Potential role of Conservation Agriculture in South Africa for carbon sequestration for climate mitigation: A provisional research agenda

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1 Introduction

In both the Netherlands and South Africa research on soil, water and land use is at the forfront of science. Especially integrated crop and livestock management in relation to the climatic conditions has been focus of study. In these studies innovative practices such as precision agriculture and conservation agriculture are seen as an option for sustainable land management and working towards a circular food system. In the light of climate mitigation, these agricultural practices are also interesting to consider. Storing carbon in soils is seen as one option to mitigate climate change. The 4 per 1000 initiative is one example of the ambition and potential of soils for carbon sequestration. Conservation agriculture is seen as a way to promote this. However, many questions remain that need to be answered to know the real potential of management options like conservation agriculture such as what type of C is needed to sustain crop growth, through which rouths and mechanisms (e.g. nutrient and water availability) do different soil C fractions stimulate crop growth?

1.1 South African context

In South Africa Conservation Agriculture has been fairly widely accepted by dryland crop farmers in the winter rainfall areas of the Western Cape. In the summer cropping areas of central and eastern South Africa, this practice has been less widely adopted. With the climate target in mind, agricultural soils are seen as a potential to store carbon in soils for climate mitigation. However, it is unknown how much carbon can be stored in the different types of soil, and which conditions (climatic, soil, agricultural management) are needed for that.
In international literature (e.g. CIRCASA project) general information is available, however, this need to be aligned and made useful for the South African setting.

1.2 Problem definition and project objective

For large-scale implementation of Conservation Agriculture for circular sustainable agriculture and climate change mitigation through soil carbon sequestration, an overview is lacking of current scientific insights and potential barriers to adopt CA in different parts of South Africa.
The objective of this project is to develop, through a literature review and a workshop, a research agenda that will be guiding towards circular sustainable agriculture working on climate change mitigation through soil carbon sequestration. The collaboration with European partners (WUR) and projects on this topic knowledge can be shared and implemented in the South African context. South African running projects in different climatic and soil regions can form an excellent case study to test general hypothesis on the soil carbon sequestration potential of Conservation Agriculture.

1.3 Project execution

The first part of the project focused on collecting literature in and outside South Africa on soil carbon sequestration. Specific attention was given to the role of conservation agriculture. The main focus was on the changes in soil physical parameters and changes in surface conditions of fields managed with conservation agricultural practices. Attention was given to differences in climatic and soil conditions.

For the international setting findings of the CIRCASA project were incorporated. The CIRCASA (Coordination of International Research Cooperation on soil Carbon Sequestration in Agriculture; https://www.circasa-project.eu/) aims to develop international synergies concerning research and knowledge exchange in the field of carbon sequestration in agricultural soils at European Union and global levels, with active engagement of all relevant stakeholders.

After the literature assessment a workshop was held held in South Africa in December 2019 where key stakeholders were invited to participate and give their opinion on our findings and how this relates to the agricultural, climatic, soil settings they are working in. Key stakeholders in South Africa are universities, the Agricultural Research Council, and Grain SA. The University of the Free State was co-organizer of the workshop and co-author of the literature review and final report.

The target group was composed of South African researchers at universities and research institutes working on the implementation of conservation agriculture with the aim to contribute to circular sustainable agriculture and climate mitigation.

1.4 Workshop and expected outcomes

The workshop was organized by the University of the Free State in collaboration with Wageningen University and Research was held on the 3rd and 4th of December 2019. Informative lectures by scientists for the invited stakeholders were given and three workshops were held to exchange information from scientists to the key stakeholders in South Africa working with Conservation Agriculture.
The first draft report formed the basis of the workshop, and this report is the updated final version where the additional information that was collected at the workshop is incorporated.

2 International setting of the project

This project links to International policies such as the Sustainable Development Goals, the UN Climate conventions, Common Agricultural Policies, 4 per 1000 initiative, EU Soil Thematic Strategies, that all aim to work towards the common societal goals: Climate Change Mitigation and Adaptation, Food security and sustainable use of ecosystem services.

2.1 The sustainable Development Goals

In Keesstra et al., (2016) an inventory of the link between soil science, soil functions, ecosystem services and finally the SDGs was described. From this analysis it is clear that there are several SDGs where soils play a more important role than in others. Especially SDG15: Life on Land, SDG13: Climate Action and SDG2: Zero Hunger rely heavily on soils as a natural resource.

Good agricultural management makes use of ecosystem services and can even contribute to them.

Even though soil-related Climate Change Mitigation and Adaptation strategies both aim for storing carbon in the soil, their approaches are fundamentally different, therefore we have separated these two topics. Soil carbon storage helps SDG13 (Climate Action) in two ways: (i) by creating sinks for atmospheric carbon dioxide, and (ii) improving resilience to climate change, such as droughts (Lal, 2016; Keesstra et al., 2016). The first one mainly focusses on climate change mitigation, the second on climate change adaptation. Furthermore, other interactions between soils and climate change have been described in recent literature: increased wind and water erosion due to more erratic and high intensity rainfall and wind speeds (Borelli et al 2014; Cerda et al., 2018), increased land slide risk due to heavy rainfall events (Garriano and Guzzetti, 2016), increased salinization due to prolonged droughts (Kreuzwieser and Gessler, 2010), increased soil organic matter loss due to increased temperature (Smith et al., 2007, EEA, 2012) and thawing permafrost (Crowther et al., 2016). In Figure 2 the SDGs are grouped in three layers: economy, society and biosphere, that are connected by SDG 17 (the arrow). **The key message is that one goal cannot be achieved without the other, therefore we need to find solutions that consider the benefits and trade-offs for all goals**.

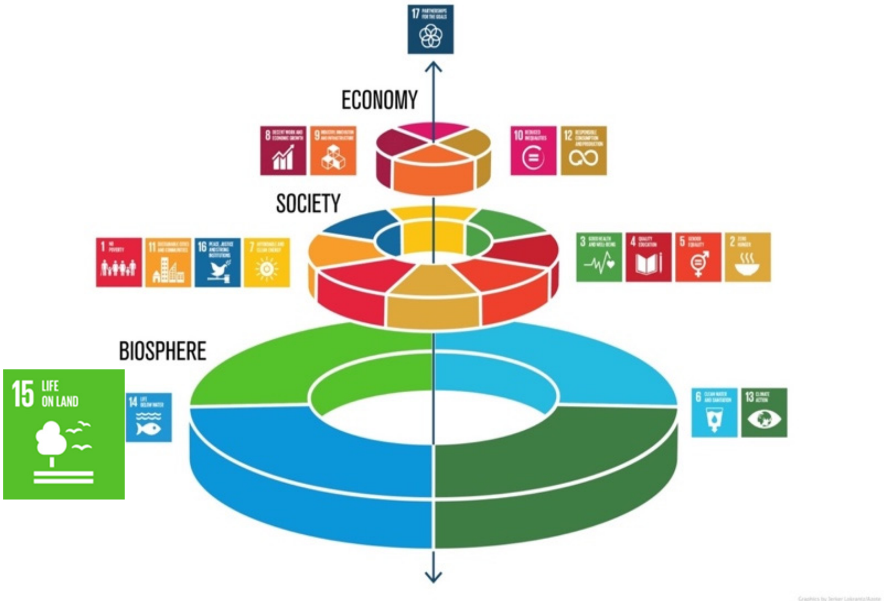


Figure 2 Relation of different domains within the SDGs, Biosphere, Society and Economy (adapted after the original figure of the Azote Images for Stockholm Resilience Centre).

2.2 4/1000 initiative

The Paris Agreement is an agreement within the United Nations Framework Convention on Climate Change (UNFCCC), dealing with greenhouse-gas emissions mitigation, adaptation, and finance, signed in 2016. The Paris Agreement's long-term goal is to keep the increase in global average temperature to well below 2 °C above pre-industrial levels, and to limit the increase to 1.5 °C, since this would substantially reduce the risks and effects of climate change.

As part of the Paris Agreement, France launched on 1 December 2015 at the COP 21 the international initiative "4 per 1000" (UNFCCC, 2015). The aim of the initiative is to demonstrate that agriculture, and in particular agricultural soils can play a crucial role where food security and climate change are concerned. Supported by solid scientific documentation, this initiative invites all partners to state or implement practical actions on soil carbon storage and the type of practices to achieve this (e.g. agroecology, agroforestry, conservation agriculture, landscape management, etc.). The ambition of the initiative is to encourage stakeholders to transition towards a productive, highly resilient agriculture, based on the appropriate management of lands and soils, creating jobs and incomes hence ensuring sustainable development.

An annual growth rate of 0.4% in the soil carbon stocks, or 4‰ per year, in the upper 30-40 cm of soil, would substantially reduce the increase in CO2 concentration in the atmosphere related to human activities. This growth rate is not a normative target for each country, but is intended to show that even a small increase in the soil carbon stock (agricultural soils, notably grasslands and pastures, and forest soils) is crucial to improve soil fertility and agricultural production and to contribute to achieving the long-term objective of limiting the temperature increase to the +2°C threshold, beyond which the IPCC (Intergovernmental Panel on Climate Change) indicates that the effects of climate change will be dramatic. The "4 per 1000" initiative is intended to complement those necessary efforts to reduce greenhouse gas emissions, globally and generally in the economy as a whole. It is voluntary; it is up to each member to define how they want to contribute to the goals.

In the "4 per 1000" initiative CA is explicitly mentioned as a farming system that maintains or even increases soil organic matter contents, thereby contributing to climate mitigation.

2.3 European Joint Programme on SOIL

In Europe a large programme on soils is aimed to kick off in February 2020: European Joint Programme SOIL (EJP SOIL). The main objective of EJP SOIL is to create an enabling environment to enhance the contribution of agricultural soils to key societal challenges such as climate change adaptation and mitigation, sustainable agricultural production (food security), protect ecosystem services and land and soil degradation prevention and restoration.
EJP SOIL will build a sustainable European integrated research community on agricultural soils and will develop and deploy a roadmap on climate-smart sustainable agricultural soil management.
The roadmap of EJP SOIL is based on a knowledge framework with 4 interacting components: knowledge development set out in project calls with internal and external partners, knowledge sharing & transfer framed in capacity building for young scientists and in enhancing general public awareness and fostering improved societal understanding and appreciation of agricultural soil management and its contribution to society, knowledge harmonization, storage & organization addressed at the various levels of the EJP governance to lower barriers to implement harmonised soil information and reporting practices and knowledge application with scientific analyses of (ways to overcome) barriers for adoption of novel practices and technologies in a European context. EJP SOIL actions in interaction with stakeholders, MS's and DG AGRI will foster the long-term goal of promoting farmers as stewards of land and soil resources and to support policy development and deployment. The 6 outcomes include targeted actions and activities in response to societal, scientific, policy and operational challenges. A first annual workplan based on the roadmap is provided as part of the proposal.
The EJP Soil consortium unites a unique group of 27 leading European research institutes and universities in 25 countries.
The provisional roadmap and the knowledge framework that lies at the basis of it will also be used to base the roadmap aimed to be presented at the end of this project for climate smart agricultural soil management in South Africa. The provisional roadmap is available on the following website:
http://dca.au.dk/fileadmin/user_upload/EJP_SOIL_roadmap_final-23-01.pdf

2.4 CIRCASA

The CIRCASA (Coordination of International Research Cooperation on soil Carbon Sequestration in Agriculture; https://www.circasa-project.eu/) is a European Project funded under HORIZON 2020. The overarching goal of CIRCASA is to develop international synergies concerning research and knowledge exchange in the field of carbon sequestration in agricultural soils at European Union and global levels with active engagement of all relevant stakeholders. This includes four specific objectives:

- O1 Strengthen the international research community on soil carbon sequestration in relation to climate change and food security;
- O2 Improve our understanding of agricultural soil carbon sequestration and its potential for climate change mitigation and adaptation and for increasing food production;
- O3 Co-design a strategic research agenda with stakeholders on soil carbon sequestration in agriculture;
- O4 Better structure the international research cooperation in this field.

