Environmental Benefits of Conservation Agriculture

A literature review with special consideration of Zambia

CFU Conservation Farming Unit, Lusaka

Aid by Trade Foundation (AbTF) Hamburg

Conservation agriculture and its main impacts on the environment

Conservation agriculture (CA), i.e. minimum tillage, crop cover and crop rotation, combines profitable agricultural production with environmental sustainability. It reduces soil erosion to almost zero and enhances the build up of organic matter in the soil; thus, together with organic soil management practices, the soil biota and soil fertility is increased. CA leads to a higher water retention capacity of the soil and buffers increasing climate variability for both drier and wetter conditions as well as for sudden changes between the two extremes. Furthermore, CA has considerable potential to mitigate climate change: (i) greenhouse gas emissions can be reduced, since mineral fertilizer use and fuel consumption are much lowered; and (ii) carbon from the air can be sequestered in the soil and bound into long-lived humus complexes. However, to quantify the effects is difficult, since the extent depends on both the agricultural reference system and on the soils where it is applied.

This leaflet is a literature review that outlines the environmental benefits of CA. Zambia is particularly considered, since it belongs to the countries, where CA is successfully promoted.

Key elements of CA

The three key principles of CA are:

- minimizing soil disturbance by applying minimum or zero tillage;
- maximizing soil cover by retaining crop residues rather than incorporating or burning them;
- incorporating legumes into the farming system as rotations, intercrops, strip crops or fallows.

For full benefits, all the above-mentioned principles must be applied in conjunction with other good agronomic practices, such as timely planting, effective weed control and integrated pest management. Right timing plays a crucial role in CA, thus farmers who apply the system successfully are good managers, who stick to their schedules.

CA is not a blueprint solution but has to be tailored to the regional context

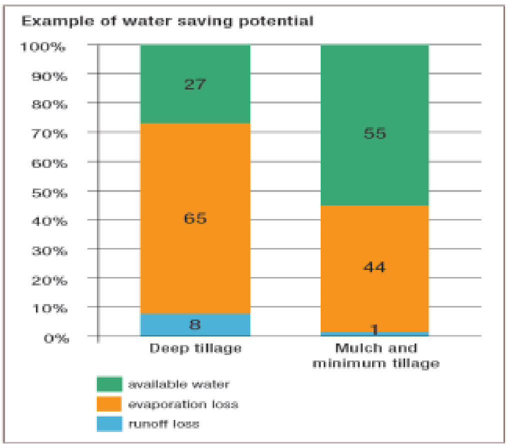
CA management depends on the specific conditions and farming system where it is applied. In Zambia, CA includes: (i) dry-season land preparation using either ox-drawn rip lines or hand-hoe basins; (ii) retention of crop residues from the previous harvest; (iii) planting and input application in fixed planting stations and under a precise layout of grids and planting lines; and (iv) the inclusion of nitrogen-fixing crop rotations and other techniques. CA is effective for both semi-arid and sub-humid areas. In drier areas, for example the southern part of Zambia, the rainwater harvesting effect of the planting basins is crucial. In wetter areas, for example the northern part of Zambia, the build up of organic matter is the central means through which the soil structure and drainage features can be improved.

How does CA improve water infiltration and water use efficiency?

CA improves the physical as well as the bio-chemical properties of agricultural soils and thus improves their capacity to hold and to provide water and nutrients to the crops.

Through the specific land preparation techniques, i.e. ripping or planting basins, as well as the vegetative cover, water infiltration rates are increased and thus water run-off and erosion are largely reduced. In addition, water evaporation in minimum tilled soils is much less than in ploughed soils. Thus, the humid period in the soil is prolonged and more water can be used by the present or succeeding crop. These effects not only lead to more water being available for the crop but also to an increased water use efficiency of the entire cropping system.

Figure 1: Water use efficiency: differences between deep tillage and minimum tillage systems



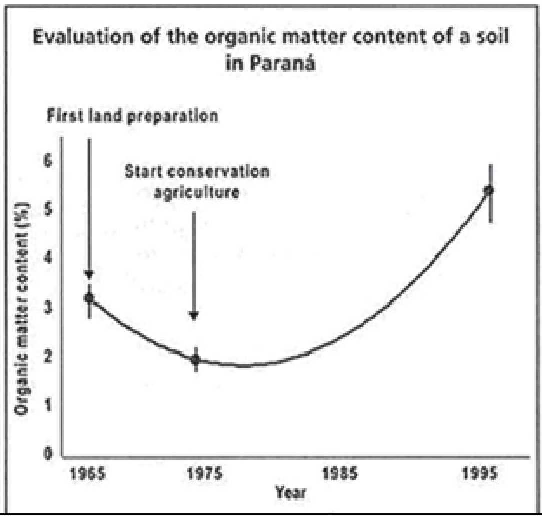
Source: Gitonga (2005) in Lininger et al. (2011:

How does CA lead to higher organic matter contents and soil fertility?

