6 Land management through conservation agriculture and associated practices

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Introduction

Agricultural production in East and Southern Africa (ESA) is hampered by frequent droughts, in-season dry periods, and increasing heat stress. Moisture constraints are exacerbated by unsustainable land-use practices, which result in declining soil fertility, excessive water loss through runoff, and soil erosion, with limited adoption of improved agricultural technologies (Thierfelder *et al.*, 2015a). Climate projections for southern Africa to 2050 suggest temperatures will increase by between 2.1 and 2.7°C. This will increase evaporation and result in even less available moisture for plant growth. Climate change is also expected to delay the onset of the rainy seasons and to increase extreme events such as floods and severe droughts (Cairns *et al.*, 2012). If no measures are taken to reduce the effects of climate change or to adapt farming systems to this new situation, maize production in ESA is projected to decrease by 10–30% or more by 2080 (Tesfaye *et al.*, 2015).

Research from southern Africa shows that conservation agriculture (CA) could provide a solution by helping smallholder farmers deal with the increased uncertainty associated with climate change (Steward *et al.*, 2018). The Food and Agriculture Organization of the United Nations (FAO) describes CA as a crop management system that can prevent losses of arable soil while regenerating degraded lands. It improves biodiversity and natural biological processes above and below the soil surface. This contributes to increased water and nutrient use efficiency, and improved and sustained crop production. It also helps to gradually increase soil carbon, depending on context, and contributes to reducing the effects of global climate change.

CA encourages minimum soil disturbance (i.e., no tillage), permanent soil cover, and diversification of plant species by intercropping or crop rotations. A recent regional study has shown that even if temperatures rise dramatically, CA still results in increased grain yields (Komarek *et al.*, 2021). Additional research has shown that while CA may not provide the same benefits to rice grown in tropical areas, it will significantly improve maize yields in semi-arid areas over the long term, despite climate change (Su *et al.*, 2021).

While CA systems have been adopted worldwide on more than 180 million ha by 2016, with an annual increase of approximately 11 million ha, it has been applied mostly on large commercial farms in the Americas and Australia (Kassam *et al.*, 2019). The rapid adoption of CA systems in these areas has been attributed to reduced production costs and the need to overcome challenges of soil degradation. Adoption in sub-Saharan Africa has remained lower and covers around 1.5 million ha, with only a gradual

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increase since 2000. Major challenges highlighted as impediments to more widespread adoption include a lack of knowledge and capacity to implement CA; lack of availability and high cost of specialized equipment and inputs; challenges associated with retaining crop residues, and managing crop diversification and weeds; land fragmentation; and the prevailing culture and traditions among African smallholder farming communities, which still focus largely on soil tillage. All these factors contribute to the slow rate of uptake.

Description of the technology

CA is characterized by three interlinked principles (Figures 6.1 and 6.2).

- **Minimum soil disturbance or movement**: This basically means no soil inversion by tillage. Seeds are usually planted in rip lines or in small planting holes created by a hoe or a planting stick. Farmers may use a dibble stick (a hard-pointed stick for making holes); rippers, which create a small furrow in the soil into which the seeds are planted; or an animal traction direct seeder, which creates a furrow, plants seeds, and adds fertilizer all at once. Occasionally, direct seeders driven by two- or four-wheel tractors are being introduced to increase the efficiency of direct planting. However, unlike with soil tillage, weeds in CA systems must be controlled through mechanical or chemical weed control strategies.
- **Crop residue retention**: Farmers should leave stalks and leaves from previous crops of maize, sorghum, or legumes in the field without burning, grazing, or completely removing them. Some residues can be used to feed livestock, although it is recommended

Figure 6.1. The basic principles of conservation agriculture: minimum soil disturbance using an animal traction ripper (top left), crop residue retention (top right), and crop diversification (bottom). (Photos courtesy of Christian Thierfelder, 2012.)