The project aims to create significant outcomes for the implementation of the UN Sustainable Development Goals (SDGs) and of the Paris agreement (COP21, 4 per 1000 voluntary initiative) of the UN Framework Convention on Climate Change (UNFCCC).

Methodology

CIRCASA applies an interdisciplinary and global approach to coordinate international research cooperation in different agricultural systems and pedo-climatic conditions through a strong international partnership.

By bringing together the research community, governments, research agencies, international, national and regional institutions and private stakeholders CIRCASA takes stock of the current understanding of carbon sequestration in agricultural soils, identifies stakeholders' knowledge needs, and fosters the creation of new knowledge.

An Online Collaborative Platform (OCP, still not operational) will structure and integrate existing knowledge in a comprehensive knowledge system on soil carbon in agriculture, delivering a scientific resource of global and local significance (e.g. maps with technical potential for diverse agricultural practices). Active dialogue with stakeholders will be pursued through regular scientific and policy channels and dedicated regional / national stakeholder hubs, gathering their perspectives of SOC sequestration potential, role and management options, barriers and solutions to implementation, and knowledge demands.

Also, in this project a 2020-2025 Strategic Research Agenda (SRA) on agricultural SOC sequestration will be co-designed with stakeholders, grounded on scientific evidence and stakeholders' knowledge demands. The OCP and a range of state-of-the-art information and communication tools will support the communication and outreach strategy. This document is still under revision, however available to the authors of this report.

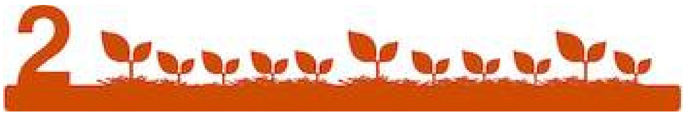
3 Definitions

3.1 What is Conservation Agriculture?

FAO (http://www.fao.org/conservation-agriculture/en/) describes Conservation Agriculture (CA) as a farming system that promotes maintenance of a permanent soil cover, minimum soil disturbance (i.e. no tillage), and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

According to FAO Conservation Agriculture is based on the following three principles:

Minimum mechanical soil disturbance
(i.e. no tillage) through direct seed and/or fertilizer placement.



Permanent soil organic cover
(at least 30 percent) with crop residues and/or cover crops.

Species diversification
through varied crop sequences and associations involving at least three different crops.

FAO describes Conservation Agriculture (CA) as a farming system that can prevent losses of arable land while regenerating degraded lands. It promotes maintenance of a permanent soil cover, minimum soil disturbance, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contribute to increased water and nutrient use efficiency and to improved and sustained crop production.

According to the FAO, CA principles are universally applicable to all agricultural landscapes and land uses with locally adapted practices. Soil interventions such as mechanical soil disturbance are reduced to an absolute minimum or avoided, and external inputs such as agrochemicals and plant nutrients of mineral or organic origin are applied optimally and in ways and quantities that do not interfere with, or disrupt, the biological processes.

CA facilitates good agronomy, such as timely operations, and improves overall land husbandry for rainfed and irrigated production. Complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, etc., CA is a base for sustainable agricultural production intensification. It opens increased options for integration of production sectors, such as crop-livestock integration and the integration of trees and pastures into agricultural landscapes.

In a recent study by Laborde et al. (2020) the drivers for the potential implementation of CA as a viable system for sustainable intensification was assessed globally for a diverse set of agri-ecological and socio-economic landscapes using a machine-learning modelling technique. The study looked at the performance of three rainfed crops: maize, wheat and soybean. The study showed that according to this modelling study, that a combination of climate, soil, geographic and management variables predict the potential of increased yield under Conservation Agriculture. The result showed that in areas with an average temperature of more than 20 degrees C (so humid tropics and sub-tropics) with good plant stand establishment, when implemented for more than 13 years the yield will increase under CA.

3.2 What is circular agriculture?

From a broader perspectives circular systems in the blue and green society can be defined as systems in which water, nutrient and carbon cycles are closed and from this, minimize resource loss and climate change effects (Figure 3). Integrated systems, making smart connections between terrestrial production cycles (plant and animal based) and marine production cycles, close and strengthen production cycles and networks to replace linear chains. This knowledge (that partially still is under development) will provide the necessary building blocks of such a circular and climate positive society that ensures climate restoration. This includes efficient use of land, water and energy, carbon sequestration, change in consumer behaviour, as well as the needed governance structures. Efficiently using resources in the food, feed, chemical and materials industry is crucial, while at the same time preventing losses and accumulation of safety hazards when closing loops (after the vision document of KB Circular Systems).

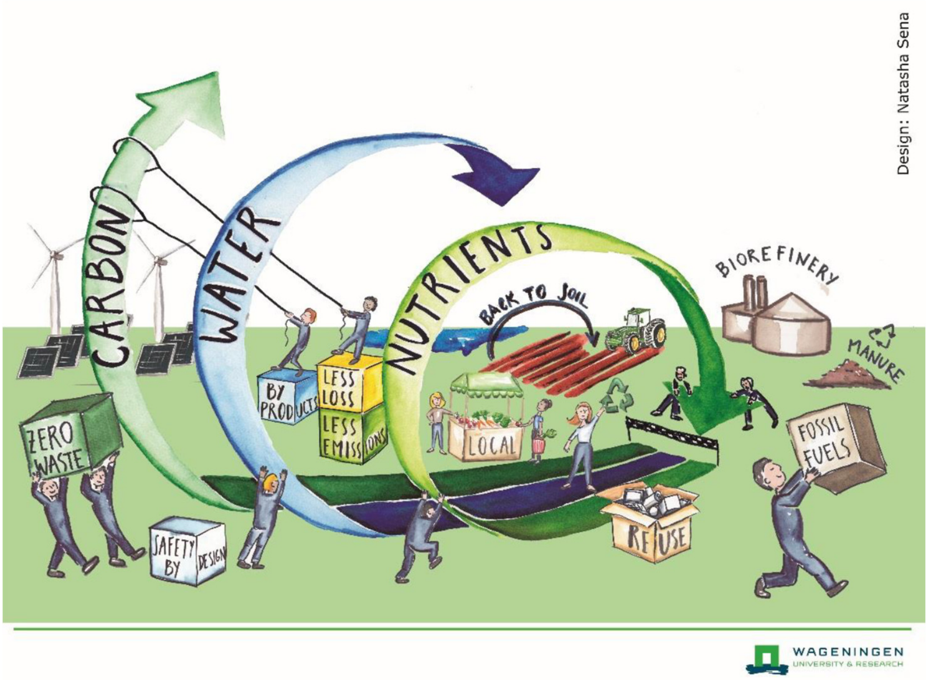


Figure 3: Circular systems in the blue & green society will close water, nutrient and carbon cycles and minimize resource loss

Therefore, circular agriculture is about reducing resource consumption and emissions to the environment by closing the loop of materials and substances. Losses of materials and substances are prevented, and otherwise be recovered for reuse, remanufacturing and recycling. In line with these principles, circular agriculture implies searching for practices and technologies that minimise the input of finite resources, encourage the use of regenerative ones, prevent the leakage of natural resources (e.g. carbon (C), nitrogen (N), phosphorus (P), water) from the system, and stimulate the reuse and recycling of inevitable resource losses in a way that adds the highest possible value to the system (Jurgilevich et al., 2016).

The circular, climate positive society covers all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles. It includes and interlinks: land and marine ecosystems and the services they provide; all primary production sectors that use and produce biological resources (agriculture, forestry, fisheries and aquaculture); and all economic and industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services. *To be successful, the European bioeconomy needs to have circularity at its heart and it is necessary to go beyond carbon neutrality.* This will drive the renewal of our industries, the modernization of our primary production systems, the protection of the environment and will enhance biodiversity.

Source: adapted from European Commission, A sustainable bioeconomy for Europe: strengthening the connection between economy, society and the environment, October 2018.

4 Importance of soil organic matter

4.1 Relevance

Stakeholders from a number of sectors have expressed concern about the decline in organic matter quantity in Dutch arable land. Time series analyses (van den Akker, 2012 and Eurofin Agro, 2017), however, show neither downward nor upward trends on a national level. Locally there may be an ascending or descending soil organic matter quantity, for example when grassland is converted into arable land, or vice versa (Smit *et al*., 2007). However, the composition and quality of soil organic matter is changing structurally (Eurofins, 2017).

Sufficient soil organic matter is fundamentally important to availability of water and nutrients, trafficability, carbon sequestration, resilience against diseases and plagues and crop production. Maintaining and, where needed, increasing soil organic matter content serves to meet challenges that intensively used agricultural lands face, like dealing with extreme precipitation and drought, both occurring more frequently due to climate change.

That the organic matter content of agricultural fields should increase, has also landed as an issue in politics these days. The Dutch Minister Schouten (Agriculture and Nature) has recently stated in her vision about circular agriculture: *"A soil containing much organic matter, is better equipped to absorb water and is more resistant against drought. Such a soil can also retain more nitrogen and minerals, offers a richer soil life and contributes to healthy crops."* (Schouten, 2018., p.22). The Soil Strategy, 2016 (in Dutch) of the Soil Technical Commission (TBC) of the Dutch Government indicates specific strategies for managing organic matter on agricultural fields. The draft Climate Accord (Klimaatberaad, 2018) refers to the significance of more organic matter in the soil.

4.2 Interactions

The numerous interactions related to organic matter are shown in Figure 4.

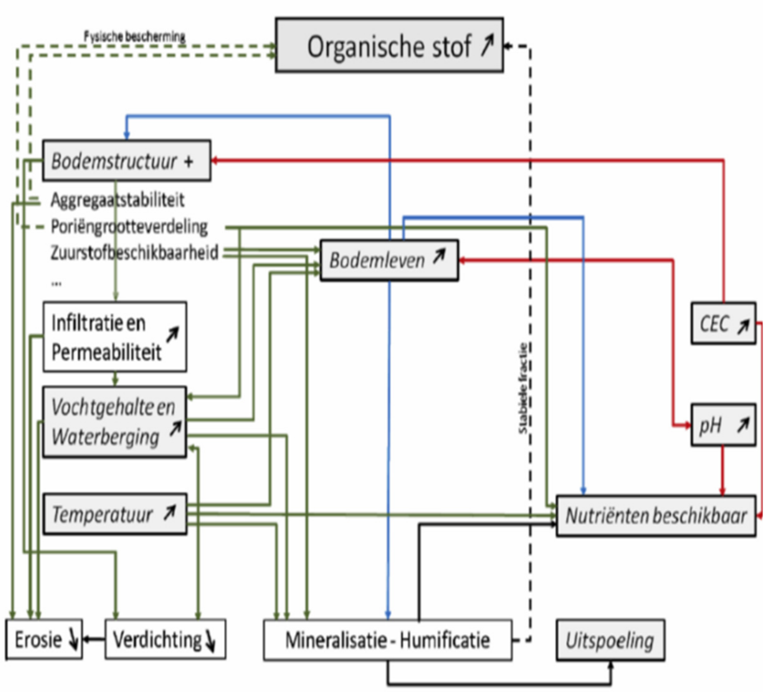


Figure 4 Schematic representation of soil interactions related to organic matter; blue lines: effect of soil life; green arrows: soil physical effects; red lines: soil chemical effects; dark lines: effects of soil processes. Dash lines: correlation with organic matter. Source: Reubens et al., 2010

Organic matter, nutrient availability and soil structure

The influence of the quantity of soil organic matter on the nutrient balance is complex. An increase of the organic matter content leads to a stronger soil bonding of nutrients due to a higher cation-exchange capacity (CEC). When organic matter is decomposing, nutrients become available, so less fertiliser will suffice. However, in case nutrients are released in a period in which the crop does not require them, a higher organic matter content may lead to larger nutrient losses to ground and surface water. Generally, clay soils have a good inherent soil fertility. Sandy soils strongly depend on organic matter for nutrient supply. In these soils availability of nutrients is largely determined by interactions between soil life and soil organic matter.

