wealth of scientific data showing that tillage results in soil and land degradation, reduced SOM and soil structural breakdown, leading to decreased soil biological activity and water infiltration, as well as increased water runoff and soil erosion. Although much of the testing of CA systems in E&S Africa has not followed a process of local adaptation and system development prior to their comparison with ConvT systems that have been adapted by and with farmers over decades, most of the reports show yield benefits to the CA systems, as well as important benefits in increased SOM and water infiltration, and reduced runoff and erosion. Given that rainfall is both the motor to agricultural production in good seasons and the brake in poor seasons, increasing water availability in poor seasons reduces risk – one of the key limitations to input use in smallholder production systems in E&S Africa.

However, there are also reports of failures of the applied CA systems. It is often difficult to understand just how these CA systems were established, and therefore what led to the failure of the system – in other reports the reason is clear, including crop stand establishment, lack of residues and/or lack of plant nutrients. However, it is the reaction to these failures that appears to divide the constituency dedicated to improving farm household livelihoods in E&S Africa. There are some (e.g. Giller *et al*., 2009; Baudron *et al*., 2012a) who suggest that CA systems (not just the one that was tested) do not work in that environment or for that group of farmers – the glass is half empty – while others, including ourselves, hold to the premise that this offers an opportunity to find out how better to manage systems based on the principles of CA under those particular conditions – the glass is half full. This is probably a healthy debate, but the alternative of continuing with soil tillage (as suggested by Giller *et al*., 2009 and Baudron *et al*., 2012a) is very unhealthy, especially for the farm families of the future who will depend on the ever degrading soils (unless this is stopped) for their livelihoods. Current scientific evidence suggests that CA systems offer the best option we have today for the sustainable production of field crops.

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References

Aagard, P. (2009) Maize production and conservation farming in zambia - an update, Lusaka, Zambia. Available at: http://conservationagriculture.org/uploads/pdf/MAIZE-PRODUCTION-AND-CF-IN-ZAMBIA.pdf (accessed 7 January 2013).

Agenbag, G.A. and Maree, P.C.J. (1991) Effect of tillage on some soil properties, plant development and yield of spring wheat (*Triticum aestivum* L.) in stony soil. *Soil and Tillage Research*, 21(1–2), 97–112.

Andersson, J.A. and Giller, K.E. (2012) On heretics and God's blanket salesmen: contested claims for Conservation Agriculture and the politics of its promotion in African smallholder farming. In: Sumberg, J. and Thompson, J. (eds) *Contested Agronomy: Agricultural Research in a Changing World.* Earthscan, London, pp. 1–21.

Angima, S., Stott, D.E., O'Neill, M.K., Ong, C.K. and Weesies, G.A. (2003) Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture, Ecosystems and Environment* 97(1–3), 295–308.

Apina, T., Wamai, P. and Mwangi, P.K. (2007) Laikipia District. In: Kaumbutho, P. and Kienzle, J. (eds) *Conservation Agriculture as Practised in Kenya: two case studies*. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations, pp. 2–56.

Bai, Z.G., Dent, D.L., Olsson, L. and Schaepman, M.E. (2008) *Global Assessment of Land Degradation and Improvement 1 . Identification by remote sensing. Report 2008/01*, Wageningen, the Netherlands, 78 pp.

Baudron, F., Mwanza, H.M., Triomphe, B. and Bwalya, M. (2007) *Conservation agriculture in Zambia: a case study of southern province, Nairobi*. African Conservation Tillage Network, Centre de Coopération Internationale de Recherche Agronomique pour le Développement, Food and Agriculture Organization of the United Nations, 57 pp.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P. and Giller, K.E. (2012a) Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. *Field Crops Research* 132,117–128.

Baudron, F., Andersson, J.A., Corbeels, M. and Giller, K.E. (2012b) Failing to yield? Ploughs, conservation agriculture and the problem of agricultural intensification: an example from the Zambezi Valley, Zimbabwe. *Journal of Development Studies* 38(3), 393–412.

