Making Climate Change Mitigation and Adaptability Real in Africa with Conservation Agriculture

Technical Report · October 2018

DOI: 10.13140/RG.2.2.32722.20161

14 authors, including:

Emilio J. Gonzalez-Sanchez
University of Cordoba (Spain) - AEACSV - ECAF

Saidi Mkomwa
African Conservation Tillage Network (ACT)

Amir Kassam
University of Reading

Rafaela Ordóñez-Fernández
Institute of Agricultural Research and Training (IFAPA)

Making Climate Change Mitigation and Adaptability Real in Africa with Conservation Agriculture

Making Climate Change Mitigation
and Adaptability Real in Africa
with Conservation Agriculture

Authors: Emilio J. González Sánchez[1&2]; Saidi Mkomwa[3]; Gordon Conway[4]; Amir Kassam[2&3]; Rafaela Ordóñez-Fernández[5]; Manuel Moreno-García[5]; Miguel Repullo Ruibérriz de Torres[5]; Jesús A. Gil-Ribes[1]; Gottlieb Basch[2]; Oscar Veroz-González[2]; Paula Triviño-Tarradas[1&2]; Antonio Holgado-Cabrera[2]; Antonio Miranda-Fuentes[1]; Rosa M. Carbonell-Bojollo[5]

1. ETSIAM, Universidad de Córdoba, Spain
2. European Conservation Agriculture Federation
3. African Conservation Tillage Network
4. Imperial College London, United Kingdom
5. IFAPA, CAPDER, Junta de Andalucía, Spain

ISBN: 978-84-09-05609-5

INDEX

1. EXECUTIVE SUMMARY

2. CLIMATE CHANGE

3. AGRICULTURE AND CLIMATE CHANGE

4. CORE PRINCIPLES OF CONSERVATION AGRICULTURE

1
Executive summary

In this report, the authors have gathered essential information on how the agricultural sector can respond to climate change through Conservation Agriculture (CA). This document aims to serve as a basis for decision-making based on science and agricultural experimentation in Africa.

Climate change in Africa

There is a need to eradicate hunger and food insecurity in this world including in Africa and a sustainable intensification of agriculture, with a focus on soil and water conservation, is part of the solution. For many developing countries, the main concern regarding agriculture relates to food security, poverty alleviation, economic development and adaptation to the potential impacts of climate change.

Africa has been the lowest source of greenhouse gas emissions (GHG) in the world, however, is the most vulnerable continent to the impacts of climate change. The Intergovernmental Panel on Climate Change (IPCC) has alerted that temperatures across Africa are expected to increase by 2-6 °C within the next 100 years. The effects of climate change will not be limited to a rising average temperature and changing rainfall patterns, as it is expected an increasing severity and frequency in droughts and floods, and also a reduction in food production. Around 90% of people in Africa depend on agriculture for their livelihoods.

Agriculture is the region's second highest GHG emitting sector. The strong link between agricultural soils and climate change might not be evident, but it certainly exists Soils are an important pool of active carbon and play a major role in the global carbon cycle and have contributed to changes in the concentration of GHGs in the atmosphere. How agricultural soils are managed has a direct effect on climate change.

It has been estimated that over the last 100 years, soil tillage may be primarily responsible for a 30–50% decrease in soil carbon worldwide. Tillage affects the soil carbon content directly by soil fracturing, which facilitates movement of carbon dioxide out of the soil immediately after cultivation; and indirectly by altering soil aggregation leading to reduced carbon adherence to clay surfaces and increased organic matter oxidation, and by accelerating carbon loss through water and wind erosion.

Conventional farming globally is based on soil tillage, which promotes the mineralization of soil organic matter whilst increasing the release of CO_2 into the atmosphere due to carbon oxidation. Also, tillage operations can incorporate plant crop residues into soil layers where microorganisms and moisture conditions favour their decomposition and thus more carbon oxidation. Moreover, soil tillage physically breaks down soil aggregates and leaves them exposed to the action of soil microorganisms which were encapsulated and thus protected within the soil aggregates that existed prior to the performance of tillage.

Another consequence of intensive tilling processes is the higher emissions of CO_2 into the atmosphere, both in short-term (immediately after tillage) and long-term (during the crop season). This is because the tillage stimulates the production and accumulation of CO_2 in the porous structure of the soil through processes of oxidation and mineralization of organic matter. The mechanical action of the tillage involves a breakdown of the soil aggregates, with the consequent release of CO_2 trapped inside the soil and its subsequent emission into the atmosphere. Conversely, a proper soil management is one of the best tools for climate change mitigation and adaptation.

Conservation Agriculture, three principles

Conservation Agriculture (CA) is one of the most studied and most developed agro-sciences in the world. FAO defines Conservation Agriculture as an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterised by the practical application of three linked principles, along with other complementary good agricultural practices of crop and production management, namely:

It has been estimated that over the last 100 years, soil tillage may be primarily responsible for a 30–50% decrease in soil carbon worldwide.