There is a clear correlation between organic matter content and soil structure (Faber et al., 2011). The more organic matter present, the better soil structure will be. A good soil structure is essential for the carrying capacity and infiltration capacity, it limits the sensitivity for sealing and the chance of soil compaction, it makes the soil less sensitive for soil diseases and gives a higher crop yield.

Organic matter and water availability
The influence of the quantity of organic matter on water availability may be exerted directly or indirectly.

Direct effect on water retention
A direct effect is the influence of organic matter on the water retention. The water availability of the soil is calculated, by multiplying the quantity of available water between field capacity at pF = 2 and wilting point at pF=4.2, with the thickness of the root zone Δz, like indicated in figure 5.

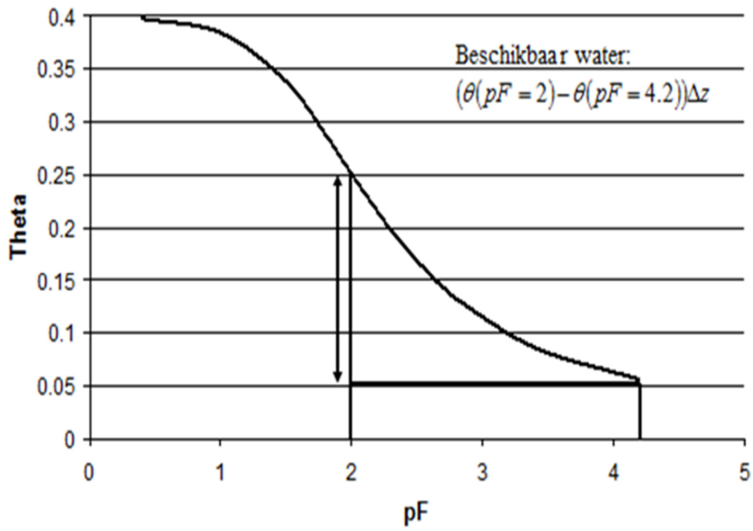


Figure 5 Water retention characteristic indicating the relationship between the pressure head (pF value) and the corresponding volumetric moisture content (Theta).

Derived from information about sandy soils in the Staring series (Wösten *et al.*, 2001), the relation is calculated between the organic matter content and moisture content when saturated, at pF 2 (field capacity) and at pF 4.2 (wilting point). Figure 3 shows the result of calculations for a sandy soil and indicates that moisture content at all 3 pressure heads increases with increasing organic matter contents.

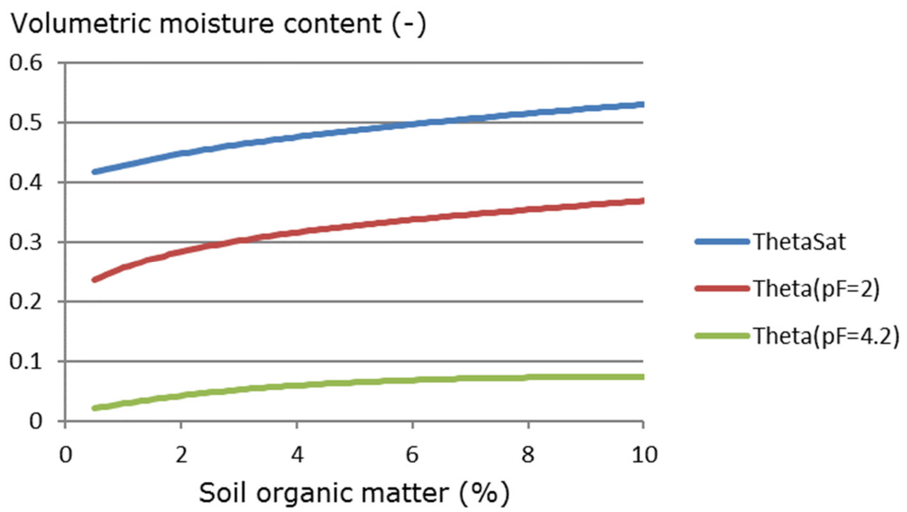


Figure 6 Curve of the volumetric moisture content at saturation, at pF 2 (field capacity) and at 4.2 (wilting point) wit organic matter content

Taking figure 6 as the starting point, figure 7 gives the increase of the water availability with increasing organic matter contents.

Since the sandy soils from the Staringreeks (Wösten et al., 2001) contain minimally 1% organic matter, increase in water availability (figure 7) is an estimation. In case organic matter contents are below 1%, these are shown, for this reason, as dotted lines.

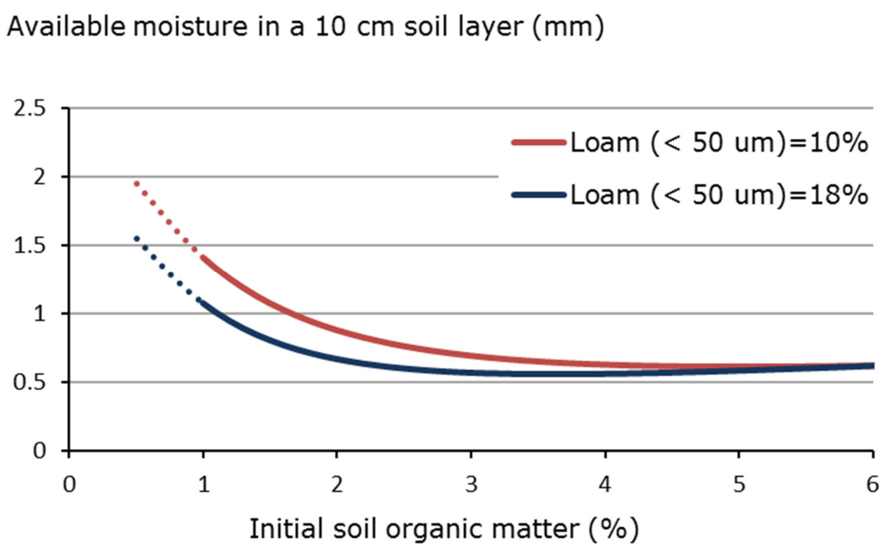


Figure 7 Increase of water availability (mm) in a layer of 10 cm with an increase of organic matter of 1%.

Indirect effect on water retention
An indirect effect of organic matter is a lowering of the bulk density of soils and therefore the resistance against penetration by plant roots. Plants on soils with higher organic matter contents may not only take up more water from a certain root zone, but this root zone can also become thicker, making again more water available.

The most important conclusions in relation to organic matter content and water availability are:

- An increase of organic matter content leads to a direct and indirect increase in water availability. The indirect effect has not been quantified.
- Poor sandy soils with 0,5 up to 1 % organic matter will render, with an increase of 1 % organic matter, an increase of 3 – 4 mm available water (Figure 7) in a root zone with a thickness of 20 cm. This roughly equals one day extra transpiration.
- In the trajectory from 1 to 3 % organic matter, an increase of 1 % organic matter leads to an increase of 2 -3 mm available water (Figure 7) in a root zone of 20 cm this equals less than one day extra transpiration.
- In the trajectory from > 3 % organic matter, an increase of 1 % organic matter leads to an increase of 1 mm available water in a root zone of 20 cm (sand).
- In a dry summer, in which the precipitation deficit continuously increases, extra water availability will have little effect. However, in a moderately dry summer with a regular shower, extra water availability of 3-4 mm can be used multiple times and it could lead to postponing a sprinkler irrigation application of 20 – 25 mm or to not apply this at all.
- The more organic matter is present, the better the soil structure, thereby giving the soil a higher infiltration capacity with less ground level run-off (indirect positive effect on the water retention and possibly reduction of peak discharges (Schipper et al., 2015). Also the composition and the ratio between dynamic and stable organic matter can have an influence on the water retention (Eurofins, 2017). No field studies are known, that quantify these indirect effects for Dutch soils, yet there are indications from field research elsewhere (Williams et al., 2017), that point to a positive effect.
- A good soil structure makes it possible that plants root well, which means increasing water availability for the crops. Based on an average of 25 % available water (Figure 6), a root zone of 20 cm renders 50 mm water. With a root zone of 30 cm this is 75 mm. This means an increase of 50%.

5 Effect of soil organic matter on crop yield

A meta-analysis by Hijbeek et al. (2017) using data from 20 long-term experiments in Europe, showed that across all experiments, the mean additional yield effect of organic inputs was not significant (+ 1.4 % ± 1.6 (95 % confidence interval). In specific cases however, especially for root and tuber crops, spring sown cereals, or for very sandy soils or wet climates, organic inputs did increase attainable yields. This conclusion was somewhat surprising because organic inputs do have a positive effects on the soil organic matter balance and as such they are an important asset for soil fertility and crop growth. The authors conclude that “using organic inputs to increase soil organic matter is often seen as a win-win situation for food security and climate change mitigation, such as the recently proposed “ 4/1000 initiative” at COP21 (UNFCCC, 2015). Using organic inputs to sequester carbon might be a viable option to buy time for developing technologies for reducing industrial emissions (IGBP, 1998), this meta-analysis however shows that benefits for crop yields cannot be assumed to follow directly”.

A statistical analysis of databases with soil data shows a non-significant relationship between soil organic matter content and infiltration capacity of the soil (Rahmati et al., 2018). However, farming systems research with different forms of long-term organic matter management in traditional and biological agriculture shows that the infiltration capacity of the soil increases with an increase in soil organic matter content (Williams et al., 2017). As a result, the effect of soil organic matter on crop yield is mostly not direct but rather indirect by means of increased nutrient and water availability.

6 Effect of soil organic matter on climate mitigation

To mitigate climate change there is the option of using 'negative emissions technologies' – methods that remove CO_2 from the atmosphere. Soil organic carbon (SOC) sequestration is a major mitigation option. Two to three times more carbon is stored in soil organic matter than in atmospheric CO_2 (IPCC, 2013). Up to 1.4 Gt C could be stored annually in agricultural soils (IPCC, 2007, 2014). SOC sequestration is among the cheapest methods with the greatest potential. It requires conserving carbon stocks, storing carbon in agricultural landscapes both in soil organic matter and in biomass through agroforestry, reducing CO_2 emissions from drained peatlands and wetlands and better recycling organic carbon through improved circularity and lifecycle of urban and agri-food industries organic wastes, thereby contributing to the bio-economy. Soil carbon sequestration could even reach to absorb one-third of the annual increase in atmospheric CO2-carbon, however, the duration of the effect would be limited, with significant impacts lasting only 20-50 years. Carbon sequestration in soils may form in the future a key technology to mitigate climate change (Smith, 2004, Roe et al., 2019). International agreements, such as the Kyoto Protocol and the Paris Agreement encourage soil carbon sequestration and could be used to formulate soil carbon sequestration polices. However, other environmental impacts as well as political, economic and societal needs, need to be taken into account in order to ensure sustainable development.