Figure 6.2. Different methods of planting under CA with an animal traction seeder (left) and a dibble stick (right). (Photos courtesy of Christian Thierfelder, 2012 and 2018.)

to retain at least 30% (or 2.5–3 tons/ha) of crop residues as ground cover. If no crop residues are available, alternative sources of biomass (e.g., thatching grass, leaves, and twigs) can be used to increase ground cover. Alternatively, green manure cover crops and their biomass can be used as living or dead mulch.

- **Crop diversification:** Crop rotations and/or intercropping includes a large diversity of species. This means not always growing the same crops, but alternating species to reduce pest and disease pressure and improve soil fertility. In Zambia, trials included maize-soybean rotations and maize-cowpea intercropping and rotations; in Malawi maize-groundnut rotations and maize-pigeonpea intercropping were tested.

In addition to the three core principles, farmers should adopt the following supporting and complementary practices:

- timely management of operations
- optimal maize planting density: 90 cm x 25 cm (44,444 plants/ha) in medium-potential and 75 cm x 25 cm (53,000 plants/ha) in high-potential areas
- the use of drought- and heat-tolerant maize and legume varieties
- adequate and timely weed control
- integrated pest and disease management
- sufficient nutrient supply through multi-cropping practices, mineral fertilizers, compost, or manure
- integration of additional soil and water conservation measures (e.g., vetiver grass barriers) or agroforestry components, where appropriate. (For more information see Chapters 3, 4, and 5 of this book).

Benefits of the technology

The main benefits of the technology over the short term are that more moisture is retained in the soil due to a higher infiltration capacity, there is less leaching of nutrients, and less labor is required. Over the long term, the soil is improved with better microflora and fauna. CA also encourages storage of soil carbon, depending on the specific system used, thereby gradually contributing to carbon sequestration. Figure 6.3 illustrates the benefits of CA compared with conventional tillage.

Results from the region also highlight that CA has many medium-term biophysical and economic benefits (Thierfelder *et al.*, 2015a). These result from increased soil water infiltration, increased biological activity, reduced water runoff and topsoil loss, and increased rainwater