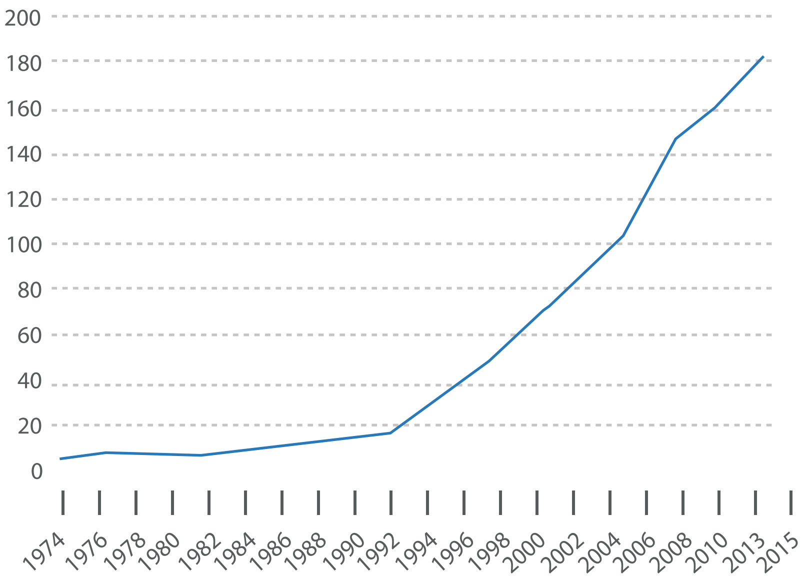


Figure 1.
Evolution of the adoption of Conservation Agriculture worldwide.

1. Principle 1: Continuous no or minimal mechanical soil disturbance (implemented by the practice of no-till seeding or broadcasting of crop seeds, and direct placing of planting material into untilled soil; no-till weeding and causing minimum soil disturbance from any cultural operation, harvest operation or farm traffic);

2. Principle 2: Maintenance of a permanent biomass soil mulch cover on the ground surface (implemented by retaining crop biomass, root stocks and stubbles and cover crops and other sources of ex-situ biomass); and

3. Principle 3: Diversification of crop species (implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, including a balanced mix of legume and non-legume crops).

Conservation Agriculture is not a single technology but a systems approach to farming based on a set of linked complementary practices that should be implemented in combination with other good technologies and practices by the farmers in order to obtain full benefits. These practices cover a large range of expertise from equipment and machinery to soil management, residue management and cover crops to pest and diseases management to nutrient and water management including crop and cropping system management.

Africa faces unprecedented challenges for food security. It is estimated that production should increase by 70% as a whole, but 100% in developing areas, in order to feed its population in the year 2050. Conservation Agriculture is a holistic system that complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, conform the basis for sustainable

agricultural production intensification, able to save resources along with conserving the environment.

Adoption of Conservation Agriculture in Africa and worldwide

Conservation Agriculture crop production systems are popular worldwide. There are few countries where CA is not practised by at least some farmers and where there are no local research results about CA available. The total cropland area under CA in 2008/09 was estimated to be 106 M ha, whereas the latest global estimate for CA cropland reported for 2015/16 is about 180 M ha.

Conservation Agriculture systems help Africa's resource-poor farmers to maintain subsistence with sustainability, so as to meet the challenges of climate change, high energy costs, environmental degradation, and labour shortages. Conservation Agriculture has been shown to be relevant and appropriate for small and large scale farmers at all levels of farm power and mechanization, from manually-operated hand tools to equipment drawn by animals to operations performed by heavy machinery.

Farmers in almost 20 African countries are promoting and supporting CA, including in Algeria, Ghana, Kenya, Lesotho, Madagascar, Malawi, Morocco, Mozambique, Namibia, South Africa, Sudan, Swaziland, Tanzania, Tunisia, Uganda, Zambia and Zimbabwe. CA has also been incorporated into the regional agricultural policies, and increasingly, has been 'officially' recognized as a core element of climate-smart agriculture.

Country	CA area 2008/09	CA area 2013/14	CA area 2015/16
South Africa	368.00	368.00*	439.00
Zambia	40.00	200.00	316.00
Kenya	33.10	33.10*	33.10#
Zimbabwe	15.00	90.00	100.00
Sudan	10.00	10.00*	10.00#
Mozambique	9.00	152.00	289.00
Tunisia	6.00	8.00	12.00
Morocco	4.00	4.00	10.50
Lesotho	0.13	2.00	2.00
Malawi	-	65.00	211.00
Ghana	-	30.00	30.00#
Tanzania	-	25.00	32.60
Madagascar	-	6.00	9.00
Namibia	-	0.34	0.34#
Uganda	-	-	7.80
Algeria	-	-	5.60
Swaziland	-	-	1.30
Total	**485.23**	**1,235.34**	**1,509.24**
Difference %		**154.6 since 2008/09**	**211.0 since 2008/09 22.2 since 2013/14**

*from 2008/09 update; # from 2013/14 update

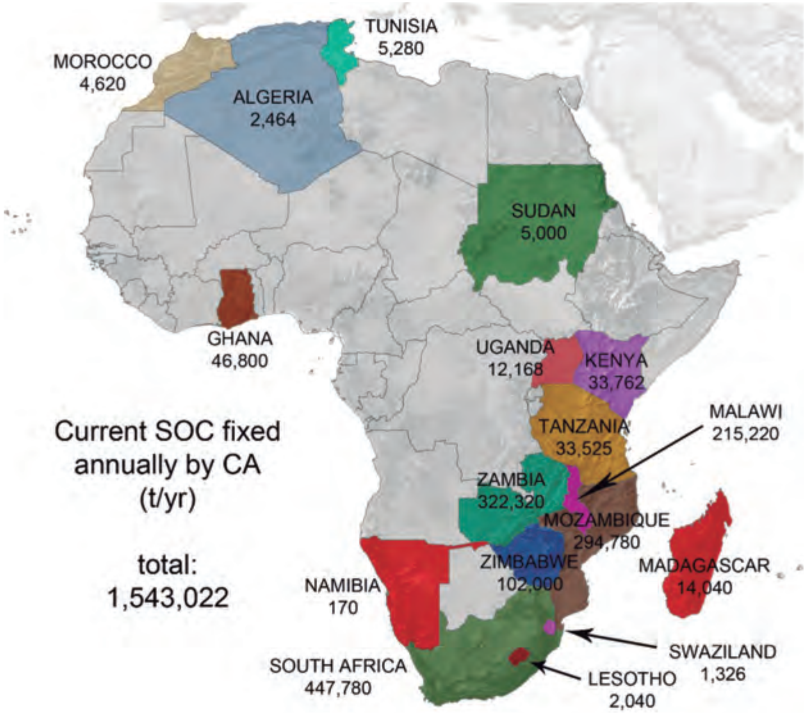
Table 1.
Extent of CA adoption ('000 ha) in Africa in the 2008/09, 2013/14 and 2015/16 updates.