The concentration of organic carbon in soil is regulated by the relative rates of organic carbon addition and loss. In natural soils across the earth, these rates are generally controlled by average annual temperature and average annual precipitation. At a smaller scale, other factors heavily influence soil organic carbon content. By understanding the processes controlling organic carbon cycling in soils we can better predict effective and efficient land use and management practices for increasing agricultural soil organic carbon. The actual environmental setting will be definitive to decide the best agricultural practice to increase soil carbon concentrations as new organic carbon is introduced to soils via plant activity. Simply, atmospheric carbon fixed via photosynthesis is transferred to the soil by plant exudates and plant organic matter degradation. This organic carbon is either respired and released as CO_2 (mineralised) or stabilised, e.g. in association with soil particles.

Approximately 12% of earth's land surface is classed as arable by the Food and Agriculture Organization of the United Nations (FAO), and 38% classed as Agricultural (excluding land used for wood/timber production). For effective agricultural land management to maximise soil organic carbon, current and reliable data is needed on soil parameters. This requires improved soil monitoring and management across the globe. To be able to assess this, well-established monitoring methods need to be developed. Changes in soil carbon are small compared to the large stocks of carbon present in the soil, meaning that changes can be difficult to measure. Soil organic carbon monitoring requires the accurate measurement of a number of other soil parameters, which is not trivial.

In a paper by Smith et al., 2019 the role of soil carbon sequestration was highlighted for how it contributes to the various NCP (Natures Contribution to People) and the land and soil related SDGs. In chapter 7 different ways to increase soil carbon in agricultural soils. However, also in other land use types such as grazing land and forests carbon can be sequestered in soils. Practices that increase soil organic matter content include a) *land use change* to an ecosystem with higher equilibrium soil carbon levels, b) *management of vegetation*: including high input carbon practices, e. g. improved rotations, cover crops, perennial cropping systems, c) *nutrient management to increase plant carbon returns to the soil*, e.g. through optimised fertiliser application rate, type, timing and precision application, d) *reduced tillage intensity and residue retention*, and e) *improved water management*: including irrigation in arid conditions (Smith, 2019). In Figure 8 published in Smith et al., 2019 it is depicted how SCS can impact upon soil functions, NCPs and the SDGs.

Figure 8. Summary of the impact of SCS on soil functions, on NCPs and on the SDGs, showing the contribution to the SDGs from each soil function and NCP impacted by SCS (after Smith et al., 2019).

What we can see in this figure are some clear links to how storing more carbon in soils (SDG 13) cannot be achieved alone*. Climate Action* is supported by carbon storage by creating a large (but potentially reversible) sink for atmospheric CO_2, and improved resilience to climate change (e.g. 41,45). But to do this solely for the sake of climate mitigation, this will not be feasible from a socio-economic point of view. If measures as described above are implemented for carbon storage this will have a positive effect on several other SDGs: Prevention of erosion and polluted substances from reaching water bodies will help *Life below water (SDG14)*. Improved soil health will be beneficial for *SDG 15, Life on land*, which will in turn enhance biodiversity and healthy ecosystems. Furthermore, soil health will improve clean water and sanitation (SDG 8), make agriculture more resilient (see chapter 5) to droughts, thereby helping towards SDG2 *No poverty* and *Zero Hunger* (Lal et al., 2016; Keesstra et al., 2016).

7 Ways to increase organic matter content

It is important to note some general limitations to storing more carbon in agricultural soils. Firstly, there is a maximum or equilibrium amount of carbon that can be stored in stable form attached to soil aggregates for the long-term. This is different for specific soil types and characteristics and limits the carbon sequestration potential of agricultural soils already within 20 years (King et al., 2018; Weiske, 2007). It is important to consider that increasing SOC is a long-term process in which the benefits only become visible after many years, whereas the cost will arise every year. Also, nitrogen availability can become a limiting factor, since organic matter has a specific C/N ratio. When only adding carbon, there will be a nitrogen shortage that limits further organic matter production by plants and thereby uptake of carbon in soils. Moreover, the critical C input to maintain current C stocks is positively related to the amount of the current C stock (Wang et al., 2016). This basically means that a higher SOC level requires higher annual SOC inputs. Also microbial decomposition rates increase with rising temperatures and therefore, due to climate change, carbon storage can become increasingly difficult (M. Hagens, personal communication, October 7, 2019). For these reasons, enhancing carbon uptake by soils can only be a temporary solution for offsetting the increase in atmospheric greenhouse gas emissions. First of all, it is important to quantify what an increase of 1 - 5 % organic matter means in terms of the yearly supply of organic matter. It is important hereby, to make a distinction between two forms of organic matter: old organic matter ("humus") that degrades at a rate of 2% under Dutch circumstances, and fresh organic matter of which 40 % is converted into humus within one year. Kortleven (1963) provides a calculation scheme for the accumulation and decay of soil organic matter:

$H = H_E + (H_0 - H_E)\exp(-\alpha t)$

Where:

H_E is the equilibrium value of humus:

$H_E = pI/\alpha$, p= the transformation fraction of fresh organic matter (0.4 y^{-1})

α = decomposition speed humus (0.02 y^{-1})

I = annual input fresh organic matter (kg ha^{-1} y^{-1})

H_0 = initial amout of humus (kg ha^{-1})

Fresh organic matter is superficially supplied and subsequently ploughed through. Conversions will then take place in the 20-25 cm thick root zone. Such a root zone corresponds with ca 3 10^6 kg soil / ha and 1% increase of this is 3 10^4 kg organic matter ha^{-1}. The yearly supply would then amount to 0.02*3 10^4/0.4 = 1,500 kg fresh organic matter per hectare, which is quite a significant volume. This is why it is more practical to follow a long-term strategy, instead of aiming to reach this 1% increase in 1 year. The strategy would then be to increase the organic matter content by 1% gradually, over several years.

The soil organic matter content, in general, can be raised in the following 3 ways (SmartSoil project, 2015):

1. Advancement of input in the soil of crop- and root residues
2. Increase of the quantity of soil organic matter by supplying manure and compost (both from external sources as from the farm itself)
3. Reduction of de-composting losses by limiting disturbance of the soil

The following cultivation measures have a positive effect on conserving and increasing of the soil organic matter content:

- **Crop rotation**

Cultivation of crops with a long growing season combined with the cultivation of leguminous plants that improve the quality of organic matter.

- **Crop residues**

Crop residues are those materials that are left on the field after the crop has been harvested. This includes stems, stubbles, leaves, roots and chaff. Insert these crop residues maximally into the soil.

- **Supply of manure and compost**

Supply of manure and compost effectively enhances the organic matter content, because it decomposes less quickly than fresh crop- and root residues. Supplying manure and compost will also often decrease the necessity to apply fertiliser.

- **Soil covering and catchment crops**

Prevention of fallowing in winter, by cultivating crops year-round, enhances the insertion of organic matter and decreases soil erosion and leaching of nutrients.

- **Conservation agriculture**

Conservation agriculture consists of minimizing soil tillage and having permanent soil coverage and diversity in crops. Minimal- and eventually no soil tillage, by a transition from frequent ploughing to forms of non-inversion tillage, diminishes the decomposition of organic matter.

The five measures are summarised in Table 1. Both the prevention of fallowing and the reduction of tillage take time before it results in an obvious increase of organic matter content.

Table 1: Promising measures for the increase of organic matter content and their most important characteristics in the short (0 -5 years), medium (5 – 10 years) and long (> 10 years) term.

Measure	**Effect on the organic matter content in soil on various time scales**		
	short	medium	long
Optimisation of crop rotation	++	++	++
Leaving crop residues behind	++	++	++
Supply of manure and compost	+++	++	+
Prevention of fallowing	+	++	+++
Lowering intensity and frequency of soil tillage	+	++	+++

8 The South African Context

8.1 Soil organic carbon status of soils in Southern Africa

Soil organic carbon (SOC) in much of Africa is lower than in the temperate climates (Figure 9) due to warm temperatures and abundant rainfall resulting in high rates of decomposition of organic matter. In South Africa, Du Preez et al. (2011) reported that 58% of soils have less than 0.5% OC while Schütte et al. (2019) in a recent mapping of organic C in soils found that only 3.2% of surveyed terrain units had soils with ≥ 2% OC levels. The majority of soils sampled during validation on-farm trials in Malawi, Mozambique, Zambia and Zimbabwe had C concentration below 11 g kg^{-1} which is below the critical level required to sustain crop production and avoid soil degradation (UNCCD, 2015; Cheesman et al., 2016).

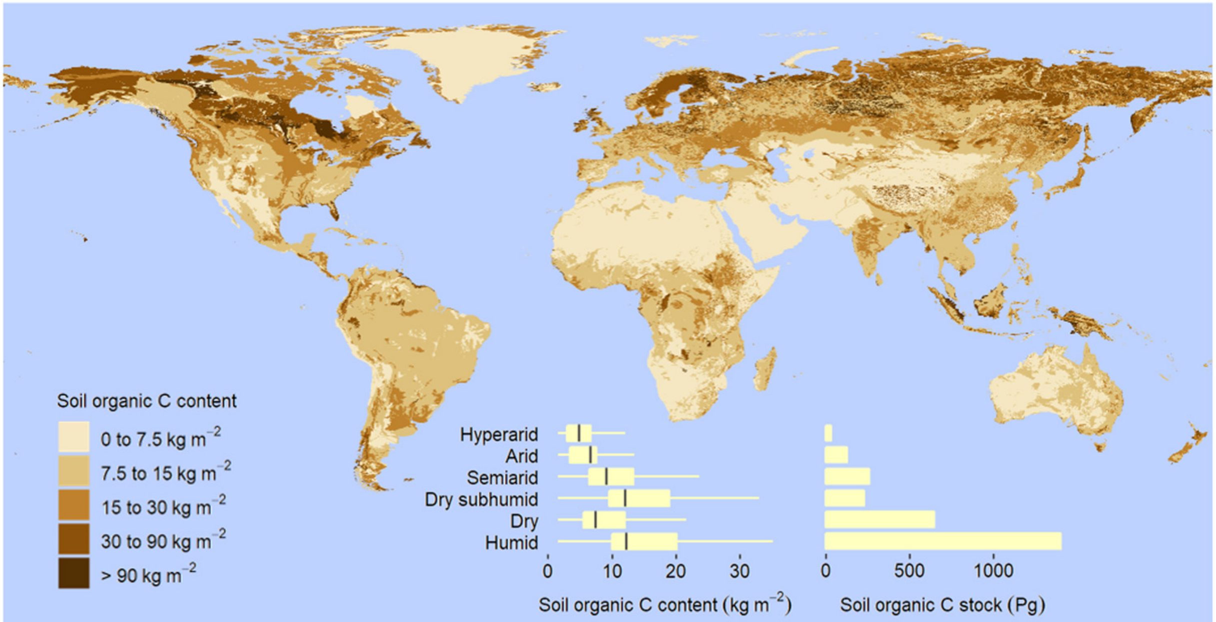


Figure 9 Distribution of soil organic carbon to one metre depth (USDA Natural Resources Conservation Service, 2006)

A number of management practices have contributed to the decline in SOC across farming systems in the region. About 46% loss of SOC in South Africa was attributed to cultivation by Swanepoel et al. (2016) as tillage results in increased decomposition of organic matter. Under smallholder agriculture, additional contributory factors to SOC depletion are reduced net primary production, the low amounts of C inputs added to the soil and by poor land management practices that result in erosion of the top soil (Corbeels et al., 2019). The low SOC stocks in African soils present an opportunity for the soils to become C sinks through the use of management practices that can increase soil C inputs and / or reduce top soil erosion and increase crop productivity. This sequestering of C by soils can reduce the amount of CO_2 released into the atmosphere and thus contribute to mitigate increasing concentrations of greenhouse gas emissions. Among management practices that reduce C loss are erosion control, reduced / no tillage and use of cover crops while increasing C input can be achieved through addition of compost, manure and crop residues to soils. Conservation agriculture (CA), comprising the simultaneous application of continuous no or minimum mechanical soil disturbance; permanent soil mulch cover and crop diversification, has been identified as one of the feasible and sustainable means to increase C stocks in the soil (Corbeels et al., 2019; Gonzalez-Sanchez et al., 2019).