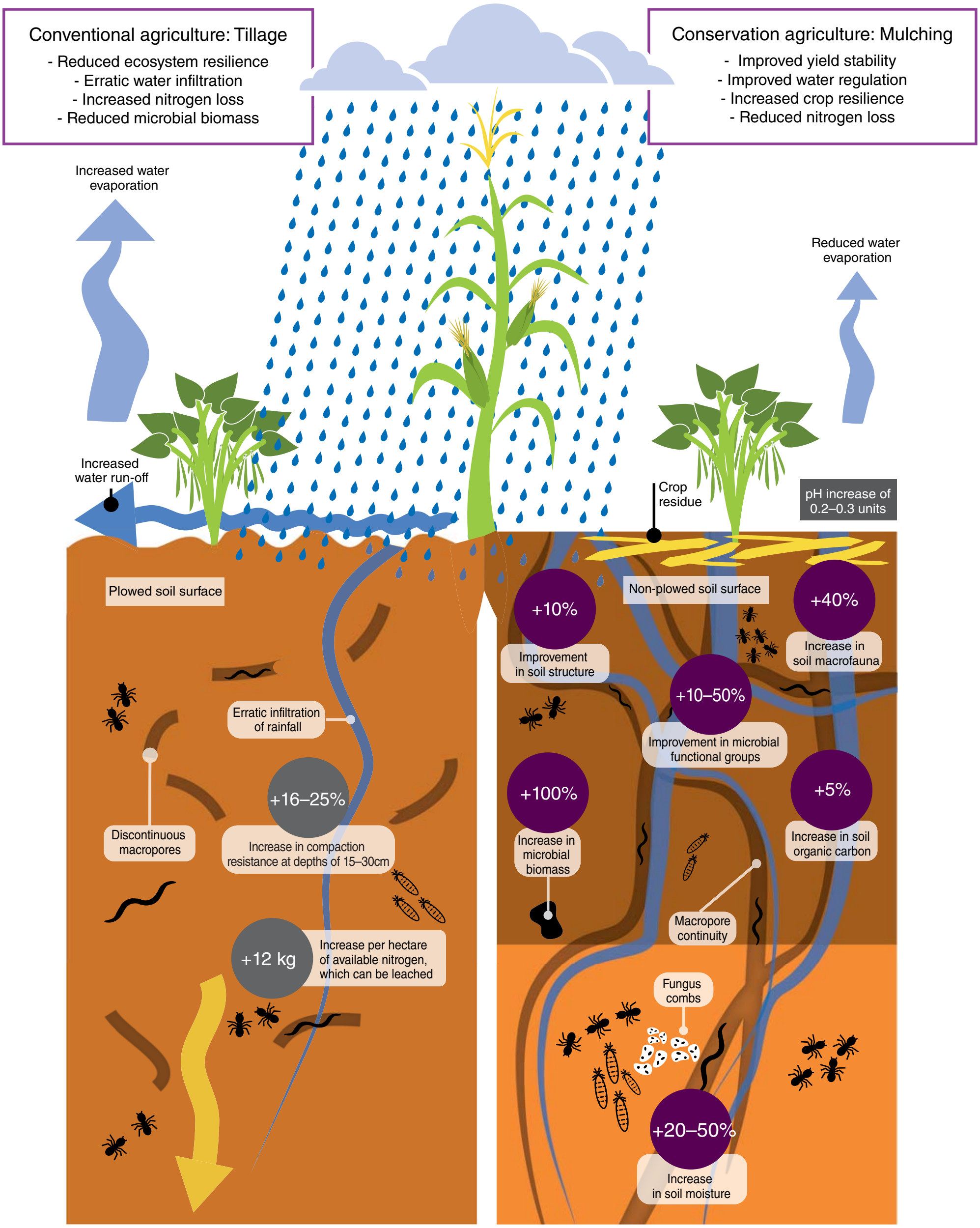

Figure 6.3. Illustration of relative effects of CA and conventional tillage on selected soil properties. Source: Modified with permission from Kihara *et al*. (2017).

retention. Surface residues reduce evaporation losses and improve the crop water balance, resulting in less frequent and intense crop moisture stress. Table 6.1 summarizes the immediate biophysical and economic benefits of CA.

It is important to highlight that many CA benefits appear in the medium to long term when farmers apply the principles continuously over at least two to five years. It is critical that, in addition to no-till practices, farmers continue to

Table 6.1. Immediate biophysical and economic benefits of CA

	Productivity		Environment		Economics	
	Yield increase	Water productivity	Erosion reduction	Soil quality improvement	Net benefit	Reduction in labor
% change (direction of effect)	+ 2–99%[1]	+ 20–50%[2]	+ 111–140%[3]	+ 5–40%[4]	+ 5–150%[5]	+ 350%[6]

[1]Yield benefit as measured in target communities of Eastern Zambia occurs after two to five cropping seasons (Thierfelder *et al*., 2015b), delays are caused by nitrogen lockup and failure to implement CA systems at standard. Yield benefits are dependent on season and farming system.
[2]An immediate benefit of CA is increased water infiltration and soil moisture, which increases water productivity (Thierfelder *et al*., 2013; Thierfelder and Wall, 2009).
[3]Another immediate benefit of no-tillage and residue retention is erosion control (Thierfelder *et al*., 2012).
[4]CA leads to increased earthworm and microbial activity but increases in soil carbon are context specific and depend on the level of residue retention and crop rotation (Kihara *et al.*, 2017; Powlson *et al.*, 2016).
[5]Application of CA principles leads to an increase in net benefits; these vary substantially between systems depending on the traction force used.
[6]Labor reductions in manual CA systems have been measured at 25–35 labor days saved on planting and 10–15 days saved on manual weeding if herbicides are used (Thierfelder *et al*., 2016a).
Source**:** The evidence for this table was supplied by a range of experiments.

apply mulching and crop rotations. Significant yield increases in paired plots have been documented from CA long-term trials in Zambia and Malawi. Reported economic benefits include reduced traction and labor requirements for land preparation and weeding if herbicides are used, hence saving on costs of manual labor, animal draft power, and fuel, depending on the farming system (Thierfelder *et al.*, 2016a).