Bennie, A.T.P. and Hensley, M. (2001) Maximizing precipitation utilization in dryland agriculture in south Africa – a review. *Journal of Hydrology* 241(1–2), 124–139.

Berry, W.A.J., Birch, E.B., van Rensburg, J.J., Fowler, R.M. and Findlay, J.B.R. (2001) A case study of conservation and no-tillage technology transfer – KwaZulu Natal, South Africa. In: Garcia-Torres, L., Benites, J. and Martínez-Vilela, A. (eds) *Conservation Agriculture, A Worldwide Challenge. First World Congress on Conservation Agriculture.* Vol. II: *Offered Contributions.* XUL, Cordoba, Spain, pp. 743–748.

Bolliger, A., Damgaard Hansen, K. and Fowler, R. (2005) Constraints limiting smallholder adoption of conservation agriculture: some observations based on three south African smallholder-orientated programmes. In: *Proceedings of the III World Congress on Conservation Agriculture, Nairobi, Kenya.* On CD.

Bot, A. and Benites, J. (2001) *Conservation Agriculture: case studies in Latin America and Africa*. Food and Agriculture Organization of the United Nations, Rome.

Boye, A. and Albrecht, A. (2005) Soil and water conservation by crop rotation with leguminous shrubs – a case study on runoff and soil loss under natural rainfall in western Kenya. In: *Proceedings of the III World Congress on Conservation Agriculture, Nairobi, Kenya*. On CD.

Brady, N.C. and Weil, R.R. (2007) *The Nature and Properties of Soils*, 13th edn. Prentice Hall, New Jersey.

Chaplot, V., Mchunu, C.N., Manson, A., Lorentz, S. and Jewitt, G. (2012) Water erosion-induced CO2 emissions from tilled and no-tilled soils and sediments. *Agriculture, Ecosystems and Environment* 159, 62–69.

Chivenge, P.P., Murwira, H.K., Giller, K.E., Mapfumo, P. and 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.

Chuma, E. (1993) Effects of tillage on erosion-related properties of a sandy soil in semi-arid Zimbabwe. In: Kronen, M. (ed.) *Proceedings of the Fourth Annual Scientific Conference, SADC Land and Water Management Research Programme.*SACCAR,Gabarone, Botswana, pp. 331–349.

Chuma, E. and Hagmann, J. (1995) Summary of results from on-station and on-farm testing and development of conservation tillage systems in the semi-arid Masvingo, Zimbabwe. In: Twomlow, S. (ed.) *Proceedings of a Technical Workshop on Soil and Water Conservation for Smallholder Farmers in Semi-Arid Zimbabwe.* Belmont Press, Masvingo, Zimbabwe, pp. 41–60.

Conservation Farming Unit (2007) *Conservation Farming and Conservation Agriculture Handbook for Hoe Farmers in Agro-Ecological Regions I and IIa - Flat Culture*. ZNFU, Conservation Farming Unit, Lusaka, Zambia, 60 pp.

Derpsch, R. and Friedrich, T. (2009) Global overview of conservation agriculture adoption. In: *4th World Congress on Conservation Agriculture: Innovations for Improving Efficiency, Equity and Environment.* ICAR, New Delhi, India. Available at: http://www.fao.org/ag/ca (accessed 15 October, 2011).

Derpsch, R., Friedrich, T., Kassam, A. and Li, H. (2010) Current status of adoption of no-till farming in the world and some of its main benefits. *International Journal of Agricultural and Biological Engineering* 3(1), 1–26.

Dixon, J., Hellin, J., Erenstein, O. and Kosina, P. (2007) U-impact pathway for diagnosis and impact assessment of crop improvement. *Journal of Agricultural Science* 145,195–206.

Dixon, J., Gulliver, A. and Gibbon, D. (2001) Farming systems and Poverty. In: Hall, M. (ed.) *Improving Farmers' Livelihoods in a Changing World.* FAO and World Bank, Rome and New York, p. 412.

Du Preez, C.C., Steyn, J.T. and Kotze, E. (2001) Long-term effects of wheat residue management on some fertility indicators of a semi-arid Plinthosol. *Soil and Tillage Research* 63(1–2), 25–33.