Conservation Agriculture is Climate Smart Agriculture

There are many factors involved in the release of GHG emissions from agricultural soil, such as: type of soil management, soil organic matter, degree of soil mechanical disturbance through tillage and soil temperature and moisture conditions at the time of its release, crop phenological stage, weather conditions, biomass management, among others. In the long-term, the interactions among these factors seem to determine the balance of CO_2 emissions.

Numerous scientific studies confirm that soils are an important pool of active carbon, and play a major role in the global carbon cycle. Since soils occupy about 30% of the global surface area, a major shift from tillage-based farming to climate-smart systems, such as CA, would have a significant impact on global climate and food security.

Figure 2.
Current soil organic carbon (SOC) fixed annually by CA cropland systems compared to systems based on tillage agriculture in Africa.



Average rates of carbon sequestration by CA in agricultural soils for each climatic zone in Africa are presented in Table 1. The total carbon sequestration estimated for the whole of Africa, of 1,543,022 t C yr^{-1} is shown in Figure 2. On average, the carbon sequestered for Africa due to CA is thus around 1 t C ha^{-1} yr^{-1}, corresponding to a total amount of 5,657,747 t CO_2 yr^{-1}. This relatively high figure is because degraded soils are 'hungry' for carbon, as the degradation caused by years of tillage and crop biomass removal has resulted in a drastic reduction of soil's organic matter. However, the increase of C is not permanent in time, and after a number of years, a plateau is reached. The time to reach the plateau is considerable, and may take over 10-15 years before a deceleration in the rate of carbon increase is observed. Therefore, even if after 10-15 years C sequestration rates are lower, carbon is still being captured in the soil, which supports the value of long-term engagement with CA. Also, even when top soil layers may be reaching plateau levels, deeper soil layers continue to sequester C through the action of earthworms and biomass provided by deeper root systems.

In Figures 3 and 4, the potential area that could be shifted from conventional tillage agriculture to CA is presented, for both annual and permanent crop systems.

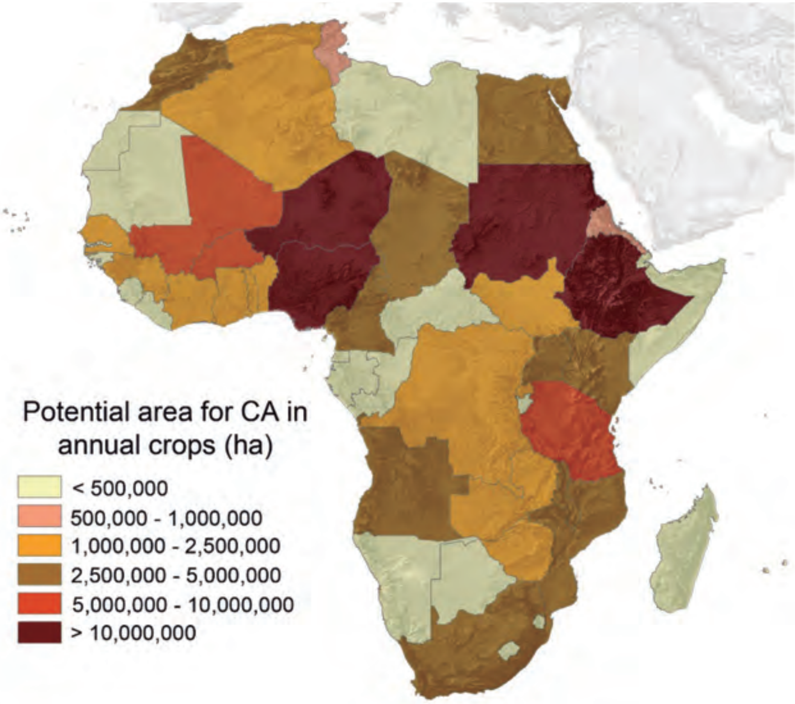


Figure 3.
Potential application surface of CA in annual crops in Africa in 2016.

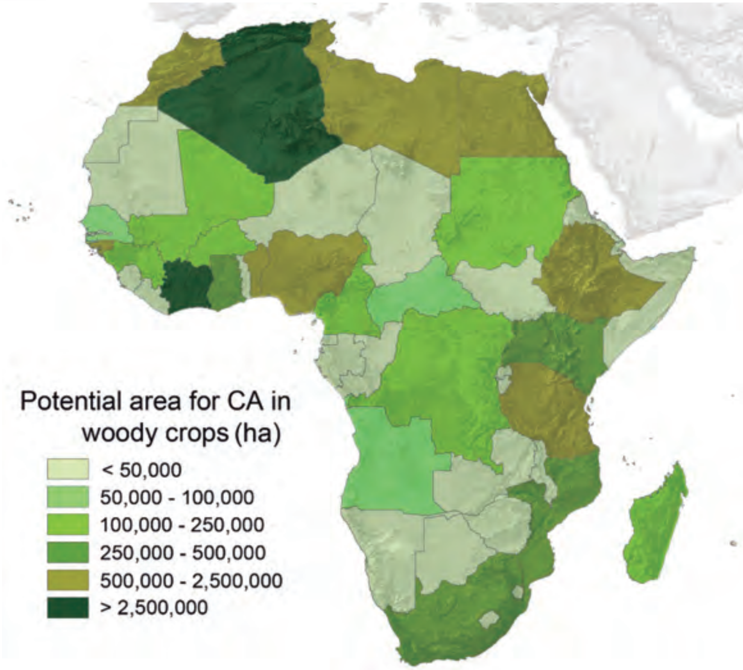


Figure 4.
Potential application surface of groundcovers in woody perennial crops in Africa in 2016.