In a nine-year experiment in eastern Zambia, no-till maize out-yielded conventional ridge tilling with only maize (Mhlanga *et al.*, 2021). The yield benefit increased in a maize–cowpea rotation. In years of poor rainfall (e.g., in cropping season 2014/15 and 2015/16), the difference was greater, highlighting that CA can reduce uncertainty and assist farmers in years of poor rainfall. Maize in manual systems was planted with a dibble stick under CA. In animal traction systems, seeds were planted in rip line no-till systems and compared with conventional moldboard ploughing (Figure 6.4).

Figure 6.5 reflects the economic returns associated with CA. For the calculation of net benefits, all gross benefits of all crops in the CA cropping systems (yields x market value of the crops in US$) are aggregated and all production costs (labor and input costs) deducted. Family labor is costed in the analysis, although farmers often do not give an economic value to family labor. Likewise, the costs of retaining crop residues and the benefits of gaining from residual nitrogen in a maize–legume rotation are accounted for (Mupangwa *et al.*, 2017; Mutenje *et al.*, 2019).

One immediate benefit when applying the principles of CA is a reduction in labor on land preparation and weeding when compared with manual ridge tillage or animal traction moldboard ploughing. Figure 6.6 shows an example from Malawi, where two manual CA systems are compared with a conventional ridge tillage system. Even though mulch application requires some labor, the labor required for CA is significantly less as seeding is only done with a dibble stick. In this example, farmers are planting in CA systems on flat land without making ridges, and control weeds with herbicides. Improved weed control with herbicides is effective but not essential, although it can help reduce the labor burden in the initial years of conversion to CA, making it more attractive to farmers.

Farmers' responses

It is important to acknowledge that CA systems are site specific, depending on the agroecosystem. Farmers in Malawi and eastern Zambia frequently report that CA systems save on labor. Here, many farmers cultivate using a hand hoe in ridge-and-furrow systems, and CA means that they avoid moving 540–750 tons/ha of soil and spend between 25 and 35 days/ha less time