8.2 Conservation agriculture adoption in Southern Africa

The worldwide promotion of CA in recent decades has resulted in an observed 69% (global) and 211% (Africa) increase in area under where all three CA principles were practiced between 2008 and 2016 (Kassam et al. 2018). In in Southern Africa, there was a 214% in area under CA over the same period with the greatest increases observed in Malawi and Mozambique (Table 2). There is still potential for further adoption of CA in the region if locally suitable solutions are found to challenges such as high labour requirements for manual tillage and weed management systems, competition for crop residues especially in semi-arid areas, cover cropping, integration of livestock and availability of markets for legume and other non-maize crops.

Table 2 Extent of adoption of conservation agriculture in Southern Africa by country in 2008/09, 2013/14 and 2015/16 (Adapted from Kassam et al., 2018)

Country	CA area ('000 ha)		
	2008/09	2013/14	2015/16
South Africa	368	368*	439
Zambia	40	200	316
Zimbabwe	15	90	100
Mozambique	9	152	289
Lesotho	0.13	2	2
Malawi	-	6.5	211
Namibia	-	0.34	0.34*
Southern African total	432	819	1357
Global total	106505	156739	180439

* Taken from previous period

Gonzalez-Sanchez et al. (2019) estimated C sequestered under CA croplands in Africa was estimated at 1543022 Mg C year^{-1} of which 89 % was from Southern Africa (Table 3). If the area was expanded to all areas suitable for CA in Africa, this figure would increase by 93 times highlighting the potential of African soils to mitigate climate change through reductions in emission of CO_2.

Table 3 Current SOC fixed annually by CA croplands compared to conventional tillage based agriculture in Africa (Gonzalez-Sanchez et al., 2019).

Country	No-tillage adoption$^{\infty}$, ha	C sequestration in no-tillage (Mg ha^{-1} yr^{-1})	Current annual C sequestration Mg yr^{-1}	Climatic zone
Algeria	5600	0.44	2464	Mediterranean
Ghana	30000	1.56	46800	Equatorial
Kenya	33100	1.02	33762	Tropical
Lesotho	*2000*	*1.02*	*2040*	*Tropical*
Madagascar	9000	1.56	14040	Equatorial
Malawi	*211000*	*1.02*	*215220*	*Tropical*
Morocco	10500	0.44	4620	Mediterranean

Mozambique	*289000*	*1.02*	*294780*	*Tropical*
Namibia	*340*	*0.50*	*170*	*Sahel*
South Africa	*439000*	*1.02*	*447780*	*Tropical*
Sudan	10000	0.50	5000	Sahel
Swaziland	*1300*	*1.02*	*1326*	*Tropical*
Tanzania	32600	1.02	33252	Tropical
Tunisia	12000	0.44	5280	Mediterranean
Uganda	7800	1.56	12168	Equatorial
Zambia	*316000*	*1.02*	*322320*	*Tropical*
Zimbabwe	*100000*	*1.02*	*102000*	*Tropical*
TOTAL	1509240		1543022	

∞ Source: Kassam *et al*., 2018, countries from Southern Africa italicized

8.3 Studies on CA impacting SOC in Southern Africa

The effect of CA on soil C in Southern Africa presents a mixed bag with increases, no effect and decreases in SOC reported, but on closer inspection it is noted that when all the three principles of CA are applied SOC is often seen to increase (Table 4). Therefore, the potential C sequestration benefits under CA seem to accrue when minimum tillage is practice in tandem with crop residue mulching / provision of soil cover and diversified cropping systems. In most of the studies SOC is low and does not reach the 11 g kg^{-1} limit even after several years under CA. Aune and Lal (1997) give 11 g C kg^{-1} as the critical limit that would allow supporting of crop productions in most tropical soils. This highlights that the level of C inputs particularly under smallholder agriculture and / or semi-arid area is too low to substantially change soil C concentration in the short and long term. Research also pointed to differences across seasons and soil types which also need to be considered. From this preliminary review, our findings are in agreements with those of Corbeels et al. (2019) that African soils have a large potential to act as sinks for C and CA is one strategy to achieve this. However, the need for adoption of all three CA principles for maximum benefits to be realized that reflects findings for weed suppression (Mashingaidze et al., 2017), soil improvements and yield benefits (Rusinamhodzi et al., 2012) may reduce the potential of CA to store C in crop lands in Southern Africa and much of Sub-Saharan Africa. This is because a large majority of smallholder farmers whose soils would get the most benefits from CA mostly adopt minimum tillage with limited crop residue mulching and crop diversification (Findlater, 2015; Pedzisa et al., 2015; Giller et al., 2009).

In conclusion, although C soil sequestration can be physically achievable on farms in Southern Africa and elsewhere, Amundson and Biardeau (2018) view the current targets for C sequestration by agricultural soils in literature and 4 per 1000 goal as too optimistic and unlikely to be achieved in reality. This is because the focus so far has been on the natural science aspects but now there is need going forward for social research to identify and address the economic and political barriers to adoption of proposed climate smart technologies such as CA by farmers. Policies that incentivise the adoption of these practices and /or compensate farmers for transaction costs and risks associated with a change in farming practices are key.

Table 4 Overview of studies on the effect of CA or CA principles on SOC levels in Southern Africa

Country	**Authors**	**Study site**	**Tillage**	**Soil cover**	**Cropping system**	**Effect on SOC**
South Africa	Mtyobile *et al*., 2019	E. Cape, on-station, semi-arid, Haplic Cambisol, 6 years	No till (NT) vs conventional plough tillage (NT)	Crop residues retained on soil surface	Maize-fallow-maize, maize-fallow-soybean, maize-winter wheat-maize and maize-winter wheat-soybean	1. SOC $_{(upper\ 15cm)}$ NT > CT 0-5 cm: 1.4 % > 1.2% 5-10 cm: 1.4% > 1.1% 2. Rotation SOC Rotations > maize-fallow-maize
	Swanepoel *et al*., 2018 -1	Buffelsvlei, NW province, on farm trial, arid, steepe, cold arid region, sandy soil ($SOC_{0-150cm}$-0.45%), 8 years	Reduced tillage (RT) – no till planter vs conventional plough tillage	Crop residues retained on soil surface	Maize monocrop, Maize – cowpea/ sunflower/ millet rotations	Treatments had no significant effect on SOC. - SOC differed with year of planting season, highest SOC 0.51% - Average C stocks for 0 -30 cm layer: 19.3 t ha^{-1}
	Swanepoel *et al*., 2018 -2	Zeekoegat, Gauteng province, on-station trial, warm temperate, dry winter, hot summer region, clay soil ($SOC_{0-100cm}$-1.25%), 6 years	Reduced tillage (RT) – no till planter vs Conventional plough tillage	Crop residues retained on soil surface	Maize monocrop, maize – cowpea/soybean/ rotation, maize – cowpea / oats/ vetch intercropping	RT increased SOC and C stock Gradual increase over 6 years in 0-10 cm layer under RT - SOC RT: 1.28% to 1.51% cf. CT: 1.21% - 1.3% - C stock CT: 54.9 to RT:57.9 t ha^{-1} Years / growing seasons effect on SOC
	Sithole *et al*., 2019	KwaZulu-Natal, on-station?, semi-arid, clay loam, 13 years	No till- direct seeding Conventional tillage: Mould board ploughing Rotational tillage (RT): 4 years NT followed by CT	Retained on NT (10-12 t ha^{-1}) Removed after harvesting in CT	Maize monocrop	No significant treatment effect on SOC NT 27.1 ; RT: 26 and CT: 26.5 t ha^{-1}
Malawi	Ngwira *et al*., 2012	Central and Northern Malawi, on-farmers' fields, tropical continental climate, sandy loam, loam soils, 2 – 5 years	Zero till (ZT) – no tillage vs CT – ridges with crop residue incorporation	Crop residue retained on surface in ZT	Maize monocrop	1. ZT increased SOC by 44 -75% 2. SOC increased with time under ZT $ZT_{(5\ years)}$ v CT: 10.4 v 3.9 C g kg^{-1}
Malawi, Zambia, Zimbabwe	Cheesman *et al*., 2016	23 sites, validation paired trial plots, various climates and soil	No till: dibble stick, jab planter, direct seeder	All crop residues retained in NT but removed or	Maize monocrop, maze- legume rotations or intercrops	1. CA did not increase C concentration in 0-30 cm layer across sites.

		types – sandy loam dominant, 2-7 years	Conventional tillage: hand hoe ridge and furrow, ploughing with mouldboard	incorporated in CT. Maize stover yield: 0.7 -5 tha^{-1}; legume stover: 0.1 – 4.3 tha^{-1}		Only 2 sites: CA > CT Majority of sites C in 0-30 cm: < 11 g C kg^{-1} 2. CA effect on C stocks site dependent CA maize-legume rotation :28.9 > CT 25.7 Mg ha^{-1} Large variability in C stocks. No trend of increasing C stocks with time under CA
Sub-Saharan Africa excluding South Africa	Corbeels *et al*., (2019)	21 sites in 7 countries, on-farm, various soils and climates, majority 5 years	No till: direct seeding, ripping, surface scraping of soil Conventional tillage: ox and tractor ploughing	No crop residue, crop residues	Maize monocrop, rotations, intercrops	SOC storage rates were only significantly higher than 4‰yr^{-1} (P=0.0438) when all three CA principles were applied - Relative SOC change varied from −142 to 450‰yr^{-1}
Zimbabwe	Namangara *et al*., 2013	450 sites in 15 districts, on-farm, across soils and agroecologies, Up to 9 years CA	Minimum tillage: planting basins Conventional Tillage: mould board ploughing	Retention of crop residues varied in CA	Maize- legume rotation in CA varied	CA had no effect on SOC Mean SOC < 10 g kg^{-1} -

8.4 Enabling conditions for sustainable agricultural management in South Africa

During the workshop we discussed the following topics to assess the barriers and enabling conditions in South Africa to work towards sustainable agricultural management. Essential issues to address when thinking about the future implementation of CA are:

- Which knowledge is missing?
  - Which knowledge does not exist?
  - Which knowledge is not integrated enough?
  - What are the benefits of soil carbon and soil quality in general for both agricultural productivity and resource efficiency, especially at low soil C levels (< 1%).
  - Uncertainty about the efficacy of measures and return on investment in soil management.

- Is the transfer of knowledge is blocked?
  - Knowledge is present, but in some situations, it is not available to the relevant stakeholders;
  - Knowledge is present, but not yet translated into decision support tools
  - How can research results be converted into policy messages;
  - Insufficient contact with farmers organizations

- Which socio-economic aspects should be considered?
  - Economic incentives (either policy driven, or market driven) may be misguiding and/or contra-productive
  - Social and cultural perception
  - Conflicting interests of different stakeholders

- Which paradigm shifts are needed?
  - Is a whole paradigm shift required from land and soil managers, i.e. to go from protection to sustainable use.