Table 2.
Carbon sequestration rates in Conservation Agriculture (CA) for each climatic zone.

	Carbon sequestration rate for CA in annual crops (t ha-1 yr-1)	Carbon sequestration rate for CA in woody crops (t ha-1 yr-1)
Mediterranean	0.44	1.29
Sahel	0.50	0.12
Tropical	1.02	0.79
Equatorial	1.50	0.26

Multiplying the rates of C sequestration presented in Table 2 by the potential areas per country and per type of crop (Figures 3 and 4) permits estimates of the potential carbon sequestration following the application of CA in the agricultural lands of Africa. Where more than one climate affects a single country, the climate of the major cropping area has been selected, i.e. Algeria's rate of C sequestration

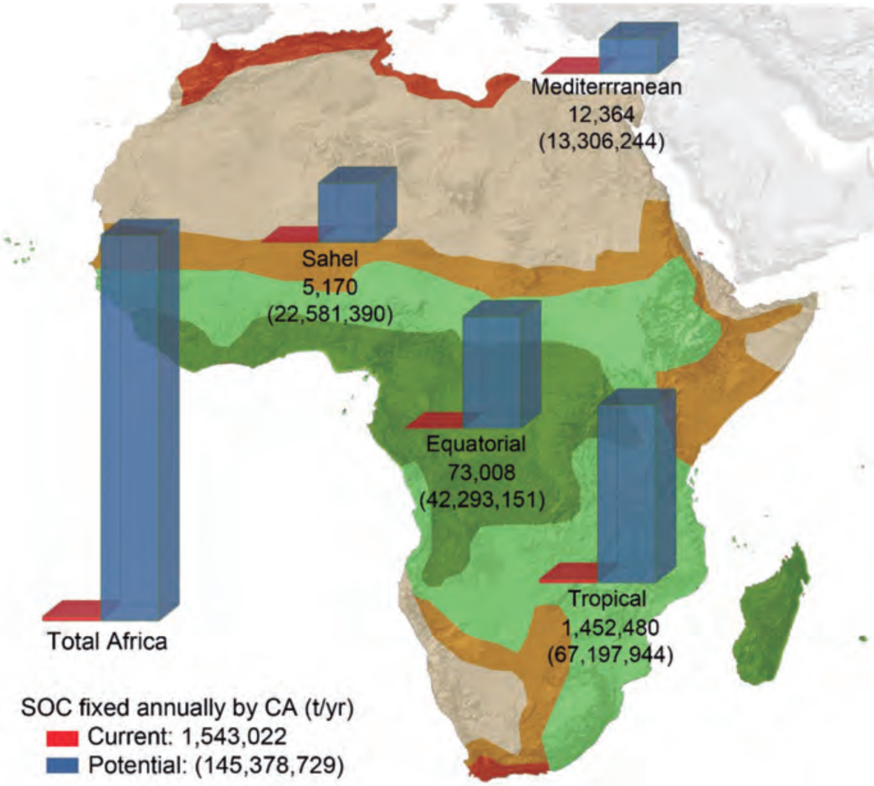


Figure 5.
Potential soil organic carbon (SOC) fixed annually by CA cropland systems compared to systems based on tillage agriculture in Africa.

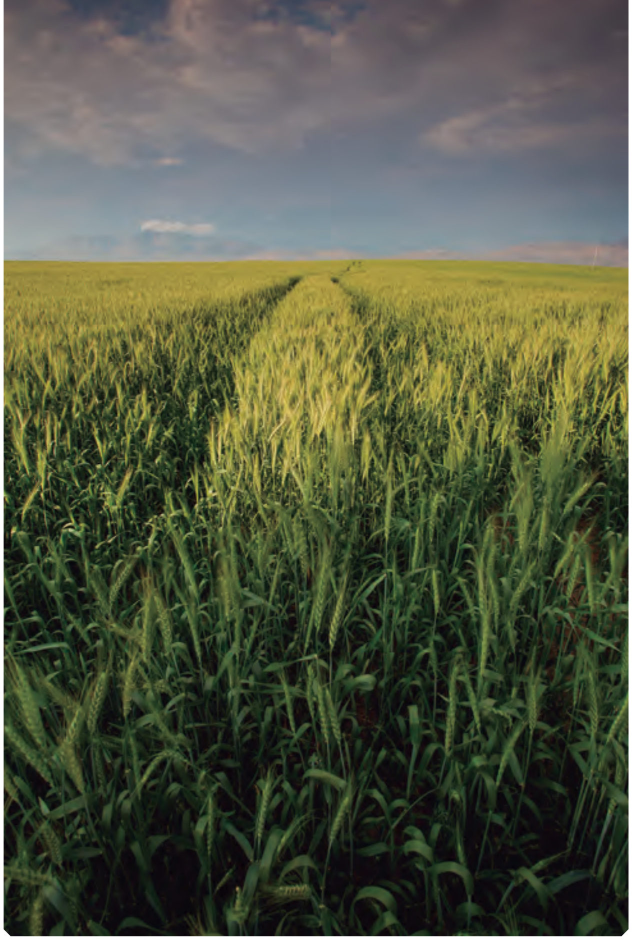
has been that of the Mediterranean, as most of its cropland is affected by that climate. In cases where there were two co-dominant climates, two rates of C sequestration have been applied.