Du Preez, C.C., Van Huyssteen, C.W. and Mnkeni, P.N.S. (2011) Land use and soil organic matter in south Africa 2: A review on the influence of arable crop production. *South African Journal of Science* 107(5/6), 2–9.

Ekboir, J. (2002) Developing no-till packages for small-scale farmers. In: Ekboir, J. (ed.) *World Wheat Overview and Outlook.* CIMMYT, Mexico City, Mexico, pp. 1–38.

Elwell, H.A. (1989) *Soil Structure under Conservation Tillage*. Commercial Grain Producers Handbook, Harare, Zimbabwe, pp. 33–39.

Elwell, H.A. and Stocking, M.A. (1988) Loss of soil nutrients by sheet erosion is a major hidden farming cost. *Zimbabwe Science News* 22(7/8), 79–82.

Enfors, E., Barron, J., Makurira, H., Rockström, J. and Tumbo, S. (2011) Yield and soil system changes from conservation tillage in dryland farming: a case study from north eastern Tanzania. *Agricultural Water Management* 98(11),1687–1695.

Erenstein, O. (2002) Crop residue mulching in tropical and semi-tropical countries: an evaluation of residue availability and other technological implications. *Soil and Tillage Research* 67(2), 115–133.

Findlay, J.B.R., Modestus, K.W., Lawrence-Brown, D. and Miheso, V. (2001) The introduction of conservation tillage practices to small-scale farmers in Kenya, Tanzania and Uganda soils. In: Garcia-Torres, L., Benites, J. and Martínez-Vilela, A. (eds) *Conservation Agriculture, A Worldwide Challenge. First World Congress on Conservation Agriculture.* Vol. II: *Offered Contributions.* XUL, Cordoba, Spain, pp. 73–76.

Fowler, R. (1999) Conservation tillage research and development in south Africa. In: Kaumbutho, P.G. and Simalenga, T.E. (eds) *Conservation Tillage with Animlal Traction. A Resource Book of the Animal Traction Network for Eastern and Southern Africa (ATNESCA).* Harare, Zimbabwe, pp. 51–60.

Garrity, D.P. (2011) Making Conservation Agriculture ever green. In: *Resilient Food Systems for a Changing World: Proceedings of the 5th World Congress on Conservation Agriculture. 25–29 September 2011, Brisbane, Australia*. Delhi, India, pp. 14–15.

Garrity, D.P., Akinnifesi, F., Ajayi, O., Weldesemayat, S., Mowo, J., Kalinganire, A., Larwanou, M. and Bayala, J. (2010) Evergreen Agriculture: a robust approach to sustainable food security in Africa. *Food Security* 2, 197–214.

Gebreegziabher, T., Nyssen, J., Govaerts, B., Getnet, F., Behailu, M., Haile, M. and Deckers, J. (2009) Contour furrows for in situ soil and water conservation, Tigray, Northern Ethiopia. *Soil and Tillage Research* 103(2), 257–264.

Gill, K.S., Arshad, M.A., Chivundu, B.K., Phiri, B. and Gumbo, M. (1992) Influence of residue mulch, tillage and cultural practiceson weed mass and crop yield from three field experiments. *Soil and Tillage Research* 24, 211–223.

Giller, K.E.,Witter, E., Corbeels, M. and Tittonell, P. (2009) Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research* 114(1), 23–34.

Govaerts, B., Sayre, K. and Deckers, J. (2005) Stable high yields with zero tillage and permanent bed planting? *Field Crops Research* 94(1), 33–42.

Govaerts, B., Sayre, K. and Deckers, J. (2006) A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. Soil and Tillage Research, 87 (2), 163-174.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K.D., Dixon, J. and Dendooven, L. (2009) Conservation Agriculture and Soil Carbon Sequestration: Between Myth and Farmer Reality. *Critical Reviews in Plant Sciences* 28(3), 97–122.