9 Outcomes Workshop

South Africa has a dynamic and active group of farmers, agricultural researchers and extension workers testing and promoting the use of CA principles with farmers being at the centre of the innovation. In the Netherlands, circular agriculture has become a key focus of agricultural development. As agricultural research in both South Africa and the Netherlands is highly developed, there are ample possibilities for joined research projects. Based on a constructive workshop and field visit December 3-5, 2019 on "The role of soil C in Conservation Agriculture and carbon sequestration in South Africa" the following outline for research on CA has been developed. After a lively workshop in Bloemfontein organised by the university of the Free State (Linus Franke and Nester Mashingaidze) and Wageningen Environmental Research (Saskia Keesstra and Henk Wösten).

In Annex 3, 4 and 5 photos of the flipovers are shown where the answers the questions we asked the participant to reflect on are given.

In general we can give the following answers for workshop 1:
The 5 questions were asked, but they were answered in an integrated way.

1. What is your definition of Conservation Agriculture?
2. Does the description of CA of FAO match current practices listed as CA in ZA?
3. What are the requirements?
4. What are the benefits?
5. What are the draw backs?

The message back was that in South Africa CA may be seen as an intermediate step towards Regenerative Agriculture and the FAO's definition does not include the integration of livestock in the farm system, which by the workshop participants is seen as an essential part of the successful implementation.
The key requirements were identified as:

- Knowledge
- Equipment
- Change in mindset
- Time for soil build-up
- Area specific plan development (no one recipe for success)

The benefits identified were:

- Yield stability
- Soil quality and all benefits related to that
- More yield with less resources (resource use efficiency)
- Free natural services

The draw backs identified were:

- It is a totally different system, which means a learning curve including making mistakes
- Adapting to the new system is knowledge intensive
- The revenues take time; benefits are long-term
- On acidic soils liming is needed and the mobility of lime in the soil is limited
- Rules for implementation should not be too strict

Workshop 2:

1. What would you like to have accomplished in terms of sustainable agricultural land use in 20 years?
2. What role do you see for CA in this view
3. How would this lead to better carbon sequestration in soils
4. Which effect would this have on agricultural yield?

Future vision:
The group in the workshop had the vision for SA that:

- No more environmental damage because of farming
- A positive C footprint
- Livestock integration for profitability efficiency
- Sustainable or even regenerative
- Increased production with low inputs, cheaper food, higher yields
- Plant breeding adapted to CA
- Lower degradation
- Increased water availability
- Better nutrient cycling/fertility
- Adoption of different approaches to increase production: biochar/cover crops/CA
- Turn abandoned land back into production via CA
- One vision/one language: standardize terminology
- Communal areas: apply RA: rangeland should be managed better
- Research in rangeland conservation; apply regenerative agriculture
- 100% pass rate
- All production systems should move towards a closed system/regenerative system
- Change mindset towards RA
- Awareness under farming community

Workshop 3:
What is needed?

- Mind shifts: we need
    - Awareness
    - Education and training
    - Policy change
    - System approaches
- Economical data and incentives
- Efficient, cheap, nutritious food through CA
- Certification
- Guidelines for switching to CA
- Paradigm shift
- Farmer support groups
- Multi-disciplinary
- Peer pressure and pressure from lobbies

Why do some farmers not like CA:

- Perceived as risky

- Cognitive Dissonance: believes/traditions/Ideas/Ignorance
- "their system still works" so why change?
- Addiction to KW's and chemicals
- Lazy/lack of patience: prefer a quick fix
- Lack of appropriate support systems (education + extension)
- No appropriate incentives
- Barriers:
    - Commitment from government
    - Government stimulates conventional practices
    - Not enough extension officers
    - Need for positive examples
    - Instability around land reform
    - Logistics for smallholder farmers
    - Sustainability is long-term
    - Context-specific knowledge
    - Very small farms owned by smallholders

10 Roadmap for research in South Africa regarding sustainable soil management for Climate Change Mitigation

Soils represent an enormous reservoir of carbon, containing nearly twice as much carbon as the atmosphere. Agricultural soils, particularly those degraded in organic carbon, have a large potential for carbon storage. Soil organic carbon is vital in controlling soil quality, agricultural productivity, biodiversity, and water protection. Storing atmospheric carbon in agricultural soils may also be an important component of climate mitigation efforts.

To identify the research needs in South Africa the workshops have been designed to deliver a roadmap for research in South Africa on sustainable agricultural soil management. In the workshops the following topics for potential collaborative research were identified:

1. Given that farmers drive the transformation to CA practices in South Africa, how can **monitoring framework** be developed for implementing CA both on large- and small-scale farms to assess how CA is adopted and how the adoption of CA practices affect the sustainability of production.
2. Which kind of **indicators** do we need on farm scale statistics to quantify the effect of CA measures.
3. Investigate what the **best cover crops** are in terms:
    a. protecting the soil from erosion,
    b. enhance water infiltration,
    c. nutritional value for cattle.
4. **Integration of livestock** in CA to increase the resilience of the CA system.
    a. What are the benefits of cattle in making CA more circular in terms of nutrient cycling, pest control, soil health and economic return?
    b. What is the potential of mixed farming systems in the Netherlands?
    c. What is the C footprint of integrated crop-livestock systems, in comparison with non-integrated systems?
5. **Impact of existing/non-existing subsidy system** on the implementation of sustainable farming systems.
6. **Socio-economic drivers and barriers** in South Africa and the Netherlands for the transition to(wards) sustainable farming.
7. How can we raise more **awareness** on the benefits of sustainable farming among land managers in general and farmers in particular both in NL as SA?
8. How can we incorporate key stakeholders in the whole food system in the development of a more **sustainable food production system**?

Research methodology

CA research requires a methodology of active involvement of farmers as they drive the CA innovations and are the main implementers. Consequently, a co-learning environment involving researchers, farmers, extension workers, and private sector is required. Existing farmer study groups as well as creation of narratives are ways to create an environment of collaboration among different stakeholders. This type of action research differs from the traditional methodology of curiosity driven research and therefore needs attention in order to be effective.

Research funding

The Netherlands government supports further collaboration between the Netherlands and South Africa. As such, they funded this first initiative. However, for further work other donors need to be approached as well. Possibilities are linking South Africa with an ongoing EU initiative, PhD fellowships, NWO – NRF joined calls, and attracting interest from the private sector.

Currently we are looking into a possible funding through a so-called Public Private partnership (PPS) funded by the Dutch Government in collaboration with the top sector funding in the Netherlands. At the ministry of Agriculture in The Netherlands there is the ambition to make our agricultural sector more international, and a PPS in collaboration with South Africa would fit well into this scope. Currently, there are some exploratory talks between the Dutch 'Soil Heroes' and WUR. We would like to link to South African Partners such as Grain SA to see how we could join forces.

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Annex 1 Program workshop

3rd December 2019:
12:30: Registration, light lunch available
13:00: opening by Jack Vera
13:20: Introduction workshop (Linus Franke and Saskia Keesstra)
13:40: What is Conservation Agriculture? (Linus Franke)
14:00: Effect of Conservation Agriculture on carbon sequestration and policies related to that (Saskia Keesstra)
14.30: Coffee / Tea break
15:00: Effect of Conservation Agriculture on soil fertility, water availability and crop production (Henk Wösten)
15:30: 1st workshop on perception and knowledge of Conservation Agriculture in South Africa
16:30: Plenary reporting back of 1st workshop
19.00: Dinner

4th December 2019
8:00 Participants presenting their Conservation Agricultural activities / research through brief (10-20 mins) presentations
10.00 2nd workshop: Aspirational targets (coffee during workshop)
11.00 report back on 2nd workshop
12.00 International policy on carbon sequestration (Saskia Keesstra)
12:45 lunch
13:30 3rd workshop on barriers for upscaling Conservation Agriculture in South Africa
14:30 report back on 3rd workshop
15:00 coffee / tea break
15:30 plenary discussion on how to move (research on?) Conservation Agriculture forward in South Africa (or not)
16:30 closing

5th of December 2019:
Optional excursion to Conservation Agriculture trials in the Eastern Free State.

Annex 2 List of participants of the workshop

Organizers:
Linus Franke (University of the Free State)
Henk Wösten (Wageningen University and Research)
Saskia Keesstra (Wageningen University and Research)

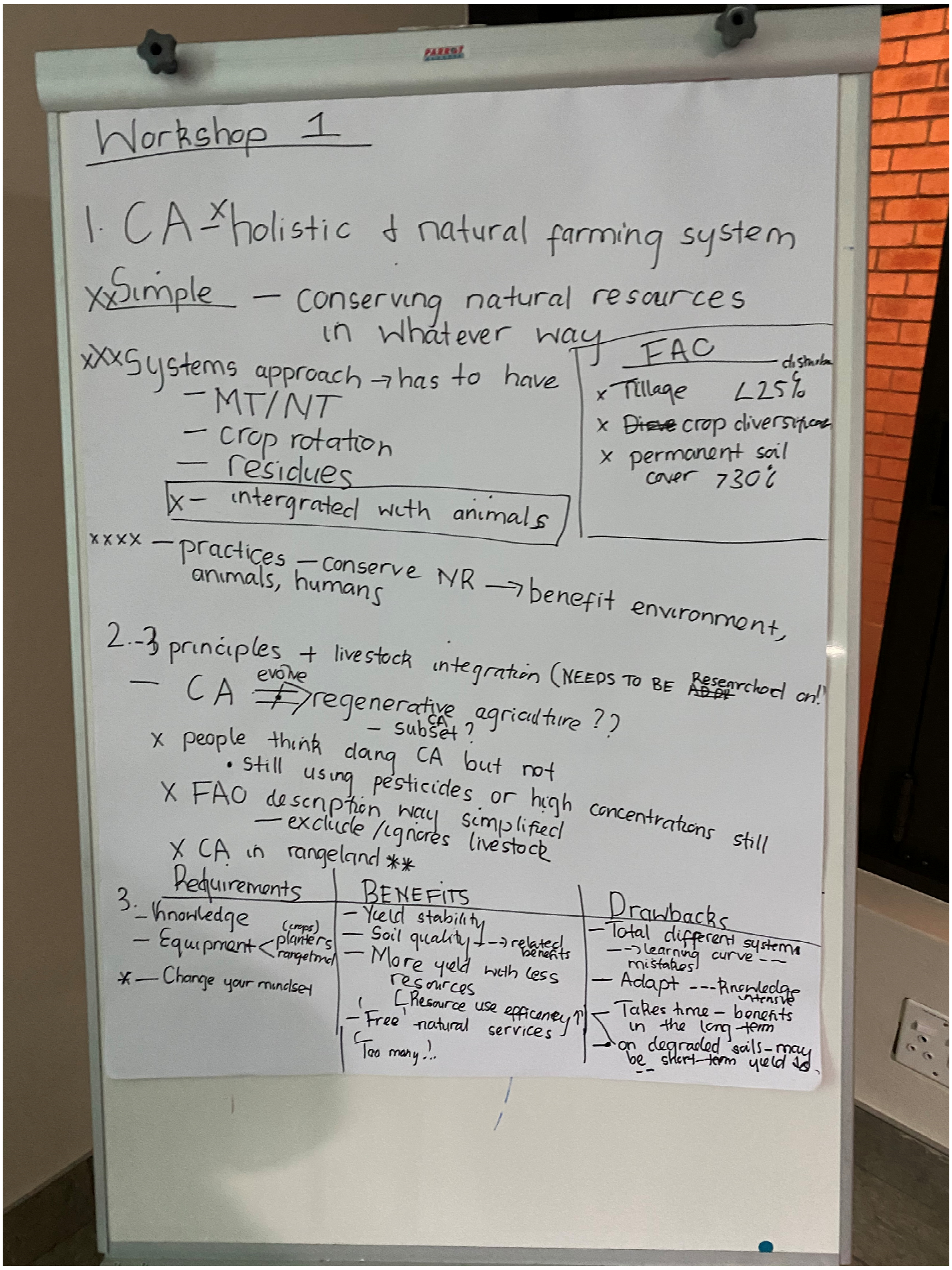
Participants:
Pieter Swanepoel (Stellenbosch University)
Tesfay Aray (University of Forth Hare)
Solomon Beyene (University of Fort Hare)
Jack Vera (NL embassy Pretoria)
Johann Strauss (Department of Agriculture Government of the Western Cape)
Lientjie Visser (ARC Betlehem)
Michael Kidson (ARC Pretoria)
Hendrik Smith (Grain SA)
Danie Slabbert (Farmer)
Gerry Rumen (Farmer)
Phesheya Dlamini (University of Limpopo)
Nester Mashingaidze (University of the Free State)
Neo Mathinya (University of the Free State)
Elmarie Kotze (University of the Free State)

Annex 3 Workshop 1 set up: Perception

Perception and knowledge of Conservation Agriculture in South Africa.
1 hour
15 min plenary reporting back
Questions:

1. What is your definition of Conservation Agriculture?
2. Does the description of CA of FAO match current practices listed as CA in ZA?
3. What are the requirements?
4. What are the benefits?
5. What are the draw backs?