Unlike in conventional systems, where organic matter content of the soil decreases over time, this increases under CA. The pace of this process depends on the initial values of organic matter, the specific climate conditions and the detailed measures implemented. Some years after having shifted from full to minimum tillage systems, CA can outbalance degradation processes and turn them into a net build up of new soils. In more humid climates, the soil under CA "grows" faster, i.e. at a rate of up to 1 millimetre per year. This process is on-going until the saturation point is reached, which is specific according to the soil type. Under drier conditions, the build up of the soil organic matter is the same in principle but it is much slower in pace when not enhanced by mulching or composting. However, if aggregate building processes in the soil gain momentum, the physico-chemical structure of the soil becomes stabilized.

Minimum tillage systems improve the rooting environment

As widely known, ploughing can lead to the development of a plough pan, especially in clay-rich soils. A plough pan hampers the development of a deeper rooting system and thus negatively influences the uptake of nutrients. Such a soil tends to be water logged, thus its drainage capacity decreases.



Source: Benites (2005) in FAO (2008a: 85)

After having broken a possible pre-existing plough pan, minimum tillage systems enable roots to penetrate soils in deeper zones again. This improves the stability of the plant as well as its access to and effective use of nutrients, since deeper roots re-translocate nutrients to upper levels of the soil. Hence, after some years, the drainage capacities of soils re-establish.

CA enhances soil biota and soil fertility

By using the plough in conventional systems, air is mixed into the soil leading to quick mineralization or oxidation of the organic matter. Little by little such soils lose their structure and eventually degrade.

In the absence of a plough, mineralization processes are reduced and the integrity of the soil is preserved. In this way, large soil pores remain stable, enhancing both water and gas exchange and thus providing ideal conditions for macro- and micro-organisms such as termites and others. This allows time for the build up of more soil aggregates and solid humus structures.

The described interplay of the biochemical and physical processes eventually results in an increased *cation exchange capacity* – which is an indicator of the soil's "natural" yield potential. A high cation exchange capacity is linked with better nutrient retention and thus a slower release of nutrients to crops, no matter whether they are derived from compost or "from the bag". Slow release of nutrients prevents leaching into groundwater bodies and thus as a whole decreases pollution and increases the nutrient uptake efficiency of crops.

Environmental effects of CA beyond farm level

When increasing areas of land are managed by effective CA, the benefits extend onwards to the local community and beyond as ecosystem services to the catchments in which the farms are located. Among others, the following effects are reported:[i]

- Benefits for the water resources and their management include: (i) more constant water flow in rivers; (ii) improved groundwater recharge with re-emergence of water in formerly dried up wells; and (iii) cleaner water because pollution, erosion and sedimentation of water bodies are reduced.
- Because of the improved water management and hydrology in the agricultural systems, CA lowers irrigation requirements and thus water withdrawal from rivers and groundwater sources.[ii]

- Benefits for infrastructure, because of less damage to road systems from (gully) erosion and floods.
- Rise of adaptive capacity of farmers' communities, increased environmental awareness and better stewardship of natural resources.
- Reduced stress on agro-biodiversity in soils and crops.

Since CA increases productivity it improves the perspective for sedentary farming for those who previously practiced slash and burn, i.e. shifting cultivation. Until now this is a common practise in many developing countries, especially of Southern Africa, where population density is still relatively low. Hence, CA prevents further bush land being used as farmland and thus protects from deforestation and land degradation.

In addition, CA can discourage families from searching for supplementary but unsustainable income sources such as poaching, off-season fishing or charcoal burning. Through CA families can become able to achieve higher incomes and food security by farming alone.

CA is an effective adaptation tool for climate change and is good for both drier and wetter conditions

Southern Africa as a whole, and Zambia in particular, is more than averagely affected by climate change. This concerns temperature rise and also changing rainfall patterns. Both floods and droughts are already much more frequent in Zambia than before. In wetter areas, such as the Northern or Northwestern Province, growing seasons tend to be prolonged, whereas in drier areas, such as the Central or Southern Province, seasons tend to be shorter. In addition, unpredictable heavy rains in all regions, as well as more frequent dry spells, make farming more risky on the whole.[iii]

These changes indicate that a suitable adaptation tool must be good for both wetter *and* drier conditions *as well as* for sudden changes between the two extremes, as already outlined for instance by Müller (2009: 40):

"The focus (…) should be on development plans that are (…) effective under a broad spectrum of possible climatic conditions (e. g. wetter – no change – drier), including e. g. water-harvest techniques that could buffer both affluent and insufficient precipitation."