Gowing, J.W. and Palmer, M. (2008) Sustainable agricultural development in sub-Saharan Africa: the case for a paradigm shift in land husbandry. *Soil Use and Management* 24(1), 92–99.

Guto, S.N., Pypers, P., Vanlauwe, B., de Ridder, N. and 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.

Gwenzi, W., Gotosa, J., Chakanetsa, S. and Mutema, Z. (2008) Effects of tillage systems on soil organic carbon dynamics, structural stability and crop yields in irrigated wheat (*Triticum aestivum* L.)–cotton (*Gossypium hirsutum* L.) rotation in semi-arid Zimbabwe. *Nutrient Cycling in Agroecosystems* 83(3), 211–221.

Haggblade, S. and Tembo, G. (2003) *Conservation Farming in Zambia. EPTD Discussion Paper No. 108.* International Food Policy Research Institute, Washington DC, 128 pp.

Haynes, R.J., Dominy, C.S. and Graham, M.H. (2003) Effect of agricultural land use on soil organic matter status and the composition of earthworm communities in KwaZulu-Natal, South Africa. *Agriculture, Ecosystems and Environment* 95(2–3), 453–464.

Hudson, B. (1994) Soil organic matter and available water capacity. *Journal of Soil and Water Conservation* 49(2), 189–194.

Ito, M., Matsumoto, T. and Quiñones, M. (2007) Conservation tillage in Sub-Saharan Africa: The experience of Sasakawa Global 2000. *Crop Protection* 26, 417–423.

Jat, R.A., Wani, S.P., Singh, P., Pathak, P., Srinivas, K., Kumar, U., Pavani, E. and Velmurgan, R. (2012a) Effect of conservation agriculture on productivity and economics of different cropping systems under rainfed condition in the semi-arid tropics. In: *Proceedings of 3rd International Agronomy Congress*. New Delhi, India. pp. 888–890.

Jat, R.A., Wani, S.P. and Sahrawat, K.L. (2012b) Conservation agriculture in the semi-arid tropics: prospects and problems. In: Sparks D.L. (ed.) *Advances in Agronomy* 117, 191–273.

Kosgei, J.R., Jewitt, G.P.W., Kongo, V.M. and Lorentz, S.A. (2007) The influence of tillage on field scale water fluxes and maize yields in semi-arid environments: A case study of Potshini catchment, South Africa. *Physics and Chemistry of the Earth, Parts A/B/C* 32(15–18), 1117–1126.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P. and Naylor, R.L. (2008) Prioritizing climate change adaptation needs for food security in 2030. *Science* 319, 607–610.

MacRobert, J.F., Winkfield, R.A. and Pilbrough, S. (1995) Conservation tillage on the Agricultural Research Trust Farm. In: Vowles, M. (ed.) *Conservation Tillage: A handbook for commercial farmers in Zimbabwe.* LaserPrint, Harare, Zimbabwe, pp. 101–108.

Malley, Z.J.U., Semoka, J.M.R., Kamasho, J.A. and Kabungo, C.V. (2006) Participatory assessment of soil degradation in the uplands of southwestern Tanzania: Implications for sustainable agriculture and rural livelihoods. *International Journal of Sustainable Development and World Ecology* 13(3), 183–197.

Mariki, W.L. (2004) *The Impact of Conservation Tillage and Cover Crops on Soil Fertility and Crop Production in Karatu and Hanang Districts of Northern Tanzania. TFSC/GTZ Technical Report 1999–2003.* Arusha, Tanzania, 38 pp.

Mashingaidze, N., Madakadze, C., Twomlow, S., Nyamangara, J. and Hove, L. (2012) Crop yield and weed growth under conservation agriculture in semi-arid Zimbabwe. *Soil and Tillage Research* 124, 102–110.

Materechera, S.A. and Mloza-Banda, H.R. (1997) Soil penetration resistance, root growth and yield of maize as influenced by tillage system on ridges in Malawi. *Soil and Tillage Research* 41(1–2), 13–24.