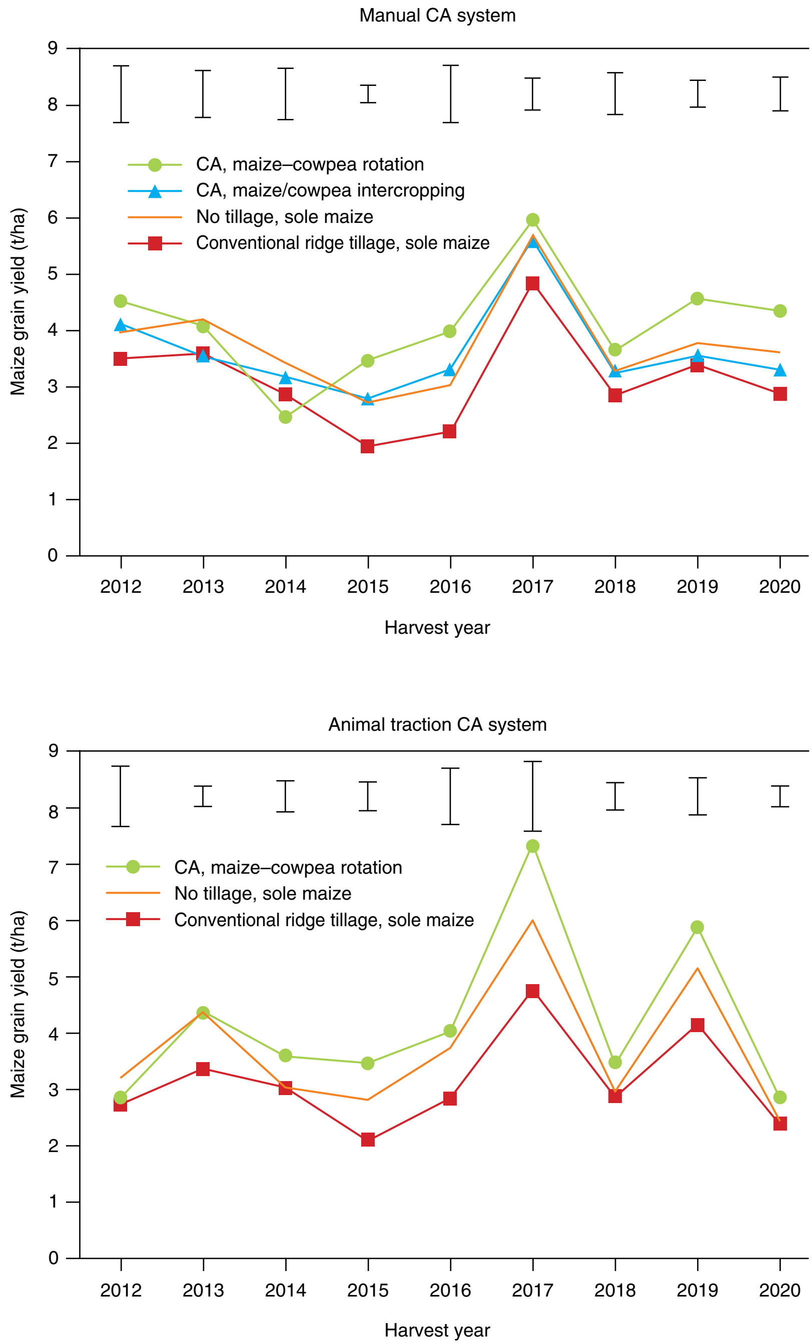

Figure 6.4. Effect of manual (top) and animal traction (bottom) conservation agriculture (CA) cropping systems on maize grain yield (kg/ha), eastern Zambia, 2012–2020.