As a "development plan" CA combines all of these desired features in one, as:[iv]

- it lowers high-energy rainfall impact, thereby avoiding the associated crusting and compaction of the surface that occurs on bare soils;
- it levels out extremes of daily temperature fluctuations in uppermost soil layers, which otherwise could be unfavourable to plant functions in bare soils;
- it increases infiltration rates and water retention capacity as explained, thus higher rainfall can be absorbed but, depending on the manner in which the land is prepared, surplus water is also better drained into water courses;
- since water use efficiency is much increased, CA makes farming systems more resilient to dry spells and later onset of rains, especially when combined with basin management.

Several independent studies show that CA can increase resilience to climate change in a holistic way.[v] This not only includes the enhancement of the buffer capacity in order to withstand climate variability, but also the strengthening of the adaptive and organizational capacities of farmers. By learning together, implementing on-farm experiments and exchanging ideas, for example in training centres or so called "cotton schools", capacities of farmers are developed in a common process.

CA can serve as a mitigation tool, since it reduces greenhouse gas emissions and enhances carbon sequestration

Agriculture contributes 10–30% to worldwide greenhouse gas emissions, depending on which activities are included and thus the sector is a relevant contributor to climate change.

The most relevant greenhouse gas, for which agriculture is the major contributor, is nitrous oxide (N_2O) and nitrogen fertilizers play the biggest role here. The second most relevant emission comes from methane (CH_4), most of which is produced by digestive processes in cattle but which is also emitted by paddy rice fields. Thirdly, carbon dioxide (CO_2) emission plays a role, which is increased by full tillage systems, such as ploughing, and erosive agricultural management practices.[vi]

In principle, mitigation of climate change can be achieved by reducing greenhouse gas emissions or by sequestering them in a solid form. One of the most effective ways is to do both; that is, to reduce nitrogen fertilizer applications and grow leguminous plants, which fix nitrogen from the air and use it for crop growth. Another way to reduce fertilizer use is to increase its use efficiency, i.e. through precise application. Both objectives are achieved under CA.

Minimum tillage reduces carbon emissions. As oxidization processes are reduced, when soil disturbance is minimized, carbon is not released into the air as CO_2 but sequestered in soils and bound into humus complexes.

Last but not least, in tractor-based systems, i.e. on commercial farms, minimum tillage saves large amounts of diesel. Fuel consumption decreases from 120 per hectare in plough based systems to 30 litres per hectare in minimum or zero tillage systems.[vii] However, since the concrete benefits always depend on the reference system with which CA is compared, these advantages do not apply compared to oxen-draft or purely manual systems, which are still most common in Zambia.

For the future this aspect can still be important, since service providers who prepare land for others with tractors are also increasingly hired by small scale farmers. As draft animals are highly prone to diseases in Zambia and therefore very difficult to keep, service providers with tractors are gaining ground and they do the job for almost the same costs as the ones using draft animals.

The long-term effect of carbon sequestration

Exactly how much CA can mitigate climate change is still being debated by scientists and existing estimates differ according to literature sources and presumptions about the manner in which CA is applied. A very optimistic perspective is taken in FAO publications, which state that during the first decade of adopting best CA practices, up to 1.8 tonnes of CO_2 per hectare per year can be sequestered into the soils.[viii] This would be a highly relevant amount.

However, there are also limitations which have to be considered:

- the sequestration capacity of each soil is finite, and the saturation point is achieved after about 30-100 years;
- when carbon is not bound into long-term humus complexes, it can be released again after relatively short periods.

Hence, long-term field trials on different soil types and under different climatic conditions and practices are needed in order to quantify and characterize the mitigation effects of CA more precisely.

But the fundamental first step, the acknowledgement of carbon sequestration in soils as a relevant mechanism to mitigate climate change, is already taken, as the Intergovernmental Panel of Climate Change clearly stresses in its Fourth Report.[ix] Therefore it is only a question of time until it is also included in the United Nations Framework Convention on Climate Change Clean Development Mechanism.[x]

Specific relevance of CA in Zambia

As outlined in this leaflet, CA is a very suitable tool for increasing the sustainability of agricultural production. In addition, CA can serve as an adaptation tool for climate change as it can also mitigate this change. Since Zambia suffers from unsustainable production, soil erosion and climate change, and its agricultural systems are suited for minimum tillage, CA is therefore an excellent way of minimizing these problems.