Mazvimavi, K. and Twomlow, S. (2009) Socioeconomic and institutional factors influencing the adoption of conservation farming by vulnerable households in Zimbabwe. *Agricultural Systems* 101, 20–29.

Mchuru, C.N., Lorentz, S., Jewitt, J., Manson, A. and Chaplot, V. (2011) No-Till Impact on Soil and Soil Organic Carbon Erosion under Crop Residue Scarcity in Africa. *Soil Science Society of America Journal* 75(4), 1503–1512.

Mills, A.J. and Fey, M.V. (2003) Declining soil quality in South Africa: effects of land use on soil organic matter and surface crusting. *South African Journal of Science* 99(9–10), 429–436.

Morris, M., Morris, M., Kelly, V.A., Kopicki, R.J. and Byerlee, D. (2007) *Fertilizer Use in African Agriculture: Lessons Learned and Good Practice Guidelines*. The World Bank., Washington DC, 146 pp.

Moyo, A. (1998) The effect of soil erosion on soil productivity as influenced by tillage, with special reference to clay and organic matter losses. In: *Proceedings of the 9th ISCO Conference, Bonn, 26–30 August, 1996*.

Moyo, A. and Hagmann, J. (1994) Growth-effective rainfall in maize production under different tillage systems in semi-arid conditions and granitic sands of southern Zimbabwe. In: Jensen, B.E. *et al*. (eds) *Soil Tillage for Crop Production and Protection of the Environment. Proceedings of the 13th International Conference of the International Soil Tillage Research Organization (ISTRO).* Aalborg, Denmark, pp. 475–480.

Mtambanengwe, F. and Mapfumo, P. (2005) Organic Matter Management as an Underlying Cause for Soil Fertility Gradients on Smallholder Farms in Zimbabwe. *Nutrient Cycling in Agroecosystems* 73(2–3), 227–243.

Muliokela, S.W., Hoogmoed, W.B., Stevens, P. and Dibbits, H. (2001) Constraints and possibilities for conservation farming in Zambia. In: Garcia-Torres, L., Benites, J. and Martínez-Vilela, A. (eds) *Conservation Agriculture, A Worldwide Challenge. First World Congress on Conservation Agriculture.* Vol. II: *Offered Contributions.* XUL, Cordoba, Spain, pp. 61–65.

Munodawafa, A. and Zhou, N. (2008) Improving water utilization in maize production through conservation tillage systems in semi-arid Zimbabwe. *Physics and Chemistry of the Earth, Parts A/B/C* 33(8–13), 757–761.

Munyati, M. (1997) Conservation tillage for sustainable crop production: Results and experiences from on-station and on farm research in Natural Region II (1988-1996). *Zimbabwe Science News* 31(2), 27–33.

Mupangwa, W., Twomlow, S., Walker, S. and 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* 32(15–18), 1127–1134.

Mupangwa, W., Twomlow, S. and Walker, S. (2012) Reduced tillage, mulching and rotational effects on maize (*Zea mays* L.), cowpea (*Vigna unguiculata* (Walp) L.) and sorghum (*Sorghum bicolor* L. (Moench)) yields under semi-arid conditions. *Field Crops Research* 132, 139–148.

Ngwira, A., Sleutel, S. and Neve, S. (2012a) 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.

Ngwira, A.R., Aune, J.B. and Mkwinda, S. (2012b) On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. *Field Crops Research* 132, 149–157.

Ngwira, A.R., Thierfelder, C. and Lambert, D.M. (2012c) Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. *Renewable Agriculture and Food Systems* 1–14.

Nhancale, I.T., Zandamela, C.B. and Massinga, R. (2006) Agricultura de conservaçâo em Moçambique: Um breve historial. In: Zandamela, C.B., Wall, P.C. and Nhancale, I.T. (eds) *Mapeando o caminho para o futuroda agricultura da conservaçâo em Moçambique. Memorias do seminario.* Agrodec, Maputo, pp. 7–11.

Nyagumbo, I. (1998) Experiences with conservation tillage practices in southern and eastern Africa: a regional perspective. In: Benites, J. *et al*. (eds) *Conservation Tillage For Sustainable Agriculture: International Workshop 22–27 June 1998*. GTZ, Eschborn, pp. 73–86.