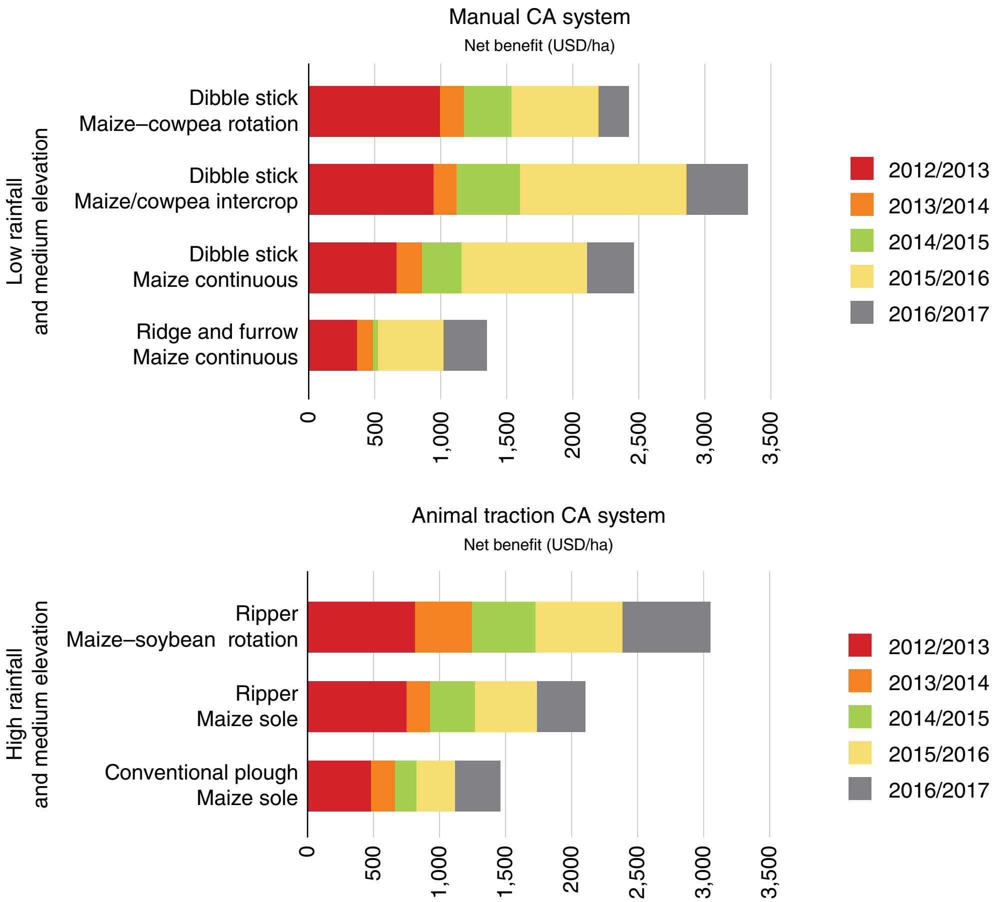

Figure 6.5. Effects of different conservation agriculture (CA) cropping systems (dibble stick and ripper) on cumulative net benefits (US$/ha) as compared to conventional tillage practices (CP), eastern Zambia, 2012–2017. Net benefits are expressed in US$/ha calculated as gross benefits minus all production costs.

planting without ridges. If they use herbicides for weed control, they can save another 10–15 labor days/ha. However, this only translates into an economic benefit if farmers can make use of this saved labor or value leisure time as a key benefit.

Farmers acknowledge that it takes at least two to five years to realize the benefits of improved soil fertility and increased yields. Some CA projects have encouraged farmers to work together; for example, farmers in Lundazi, eastern Zambia, evaluated their CA plots together. The Africa RISING program has encouraged them to continuously evaluate new technologies and keep records, and this helps them to see positive trends across the years.

Other farmers have benefited from greater resilience in times of drought or seasonal dry spells. Farmer Gertrude Banda from Sinda district in Zambia says: “When there is a drought, my crops are still growing, and they look good.” Also, it is easier to expand the area planted; Gertrude practices CA with an animal traction ripper and could expand CA to the whole farm. She now grows soybean, which generates more than US$ 2000 per year from her farm. Unfortunately for her, many farmers started to grow soybean in the last cropping season, and this adversely affected the market price.

Another farmer, Thomas Banda, used the extra money gained from his CA trials to reinvest: “I bought a pig at the cost of 600 Kwacha