Finally, Figure 5 shows the total amount of potential carbon sequestration for Africa, for each climatic region, with respect to current carbon sequestration status. In total, the potential estimate of annual carbon sequestration in African agricultural soils through CA amounts to 145 M t of C per year, that is 533 M t of CO_2 per year. This figure represents about 95 times the current sequestration rate. To put this figure into context, according to the United Nations Framework Convention on Climate Change, South Africa, the world's 13th largest CO_2 emitter, national emissions by 2025 and 2030 will be in a range between 398 and 614 M t CO_2–eq per year.

Currently, the total amount of African carbon sequestration due to CA adoption of 1.5 M ha is over 5.6 M t CO_2 yr^{-1}. The potential effect of the application of CA on carbon sequestration is to increase this to 533 M t of CO_2 per year, nearly a 100 times greater.

Conservation Agriculture is thus more than a promising sustainable agricultural system, as it can effectively contribute to mitigating global warming, being able to offset agricultural CO_2 emissions.

Therefore, not only it is important to adopt strategies to mitigate phenomena which increase climate change, but it is also necessary to adopt practices which increase the resilience of agricultural ecosystems to be able to deal more easily with the consequences of global warming, and which favour the adaptation of crops to the new climatic scenarios predicted by the atmospheric circulation models.



Adaptation strategies must be related to the expected changes according to the considered climatic zone because the measures that can be adopted in a region of arid and semiarid zone will be different from those adopted in the equatorial zone. Adaptation means looking for strategies at the local level to respond to a global problem. The options for adapting crops to the scenarios caused by climate change will increase the resilience of the ecosystems in which they are developing.

Figure 6. Possible actions to increase the resilience of agrarian ecosystems and agricultural techniques whose application involves adaption of these actions.

	WATER	SOIL	BIODIVERSITY	CROPS
Actions to increase resilience	Increase infiltration Reduce runoff Optimization of water use Improvement of soil water balance	Reduced runoff Increase in Organic Carbon Improvement of structure Increase soil fertility	Increase in the epigeal fauna Improvement of conditions for the habitability of steppe birds Increase in pollinating species	Increase resistance to drought Escape from water stress Reduction of weed invasion Reduce incidence of pests and diseases
Conservation Agriculture practices	**Conservation Agriculture**	**Conservation Agriculture**	**Conservation Agriculture**	**Crop rotation**
Another agricultural techniques	Deficit irrigation Precision farming Improvement of irrigation Green filters Multifunctional margins	High flotation tires Soil health cards	Use of integrated fighting Green filters Multifunctional margins	Use of varieties resistant to drought Advancement of planting date Use of native varieties Crop cycle variation

The adoption and development of Conservation Agriculture practices lead to a number of benefits in the water supply system within the agricultural ecosystems, such as greater availability of this resource for the crop and improvement of its quality.

Thus adaptation of soil management to climate change will entail increasing the infiltration capacity of the soil, increasing water holding capacity, improving soil structure and conditions for soil fauna and flora, thereby increasing natural soil fertility.

Soil biodiversity plays a key role in fertility, nutrient absorption by plants, biodegradation processes, the elimination of hazardous compounds and natural

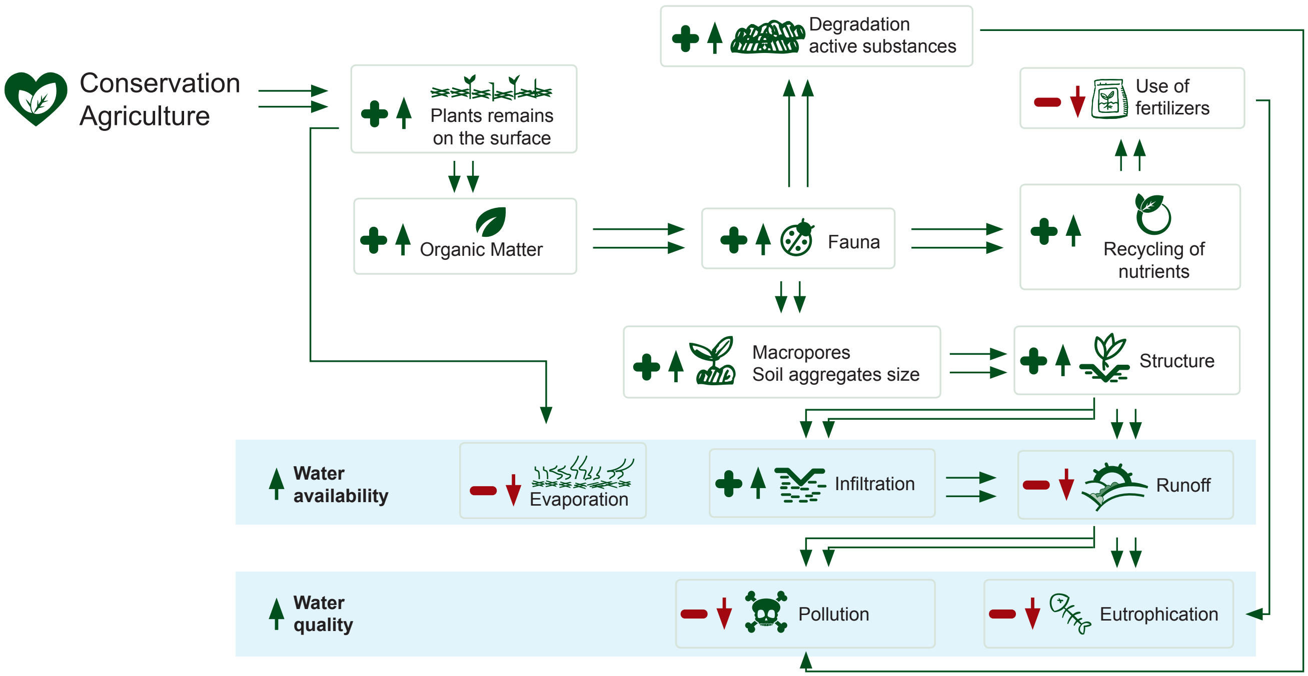


Figure 7.
Conservation Agriculture processes related to water benefits.