However, CA can do even more – it can also increase agricultural productivity and incomes, especially for poor farmers, as has already been reported in a number of publications.[xi] Thus, very poor farmers can also benefit and thereby can also actively help the environment.[xii]

References and further reading

Belloum, A. (2007) Conservation agriculture (CA) in the Arab world between concept and application. In: B. I. Stewart et al., *Conservation agriculture for sustainable land management to improve the livelihood of people in dry areas.* Proceedings International Workshop, 7–9 May 2007. Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) and Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

COMPACI/CmIA/UdC (Competitive African Cotton Initiative/Cotton made in Africa/Cotton University) (2010) Proceedings of the Workshop on Conservation Agriculture, October 17–20, 2010, Zambia.

Conservation Farming Unit (CFU), Brief No. 3, Lusaka.

FAO/REOSA (Food and Agriculture Organization of the United Nations/Regional Emergency Office for Southern Africa) (2010). *Farming for the future in Southern Africa: An introduction to conservation agriculture*. REOSA Technical Brief, July 2010.

FAO (2008a). Investing in sustainable crop intensification: The case for improving soil health. An international technical workshop. *Integrated Crop Management*, Vol. 6 - 2008. Food and Agricultural Organization, Rome.

FAO (2008b). *Soil carbon sequestration in conservation agriculture: A framework for valuing soil carbon as a critical ecosystem service*. Conservation Agriculture Carbon Offset Consultation – West Lafayette, Indiana, USA, 28–30 October 2008. (http://www.conservationinformation.org)

GRZ (Government of the Republic of Zambia) (2007). *National adaptation programme of action on climate change*. Lusaka: Ministry of Tourism, Environment and Natural Resources, mimeo.

Haggblade, S. and **G. Tembo** (2003). *Development, diffusion and impact of conservation farming in Zambia*. Working Paper No. 8, FSRP (Food Security Research Project), Lusaka. http://www.aec.msu.edu/agecon/fs2/zambia/index.htm

Haggblade, S. and **C. Plerhoples** (2010). *Productivity impact of conservation farming smallholder cotton farmers in Zambia*. Working Paper No. 47, FSRP (Food Security Research Project), Lusaka.

IPCC (2007). *Fourth report: Mitigation to climate change*. Intergovernmental Panel on Climate Change, Geneva.

Lininger, H.P., R. Mekdaschi Studer, C. Hauert and **M. Gurtner** (2011). *Sustainable land management in practice: Guidelines and best practices for sub-Saharan Africa*. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agricultural Organization of the United Nations (FAO).

Müller, Chr. (2009). *Climate change impact on Sub-Saharan Africa? An overview and analysis of scenarios and models*. German Development Institute (DIE) Discussion Paper 3/2009, Bonn.

Ringius, L. (2002). Soil carbon sequestration and the CDM: Opportunities and challenges for Africa. *Climate Change*, 54 (4), 471–495.

Rockström, J. and **K. Steiner (2004).** *Conservation farming: A strategy for improved agricultural and water productivity among small-holder farmers in drought prone environments*. Unesco–IHE, WaterNet, University of Zimbabwe. Soils & Water (http://betuco.be/CA/Conservation%20Farming%20.pdf).

Twomlow, S., Hove, L., Mupangwa, W. et al. (2008). *Precision conservation agriculture for vulnerable farmers in low-potential areas*. Proceedings of the workshop on Increasing the Productivity and Sustainability of Rain-fed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana, 22–25 September 2008.

Endnotes

[i] FAO (2008b: 121).
[ii] Belloum (2008: 15f).
[iii] GTZ (2007).
[iv] See Conservation Farming Unit (CFU).
[v] See Lininger et al. (2011).
[vi] http://www.eoearth.org/article/Greenhouse_gas_mitigation_in_agriculture
[vii] Haggblade and Tembo (2003).
[viii] FAO (2008b).
[ix] IPCC (2007).
[x] Ringius, L. (2002: 471).
[xi] Haggblade and Plerhoples (2010).
[xii] FAO/REOSA (2010).

This leaflet is supported by

Conservation Farming Unit (CFU)
Aid by Trade Foundation (AbTF)
German Development Bank (DEG)
Gesellschaft für Internationale Zusammenarbeit (GIZ)

Susanne.Neubert@die-gdi.de
susanne.neubert.lusaka@gmail.com
German Development Institute (DIE)
www.die-gdi.de