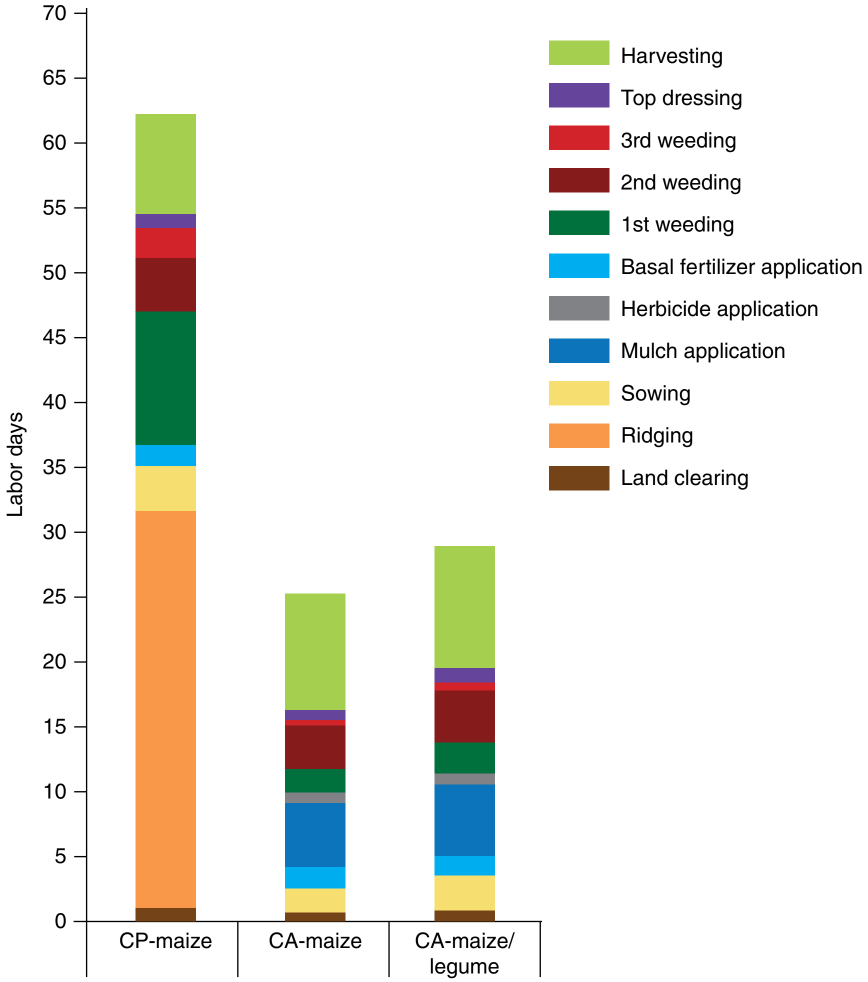

Figure 6.6. Labor use in manual CA systems in Malawi on conventional ridge-tillage (CP) and two CA systems. Major labor bottlenecks in the conventional system are on land preparation (ridging) and for manual weed control with a hoe. Adapted with permission from Thierfelder *et al*. (2016b).

(US$ 60) and then used the rest of the money to buy a new school uniform and other school requirements for my child." Inspired by this success, he plans to expand his land area in the next cropping season.

Challenges to adoption

Despite these demonstrated benefits, farmers have pointed out significant challenges and constraints to the widespread adoption of CA that remain in southern Africa. Tradition, social norms, and common practices allow free grazing of animals on harvested fields, and this does not favor the practice of leaving crop residues on the soil surface. Converting to CA requires the full acceptance of the community to grant a full year tenure to the crop farmer, and accept that crop residues are left on the soil surface. In extreme cases, it may be necessary to erect fencing to protect the fields from livestock. Furthermore, for CA to have positive yield impacts, effective crop rotations and/or intercropping systems need to be established.

Good agricultural practices common to both conventional tillage and CA need to be implemented. The highly degraded African soils need inputs of nutrients, or sufficient quantities of manure or compost. It is also important to use improved quality seed with tolerance to biotic and abiotic stresses. Weed suppression and control is also essential, as is the need for adequate credit, markets for outputs, and availability of inputs and machinery. Finally, for CA to succeed, farmers need to fully embrace the concept and accept that no-tillage farming can be productive, cost effective, and sustainable.

Opportunities for application of the technology

The principles of CA have extensive potential for adaptation, with CA systems used currently by farmers under a wide range of agroecological conditions and with numerous crops. Techniques vary depending on climate, soil, and farmer circumstances and contexts (wealth, land size, traction owned, labor availability, etc.). CA must be applied and adapted to the needs of farmers in a flexible manner. CA does not work well under waterlogged and very arid conditions, or on completely degraded soils.