pest control. In other words, richer and more biologically diverse soils have a greater capacity to respond to extreme phenomena resulting from climate change that can worsen their degradation, such as the incidence of heavy precipitation, temperature increase or the geographical displacement of pests and diseases, among others.

One of the environmental benefits of the adoption of CA practices for agrarian ecosystems is the improvement of biodiversity in them in general, and in the soil in particular. Thus, under soil conservation practices, soil biota is enriched, allowing better recycling of nutrients and helping to control pests and diseases.

Conservation Agriculture, a sustainable intensification of agriculture

Conservation Agriculture not only brings benefits for the optimized management of water and soil moisture,

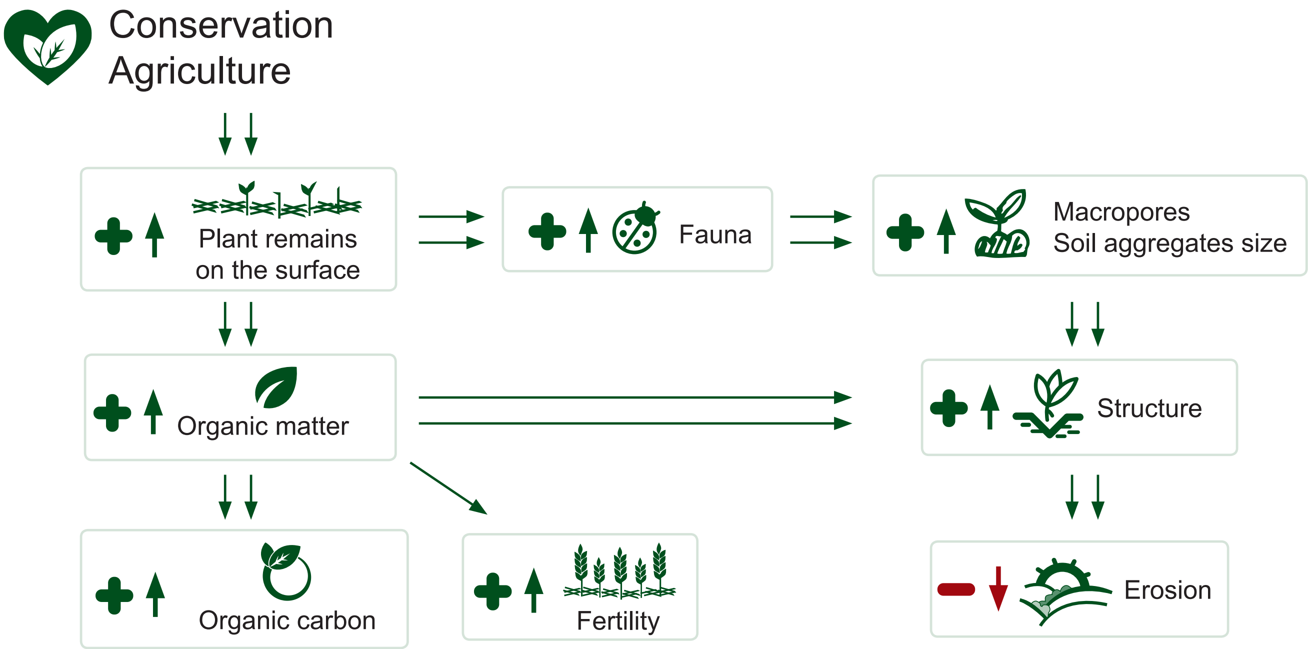


Figure 9.
Conservation Agriculture processes related to soil benefits.

but it also offers other advantages that help the agrarian ecosystem to be more and better prepared for the climatic scenarios caused by global warming, and, therefore, to be more sustainable. The rotation and diversification of crops promoted by Conservation Agriculure increases the resilience of the agricultural ecosystem, improving the soil properties in general, while increasing the crop potential to obtain higher yields

In general, CA benefits can include: increased factor productivities and yields (depending on prevailing yield levels and extent of soil degradation); up to 70% decrease in fuel energy or manual labour; up to 50% less fertiliser use; 20% or more reduction in pesticide and herbicide use; some 30% less water requirement; and reduced cost outlay on farm machinery.

Conservation Agriculture is a new paradigm of agriculture. It is referred to as being regenerative because it has many self-protective and self-repair features, and CA rehabilitates scarce resources (soil, water and biological) whilst optimising external inputs and preventing soil degradation. All these features contribute to climate change mitigation and adaptability while maximizing sustainability of production.

2
Climate Change

Introduction

Greenhouse gas emissions (GHG) occur naturally in the Earth's atmosphere. However, the atmospheric concentrations of carbon dioxide, methane and nitrous oxide have increased significantly since the industrial revolution began. In the case of carbon dioxide, the average concentration has risen from 316 parts per million (ppm) in 1959 to 403 ppm in 2016 (WMO, 2018). As well, since the 1970s, carbon dioxide emissions have increased by about 90%, with emissions from fossil fuel combustion and industrial processes contributing about 78% of the total greenhouse gas emissions (GHG) increase from 1970 to 2016 (EPA, 2016).