Nyagumbo, I. (1999) Conservation tillage for sustainable crop production systems: experiences from on-station and on-farm research in Zimbabwe (1988-1997). In: Kaumbutho, P.G. and Simalenga, T.E. (eds) *Conservation Tillage with Animal Traction. A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESCA).* Harare, Zimbabwe, pp. 108–115.

Nyagumbo, I. (2002) Effects of three tillage systems on seasonal water budgets and drainage of two Zimbabwean soils under maize. DPhil thesis, Department of Soil Science and Agricultural Engineering, University of Zimbabwe, Harare, 270 pp.

Nyagumbo, I. (2008) A review of experiences and developments towards conservation agriculture and related systems in Zimbabwe. In: Goddard, T. *et al*. (eds) *No-Till Farming Systems*. World Association of Soil and Water Conservation (WASWC), Bangkok, pp. 345–372.

Nyamadzawo, G., Chikowo, R., Nyamugafata, P., Nyamangara, J. and Giller, K.E. (2007) Soil organic carbon dynamics of improved fallow-maize rotation systems under conventional and no-tillage in Central Zimbabwe. *Nutrient Cycling in Agroecosystems* 81(1), 85–93.

Nyssen, J., Govaerts, B., Araya, T., Cornelis, W.M., Bauer, H., Haile, M., Sayre, K. and Deckers, J. (2010) The use of the marasha ard plough for conservation agriculture in Northern Ethiopia. *Agronomy for Sustainable Development* 31(2), 287–297.

Oicha, T., Cornelis, W.M., Verplancke, H., Nyssen, J., Govaerts, B., Behailu, M., Haile, M. and Deckers, J. (2010) Short-term effects of conservation agriculture on Vertisols under tef (*Eragrostis tef* (Zucc.) Trotter) in the northern Ethiopian highlands. *Soil and Tillage Research* 106(2), 294–302.

Oldrieve, B. (n.d.) *Conservation Agriculture and Smallholder Farming in Africa: A practical farmer's view*. 10 pp.

Oldrieve, B. (1993) *Conservation Farming for communal, small scale, resettlement and co-operative farmers of Zimbabwe: A Farm Management Handbook*. Prestige Business Services (Pvt) Ltd, Harare.

Rockström, J., Barron, J. and Fox, P. (2002) Rainwater management for increased productivity among small-holder farmers in drought prone environments. *Physics and Chemistry of the Earth* 27, 949–959.

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J. and Damgaard-Larsen, S. (2009) Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. *Soil and Tillage Research* 103, 23–32.

Rusinamhodzi, L., Corbeels, M., Wijk, M.T., Rufino, M.C., Nyamangara, J. and 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.

Sims, B.G., Thierfelder, C., Kienzle, J., Friedrich, T. and Kassam, A. (2012) Development of the conservation agriculture equipment industry in sub-Saharan Africa. *Applied Engineering in Agriculture* 28(6), 1–11.

Siziba, S. (2007) Assessing the adoption of conservation agriculture in Zimbabwe's smallholder sector. PhD thesis, Institute of Agricultural Economics and Social Sciences in the Tropics and Sub-tropics, Faculty of Agriculture, University of Hohenheim, 175 pp.

Skóra Neto, F. (1993) Controle de plantas daninhas através de coberturas verdes consorciados com milho. *Pesquisa Agropecuaria Brasileira* 28(10), 1165–1171.

Soil Science Glossary Terms Committee (2008). Glossay of Soil Science Terms. Madison WI., Soil Science Society of America. 92pp.

Steiner, K. (2002) *The economics of conservation tillage*. African Conservation Tillage Network, Information Series No. 2, GTZ/ACT, Harare, 4 pp.

Stoorvogel, J.J., Smaling, E.M.A. and Jansen, B.H. (1993) Calculating soil nutrient balances in Africa at different scales. 1. Supra-national scale. *Fertilizer Research* 35(3), 227–235.