Workshop outcomes on flipovers



Workshop on CA

DAY 1: 03 Dec 2019

Animal integration & cover crops → Makes for a more profitable cover crop.
→ Provides flexibility for the system

* Think of integration levels * within time & space
Regenerative practices

Group Answers: Workshop no: 1 Perception

1: Definition of CA
→ 3 principles with the addition of 2, if the system allows: No till, diversity, cover crop, livestock, crop rotation
key: Area specific management
* Main question → Degree of adoption of these principles
Fertilizers, herbicides → What are the trade offs
→ Soil biology remains the black box

2: Fine as is with a few additions
& Benefits
3: Requirements: Mind shift, technology, time for soil build-up
the knowledge base, no recipies as is area specific

4: Drawbacks: knowledge requirement, soil acidity - lime is immobile
don't be too rigid with the management
→ The why is critical for the implimentation of the how

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Annex 4 Workshop 2 set up: Aspirational targets

Aspirational targets

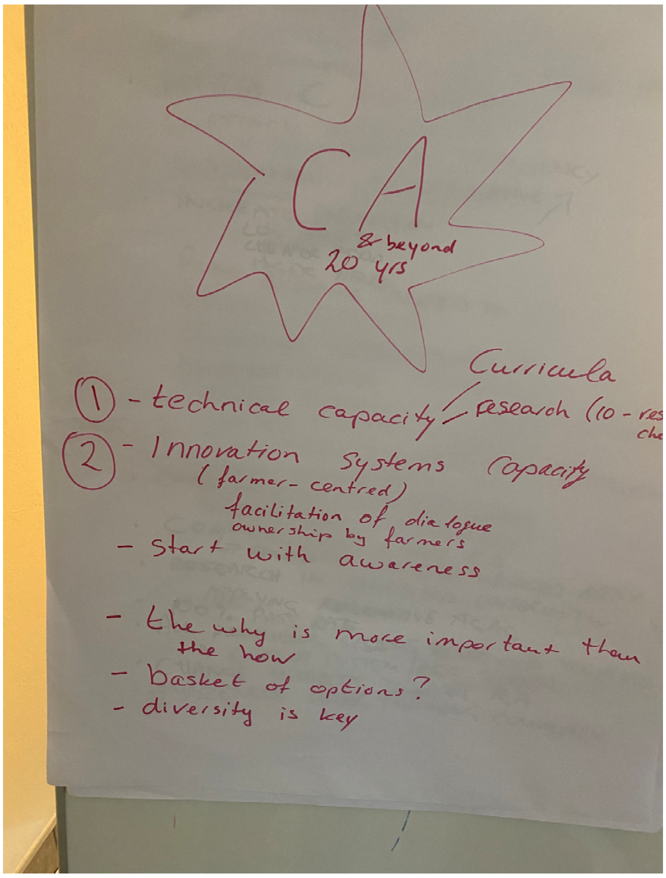
1 hour

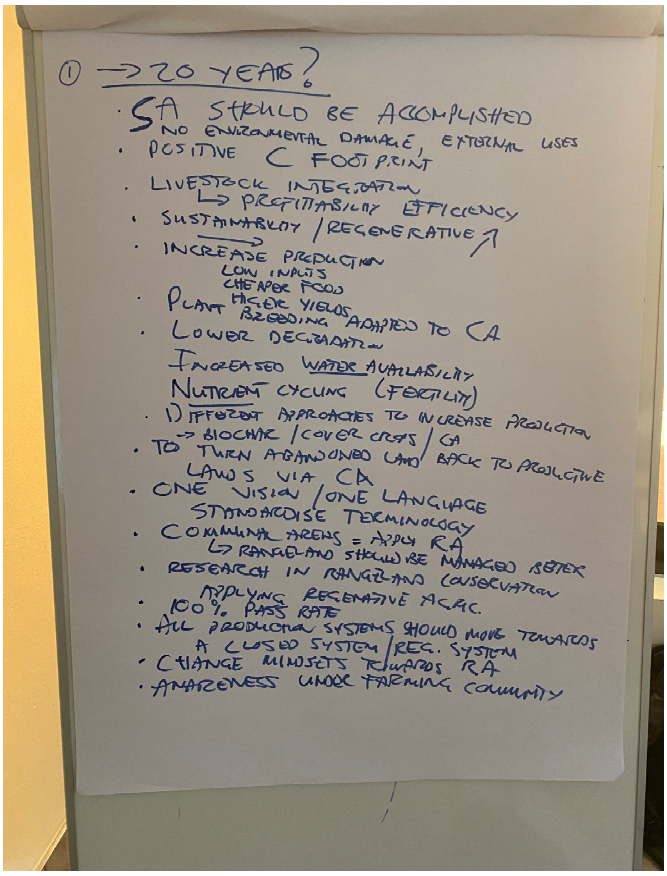
15 min plenary reporting back

Questions:

1. What would you like to have accomplished in terms of sustainable agricultural land use in 20 years?
2. What role do you see for CA in this view
3. How would this lead to better carbon sequestration in soils
4. Which effect would this have on agricultural yield?

Workshop outcomes on flipovers





Annex 5 Workshop 3 set up: barriers and solutions

Barriers and solutions for upscaling Conservation Agriculture in South Africa

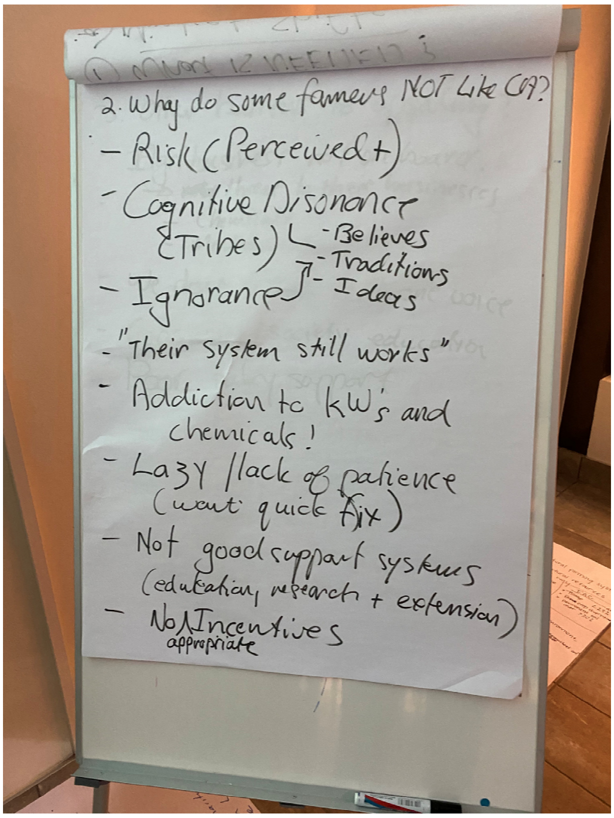
1 hour

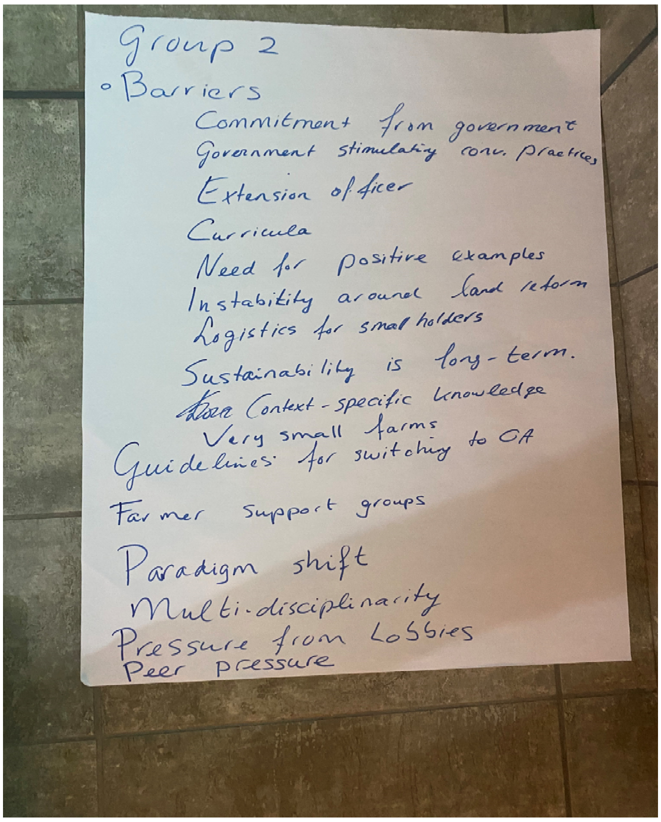
15 min plenary reporting back

Questions:

1. What do you think is needed to implement CA in SA?
2. Why do some farmers not like CA?
3. Which other barriers exist for the upscaling of CA in SA?
4. Which incentives would be necessary to change this situation?

Workshop outcomes on flipovers





Annex 6: Two-pager deliverable published in Agro-berichten

The future of Conservation Agriculture: integrating livestock into farming systems paves the way towards our dot on the horizon: regenerative agriculture

South Africa has a dynamic and active group of farmers, agricultural researchers and extension workers testing and promoting the use of CA principles with farmers being at the centre of the innovation. In the Netherlands, circular agriculture has become a key focus of agricultural development. As agricultural research in both South Africa and the Netherlands is highly developed, there are ample possibilities for joined research projects. Based on a constructive workshop and field visit from December 3-5, 2019 on “The role of soil C in Conservation Agriculture and carbon sequestration in South Africa” the following outline for research on CA has been developed. After a lively workshop in Bloemfontein organised by the university of the Free State (Linus Franke and Nester Mashingaidze) and Wageningen Environmental Research (Saskia Keesstra and Henk Wösten).