Africa RISING and other research has shown that conservation agriculture is most appropriate where:

- farmers are currently using manual labor to prepare fields and do not have easy access to mechanical or ox-drawn draft power
- there is a delay in planting because of the need to plough
- there are limits to soil moisture that require constant soil moisture conservation
- accelerated soil degradation, including soil erosion, affects yield.

How to get started

General principles

- Identify a piece of land (usually about 10% of a smallholding is enough) as a start. The small area will enable the farmer to acquire enough ground cover, prepare the land on time, seed when the first rains occur, and learn to effectively manage and control weeds. Learning to manage crop production challenges in a small field is always easier than in a large one.
- Clear shrubs from the land; it should be weed-free at seeding and there should be some ground cover if possible.
- Depending on the sowing method (manual, animal traction, or machine seeding), prepare the land beforehand. Planting basins (small planting holes in untilled land) are normally dug during the dry season to spread labor throughout the winter period. This will ensure that the land is ready for planting at the onset of the rains.
- Planting rows and stations should be kept in the same place to benefit from cumulative effects of fertility improvement in basins and/or rip lines at each planting station.
- Mulching (especially where there have been insufficient old crops left on the ground) may be needed. Mulching helps to reduce weeds, and maintains moisture and nutrients in the soil. Where mulching material is short, it can be supplemented with thatching grass, leaves, and twigs.
- Plan crop rotation or intercropping systems from the beginning to improve the nutrient status of the soil, and reduce pests and diseases (see Chapters 3 and 5 of this book).
- Adequate fertilizer application, considering the 4 'R's (right fertilizer type, placement, timing, and amount) supports good crop production (see Chapter 4). If soils are very sandy, an additional dose of nitrogen fertilizer, manure, or compost might be necessary.
- Seed the crop after the first effective rains. It is important not to delay planting. After crop emergence, extra seed can be sown to fill gaps.
- Keep fields as weed-free as possible. This might require extra weeding in the first cropping seasons when the soil has not been ploughed, but once established, CA will result in less weeding in future. Later season weed control can also help reduce the weed seed bank and is recommended.
- Apply sufficient nitrogen fertilizer as a top-dressing (e.g., as urea or ammonium

nitrate) to ensure the crop is always well-nourished. As a rule of thumb, two 50 kg bags of urea/ha as a minimum rate will be adequate.
- Harvest crops at physiological maturity and keep the crop residues on the fields to plant into mulch in the next cropping season.

Overcoming difficulties

- Community agreements may be an appropriate route to limit grazing and maintain crop residues in the field.
- If there are not enough maize residues available in the first year(s), it is advisable to use thatching grass, leaf litter, or other organic material to improve ground cover. Once the productivity of the CA field increases, it will be possible to retain enough residues from the previous season(s).
- Previous management problems such as compaction and unevenness need to be corrected before establishing CA.
- All necessary inputs need to be acquired (seeding equipment, seed, fertilizers, etc.) in time so that everything is at the farm before the rains start. For all farming practices, the largest benefits can be reaped when farmers plant with the first effective rains.
- If the soil is acidic in a particular area, a blanket application of lime at 500–1,000 kg/ha in the rip lines or planting basins is beneficial.
- Perennial weeds need to be controlled through herbicides or careful manual weeding. As with conventional tillage, it is important to aim for a weed-free field throughout the year. Weeds should be controlled when they are 10 cm tall and, if they are of a spreading type (or grow in a spreading habit), their radius should not be more than 5 cm. In the first year, when the land is not ploughed, there may be more weeds than in a conventionally tilled field.
- Pests and diseases can be carried over through crop residues. This requires careful planning and implementation of rotational systems so that pest and disease cycles are broken, and farmers can make use of biological control processes.

The best way to overcome these challenges is to talk with experienced farmers in the area and consult with researchers and extension offices who will help to solve and overcome these problems. It is therefore important to start on a small piece of land. As in all farming systems, good crop production needs precision and timeliness for success. This is especially important in CA, since many of the benefits depend on timely application and accuracy.

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