The impact of human activities, such as the burning of fossil fuels, are increasing the levels of GHG's in the atmosphere, causing global warming and climate change. This fact is reflected by many pieces of evidence. The year 2017 was characterized by warmer-to much-warmer-than-average conditions across much of the globe's land and ocean surfaces. Record warmth was observed across the globe, including Africa. Averaged separately, the global land surface temperature was 1.31°C (2.36°F) above the 20th-century average and also the third highest in the 138-year record, behind 2016 (warmest) and 2015 (second warmest). The global oceans also had their third warmest year since global records began in 1880 at 0.67°C (1.21°F) above the 20th-century average.

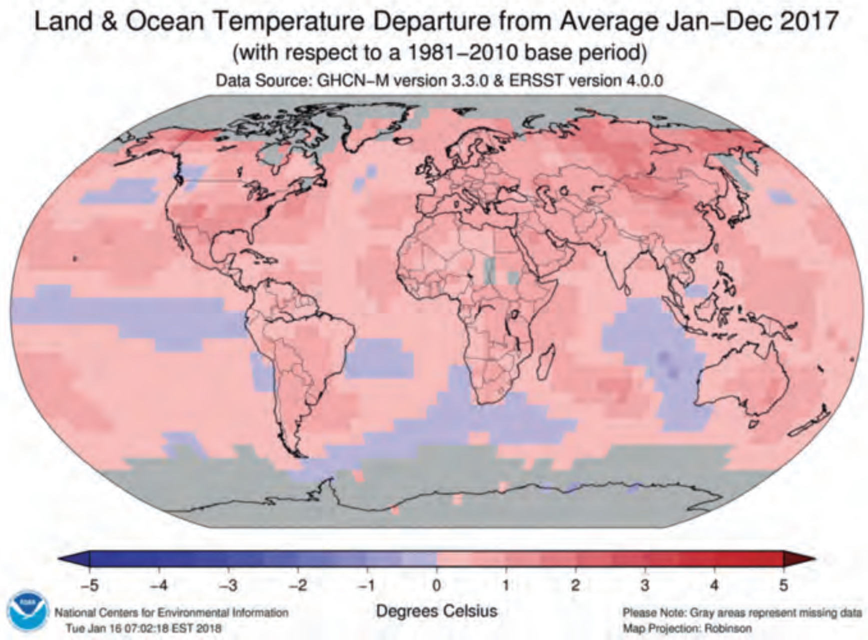


Figure 2.1.
Land and ocean temperature from average 2017. Source: NOAA, 2018.

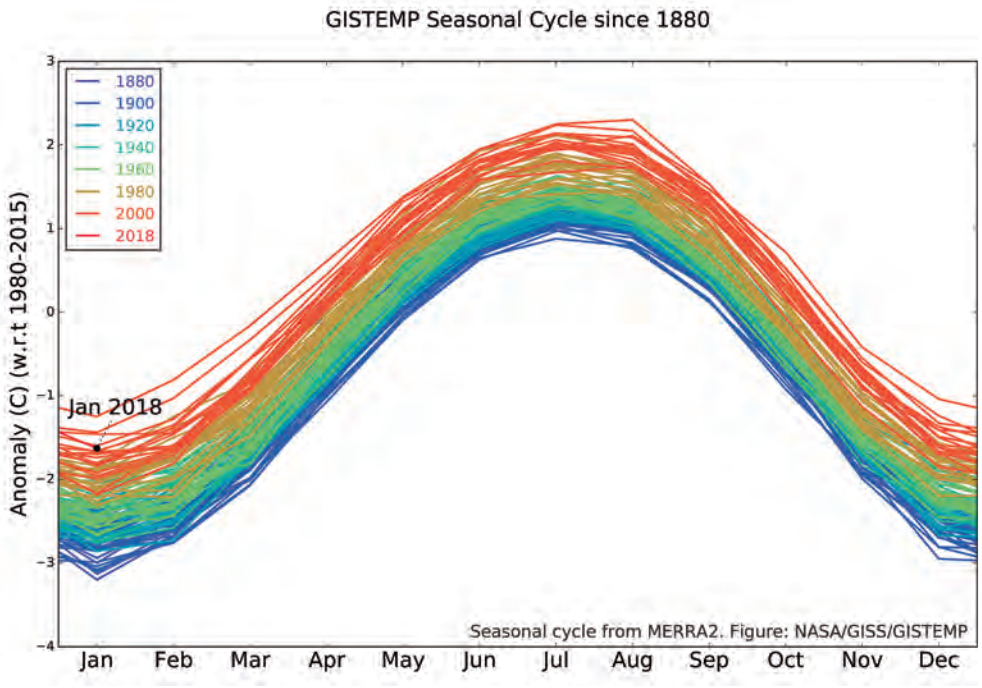


Figure 2.2
The GISTEMP monthly temperature anomalies superimposed on a 1980-2015 mean seasonal cycle. Source: NASA GISS (2018)

Africa is the most vulnerable continent to the impacts of climate change.

The year 2018 started with another record, as January 2018 was the fifth warmest January in 138 years of modern record-keeping, according to a monthly analysis of global temperatures by scientists at NASA's Goddard Institute for Space Studies (GISS) in New York (Figure 2.2).

By 2020, models project that Earth's surface temperature will be more than 0.5°C (0.9°F) warmer than the 1986-2005 average, irrespective of the emissions. This would be due to oceans, as the high heat capacity of water means that ocean temperature doesn't react instantly to the increased heat being trapped by greenhouse gases. By 2030, however, the heating imbalance caused by greenhouse gases begins to overcome the oceans' thermal inertia, and the projected temperature would depend on human activities. For that reason, we need to change our behaviour regarding climate change now, in order not to compromise a longer period in the future.