Conservation Agriculture (CA) is a farming system that promotes minimum soil disturbance (i.e. no tillage), maintenance of a permanent soil cover, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, which contributes to increased water and nutrient use efficiency and to improved and sustained crop production. The following three principles apply. **1) Minimum mechanical soil disturbance**
(i.e. no tillage) through direct seed and/or fertilizer placement. **2) Permanent soil organic cover** (at least 30 percent) with crop residues and/or cover crops. And **3) Species diversification** through varied crop sequences and associations involving at least three different crops. During the workshop in Bloemfontein, South Africa, from 3-5 December 2019, a fourth principle was identified as being crucial for successful CA implementation, namely: **4) Animal husbandry** which involves including animals (cattle, sheep, chicken) in the system.

Visionary farmer Danie Slabbert (near the village of Reitz) and his ultra-high density grazing system improving soil health, biodiversity, grass quality (veld quality) and income.

Lessons learned in South Africa:
Integrating livestock into crop systems

In the past also in the Netherlands most farms had a mixed farming system, using the manure of the livestock to fertilize the arable fields. Nowadays due to specialization, optimization and heavy regulations most farms

have only arable fields, orchards or livestock. Focusing on circular agriculture it is interesting to look at the way South African farmers are bringing back livestock into their annual cropping system.
In the workshop in South Africa we initially focused on the role conservation agriculture may play in climate mitigation and how these types of measures could be upscaled to large-scale as well as to small-holder farms. In our workshop there was a strong voice to take conservation agriculture to the next level of regenerative agriculture, as the ultimate goal. However, this goal has to be reached in manageable steps.

The main insights from the workshop were:

1. **Economic and environmental sustainability is possible without subsidy**
   In South Africa there is no subsidy system as it exists in Europe. Therefore, any change in the management system made by a farmer must be economically viable. In the opinion of several farmers and representatives of farmers organizations present in the workshop, the best way to reach this goal is to integrate livestock in farming systems. The grazing animals reduce fertilizer input and bring income by selling the meat. Their trampling incorporates into the soil the manure and crop residues they do not eat. This increases soil carbon, soil health and biodiversity, in the soil as well as above.

2. **The transition towards sustainable farming can also be slow: Every step into the direction of sustainability if a good one.**
   The step from conventional farming to regenerative agriculture is a too big a step for most farmers. Therefore intermediate steps need to be promoted too. Because South Africa does not have a subsidy system like in Europe, changing towards healthier food production from an environmental and human health point of view depends on the willingness and vision of each farmer. In our workshop dr. Hendrik Smith from Grain SA explained us the 7 steps towards regenerative agriculture:

Stage	1	2	3	4	5	6	7
Type of farming system	**Conv. tillage**	**Min. or reduced tillage**	**Conv. no tillage (NT)** (Direct seeding equipment using tines). Production system lacks adequate soil cover and sound crop rotations. High use of external inputs	**Conv. zero tillage (ZT)** (Direct seeding equipment using discs). Production system lacks adequate soil cover and sound crop rotations. High use of external inputs	**CA_{HEI}** (NT or ZT using high quantities of external artificial inputs (i.e. fertilizer, herbicides, pesticides). Production system has adequate soil cover and sound crop rotations.	**CA_{LEI}** (NT or ZT using low quantities of external artificial inputs (i.e. fertilizer, herbicides, pesticides). Production system has adequate soil cover and sound crop rotations.	**Regen Agric** (ZT using very little or no external artificial inputs (i.e. fertilizer, herbicides, pesticides). Production system has adequate soil cover and sound crop rotations.

Farmers adapting to more sustainable systems

3. **Vision and love for the land: a good farmer is a steward of the land.**
   Most famers love their land, but may be caught in a socio-economic trap by doing as their fathers or as their neighbors. Alternative strategies that are holistic, local and custom made are needed to move into the right direction while being in reach of the farmers context. Narratives are needed to gain trust

and to show that regenerative agriculture is a reachable a dot on the horizon for all. Hands-on tools and knowledge should be provided enabling farmers to earn a good living from their land in a sustainable way while being respected in their community.

4. **Ways to find hands-on local, but holistic solutions for every farm**. Typically these solutions will be developed in collaboration with farmers making it possible to serve public goals such as climate change mitigation through carbon sequestration in soils and biodiversity restoration; while ensuring a good livelihood for the farmer.

ANNEX 7: Landbou berichten

LBW **BOEREPLAN** JOHAN NORVAL jnorval@landbou.com

Boerenavorsing kry broodnodige buitelandse steun

Drakensbergers van mnr. Danie Slabbert, wat in 'n ultrahoëdrukbeweidingstelsel op sy plaas, Van Rooyenswoning, by Reitz gebruik word om die biodiversiteit van sy weiveld te verbeter. Dit is ook 'n manier om van Suid-Afrika se ergste indringerplante nek om te draai. FOTO: JOHAN NORVAL

Suid-Afrikaanse boere is navorsers ver vooruit wat herlewingslandbou betref. Akademiese steun is egter nodig, en groter samewerking tussen Suid-Afrika en Nederland is 'n belangrike ontwikkeling in die proses om die spoor van dié benadering te vergroot.

LIGGING
Bloemfontein, Vrystaat

Vee wat by boerderystelsels ingeskakel word, baan die weg vir boere om die beginsels van bewaringslandbou toe te pas en uiteindelik na herlewingslandbou oor te skakel.

Prof. Linus Franke van die Universiteit van die Vrystaat sê Suid-Afrika het 'n dinamiese groep boere, landbounavorsers en voorligters wat die beginsels van bewaringslandbou beproef. Praktiese boere staan aan die spits van dié vernuwing.

Franke en ander lede van 'n belangegroep het ná 'n werksessie in Bloemfontein oor die rol van koolstof in die grond en koolstofneerlegging in bewaringslandbou die insluiting van veeteelt as 'n vierde beginsel vasgestel wat onontbeerlik vir bewaringslandbou is. Dit behels die insluiting van onder meer beeste, skape en pluimvee in 'n plaasstelsel.

Volgens Franke val die klem op kringloopstelsels (*circular agriculture*) in die benadering van landbou-ontwikkeling wat tans baie aandag in Nederland geniet.

Drr. Saskia Keesstra en Henk Wösten, omgewingsnavorsers aan die Universiteit van Wageningen in Nederland, was twee van die buitelandse deelnemers. Volgens hulle is daar voldoende moontlikhede om gesamentlike navorsingsprojekte aan te pak, aangesien landbounavorsing in Suid-Afrika en Nederland op 'n hoë peil gedoen word.

"Bewaringslandbou is 'n stelsel wat die minste meganiese grondversteuring vereis, asook die handhawing van permanente grondbedekking van minstens 30% oesreste of dekgewasse en 'n verskeidenheid plantsoorte van minstens drie oesgewasse," het Franke gesê. "Daarvolgens word die biodiversiteit en natuurlike biologiese prosesse bogronds bevorder, wat bydra tot die doeltreffender benutting van water en voedingstowwe."

Volgens Franke is dit duidelik dat diereprodukte 'n baie groter koolstofspoor as plantaardige produkte het.

Die bespreking op die werksessie het ook op bewaringslandbou gekonsentreer. Daar is spesifiek gepraat oor hoe goeie weidingsbestuur kan meehelp om landbougrond te verander van 'n bron van koolsuurgas tot 'n opbergplek daarvan.

LESSE IN SUID-AFRIKA GELEER

1. Skakel lewende hawe by gewasstelsels in. Volgens Keesstra was Nederland in die verlede ook bekend vir sy gemengdeboerderystelsels waar dieremis as bemesting in landerye gebruik is. Deesdae het dié gebruik verval. Dit kan toegeskryf word aan spesialisasie, die optimale benutting van hulpbronne en streng regulasies wat meebring dat die meeste plase net oor bewerkbare landerye, boorde of lewende hawe beskik.

"Suid-Afrikaanse boere se praktyk om lewende hawe by hul jaarlikse gewasverbouing in te skakel, is 'n interresante benadering," het Keesstra gesê.

Bewaringslandboupraktyke kan aangepas word om uiteindelik oor 'n wye front in herlewingslandbou toegepas te word. "Dié doelwit kan in hanteerbare fases bereik word."

2. Volhoubaarheid kan sonder subsidies bereik word. Suid-Afrikaanse boere kan nie soos hul Europese eweknieë op landbousubsidies staatmaak nie.

Enige aanpassing in 'n bestuurstelsel moet dus ekonomies lewensvatbaar wees. Dié doelwit kan die beste verwesenlik word deur lewende hawe in boerderye in te skakel.

Só het mnr. Danie Slabbert, boer van Reitz en lid van die Riemland-studiegroep gesê. Die herkouers se mis verminder die behoefte aan kunsmis en die rooivleisproduksie verbeter die boer se kontantvloei. Die hoefaksie van die diere vermeng die mis en oesreste in die grond, wat op sy beurt tot verhoogde grondkoolstofvlakke, grondgesondheid en bo- en ondergrondse biodiversiteit lei.

3. Elke stap na volhoubaarheid is 'n stap in die regte rigting. Die oorgang van konvensionele boerderypraktyke na herlewingslandbou is volgens die Nederlandse waarnemers 'n uitgerekte proses en 'n té groot stap vir die meeste boere. Tussentydse stappe moet dus ook bevorder word. "Aangesien Suid-Afrika nie soos in Europa op subsidies kan steun nie, hang die oorgang na die verbouing van gesonder voedselprodukte en 'n verbetering in die gesondheid van die verbruikers af van die bereidwilligheid en visie van elke boer."

Van links is dr. Johann Strauss (Wes-Kaapse departement van landbou), prof. Linus Franke (Universiteit van die Vrystaat), drr. Saskia Keesstra en Henk Wösten (Universiteit van Wageningen, Nederland) en mnr. Danie Slabbert (Riemland-studiegroep, Reitz). FOTO: JOHAN NORVAL

4. 'n Goeie boer is die rentmeester van sy grond. Die meeste boere koester hul liefde vir die grond, maar kan ook in 'n maatskaplik-ekonomiese draaikolk vasgevang word deur hul voorgangers en bure na te volg. Alternatiewe strategieë wat holisties en in plaaslike toestande ontwikkel en verfyn is, is nodig om te wys dat almal herlewingslandboupraktyke kan toepas.

"Oplossings moet saam met boere opgestel word om onder meer klimaatsverandering te stuit deur die neerlegging van grondkoolstof en 'n beter biodiversiteit, terwyl die boer steeds 'n goeie bestaan kan voer," het Keesstra gesê.

Sy het gesê 'n stelselbenadering moet gevolg word om volhoubare omgewingbestuur te laat slaag. "Nie net die omgewing en grondgesondheid moet beskerm word nie. Dit behels ook maatskaplik-ekonomiese interaksie met mense wat die grond bewoon. As wetenskaplikes weet ons reeds baie van omgewingsbestuur vanuit 'n biofisiese perspektief, maar meer aandag moet aan 'n maatskaplike benadering gegee word om die volhoubare ontwikkelingsmikpunte aan mense oor te dra."

Mnr. Jack Vera, landbou-attaché by die Nederlandse ambassade, het samewerking tussen Nederland en Suid-Afrika bepleit om die vakkundige kennis en toepassing daarvan ten bate van verbeterde omgewingsbestuur te verbeter. "Een van die belangrike aspekte daarvan is die verbetering van die grondgehalte. Die onderskeie wetenskaplikes kan maklik saamwerk, maar die toepassing daarvan is nog belangriker."

Een van die oogmerke wat op die werksessie geopper is, is die instelling van 'n gesamentlike navorsingsprojek waarby belangegroepe en beleggers uit albei lande betrokke sal raak. LBW

NAVRAE: Prof. Linus Franke, e-pos: FrankeAC@ufs.ac.za; 051 401 2212.

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