Thierfelder, C. and Wall, P.C. (2009) Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil and Tillage Research* 105, 217–227.

Thierfelder, C. and Wall, P.C. (2010a) Investigating Conservation Agriculture (CA) Systems in Zambia and Zimbabwe to Mitigate Future Effects of Climate Change. *Journal of Crop Improvement* 24(2), 113–121.

Thierfelder, C. and Wall, P.C. (2010b) Rotation in Conservation Agriculture Systems of Zambia: Effects on Soil Quality and Water Relations. *Experimental Agriculture* 46(3), 309–325.

Thierfelder, C. and Wall, P.C. (2011) Reducing the Risk of Crop Failure for Smallholder Farmers in Africa Through the Adoption of Conservation Agriculture. In: Bationo, A. *et al*. (eds) *Innovations as Key to the Green Revolution in Africa.* Springer, the Netherlands, pp. 1269–1277.

Thierfelder, C. and 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, 209–220.

Thierfelder, C., Amezquita, E. and Stahr, K. (2005) Effects of intensifying organic manuring and tillage practices on penetration resistance and infiltration rate. *Soil and Tillage Research* 82, 211–226.

Thierfelder, C., Cheesman, S. and Rusinamhodzi, L. (2012a) A comparative analysis of conservation agriculture systems: Benefits and challenges of rotations and intercropping in Zimbabwe FCR. *Field Crops Research* 137, 237–250.

Thierfelder, C., Cheesman, S. and Rusinamhodzi, L. (2012b) Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa. *International Journal of Agricultural Sustainability* (July), 1–17.

Thierfelder, C., Mwila, M. and Rusinamhodzi, L. (2013) Conservation agriculture in eastern and southern provinces of Zambia : Long-term effects on soil quality and maize productivity. *Soil and Tillage Research* 126, 246–258.

Twomlow, S., Hove, L., Mupangwa, W., Masikati, P. and Mashingaidze, N. (2009) Precision Conservation Agriculture For Vulnerable Farmers In Low-Potential Zones. In: Humphreys, L. (ed.) *Proceedings of the Workshop on Increasing the Productivity and Sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana, 22–25 September 2008.* Colombo, Sri Lanka, pp. 37–54.

Umar, B.B., Aune, J.B., Johnsen, F.H. and 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.

Vogel, H. (1992) Effects of conservation tillage on sheet erosion from sandy soils at two experimental sites in Zimbabwe. *Applied Geography* 12, 229–242.

Vogel, H. (1994) Weeds in single-crop conservation farming in Zimbabwe. *Soil and Tillage Research* 31, 169–185.

Vogel, H., Nyagumbo, I. and Olsen, K. (1994) Effect of tied-ridging and mulch ripping on waterconservation in maize production on sandveld soils. *Der Tropenlandwirt* 95, 33–44.
Wall, P.C. (1999) Experiences with crop residue cover and direct seeding in the Bolivian highlands. *Mountain Research and Development* 19(4), 313–317.
Wall, P.C. (2007) Tailoring Conservation Agriculture to the Needs of Small Farmers in Developing Countries : An Analysis of Issues. *Journal of Crop Improvement* 19, 137–155.
Wall, P.C. (2009) Strategies to Overcome the Competition for Crop Residues in Southern Africa: Some Light at the End of the Tunnel. In: *Innovations for Improving Efficiency, Equity and Environment. 4th World Congress on Conservation Agriculture. Lead Papers.* New Dehli, pp. 65–70.
Wall, P.C., Ekboir, J.M. and Hobbs, P.R. (2002) Institutional aspects of Conservation Agriculture. Paper presented at the *International Workshop on Conservation Agriculture for Sustainable Wheat Production in Rotation with Cotton in Limited Water Resource Areas, Tashkent, Uzbekistan*, 13–18 October 2002.
Zingore, S., Manyame, C., Nyamugafata, P. and Giller, K.E. (2005) Long-term changes in organic matter of woodland soils cleared for arable cropping in Zimbabwe. *European Journal of Soil Science* 56, 727–736.