Impact in Africa, in brief

Africa has been the lowest source of GHG in the world, however, is the most vulnerable continent to the impacts of climate change. Indeed, the Intergovernmental Panel on Climate Change (IPCC) has alerted that temperatures across Africa are expected to increase by 2-6 ºC within the next 100 years (IPCC, 2014). The effects will not be limited to a rising average temperature and changing rainfall patterns, as it is expected an increasing severity and frequency in droughts and floods (Niang et al., 2014; Hummel, 2015; Rose, 2015).

It is expected that climate change will lead to the reduction in food production due to changes in rainfall patterns and temperature in Africa (Awojobi and Tetteh, 2017). Changing weather patterns in recent years are producing a detrimental impact on food security. Also, there is evidence of impacts such as flooding, drought, deforestation and land degradation leading to migration in Africa (Abebe, 2014; Science for Environmental Policy, 2015). As well, there is increasing evidence that climate change is affecting forests and forest ecosystems in Africa, as well as the livelihoods of the forest-dependent communities (Chidumayo et al., 2011).

Africa has a limited capacity to deal with further disasters from climate change. Around 90% of people depend on agriculture for their livelihoods. Therefore, any decrease or change in rainfall patterns could mean crop failure and, consequently, produce serious food shortages or even famine. There is a strong correlation between climate change and East African livelihoods (Worldwide Fund for Nature, 2006). Records show a reduction in rainfall in the period 1996-2003 of 50-150 mm for each season, and a correlated reduction in maize and sorghum production across most of the eastern African countries (Funk et al., 2005).

African countries will be amongst the worst affected by climate change. High levels of poverty and underdevelopment combined with insufficient infrastructure exacerbate the already severe impact of global warming on resources, development and human security. In order to adapt to and mitigate the effects of climate change, tangible actions are needed.

Climate Change: A brief history of climate negotiations

The drafting of an international convention on climate change was initiated at the Toronto Conference in 1988, which can be considered as the starting point of international climate negotiations. At the United Nations (UN) Conference on Environment and Development in Rio de Janeiro in 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was signed, setting the framework for negotiating specific agreements. The objective of the UNFCCC is to achieve "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system" (UNFCCC, 1992). The UNFCCC commits developed country Parties to adopt national policies and take measures on climate change mitigation.

At COP 21 in Paris, over 150 heads of state and government voiced their support for an ambitious agreement on climate change – the highest number of leaders ever to attend a UN event in a single day. Parties to the UNFCCC reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future (UNFCCC, 2015). The Paris Agreement requires all Parties to put forward their best efforts through nationally determined contributions and to strengthen these efforts in the years ahead. Among others, long-term temperature goals, carbon sinks, mitigation and adaptation aspects are addressed.

Before the Paris Agreement, there have been a number of milestones (Table 2.1) regarding climate change.

Table 2.1. Climate change milestone.
Source: Own elaboration.

Climate Change Milestones	
1979	1st World Climate Conference
1988	Intergovernmental Panel on Climate Change is established
1990	The 1st IPCC report is published. The IPCC and the 2nd World Climate Conference call for a global agreement on climate change. The negotiations of the General Assembly of the United Nations around a framework convention begins
1991	1st Meeting of the Intergovernmental Negotiating Committee (CIN)
1992	The Intergovernmental Negotiating Committee adopts the text of the Climate Convention. At the Earth Summit held in Rio, the Framework Convention on Climate Change (UNFCCC) is ready for signature along with the Convention on Biological Diversity (UNCCD) and the United Nations Convention to Combat Desertification (UNCCD).
1994	The United Nations Framework Convention on Climate Change comes into force
1995	1st Conference of the Parties, (COP 1), Berlin
1996	The Convention Secretary was established to support the shares of the Convention
1997	The Kyoto Protocol is officially adopted in the COP3 in December
2001	The third IPCC evaluation report was published. The agreements of Bonn are adopted following the action plan of Buenos Aires of 1998. Marrakech's agreements are adopted on the COP7 which the rules detail put into practise the Kyoto Protocol
2004	Buenos Aires Plan of Action was established on the COP10
2005	Kyoto Protocol comes into force. The first Meeting of the Parties in the Protocol of Kyoto (CMP 1) was celebrated in Montreal. In agreement with the requirements of the Kyoto Protocol started the negotiations around the next phase in the frame of the Special Workgroup on the new commitments of the parts of annex I in accordance with the Kyoto Protocol
2006	The Nairobi Plan of Action was adopted
2007	The 4th IPCC evaluation report was published. Bali Road Map was established by the Parties in the COP13
2009	The Copenhagen Accord was initiated at the COP15
2010	The Cancun Agreements were widely accepted by the COP in the COP16. In the above-mentioned agreements, the countries formalized the promises that they had done in Copenhagen.
2012	COP18 in Doha, Qatar. The corrections made to the Kyoto Protocol in Doha were adopted by the CMP in the CMP8
2013	The decisions adopted in the COP19/CMP9 in Warsaw includes decisions on the Durban Platform, the Green Climate Fund, the Warsaw framework for reduced emissions from deforestation and forest degradation REDD++ and the International Mechanism for Loss and Damages. In accordance with Durban Platform, the parties agreed to present the Intended Nationally Determined Contributions (INDC)
2014	In the COP20 celebrated in Lima, the Parties adopted the "Lima call for climate change" that addressed key elements for the next meeting in Paris
2015	In December intense negotiations were celebrated in the frame of the ad hoc Group on the Durban Platform during the 2012-2015 period and culminated with the approval of the Agreement of Paris (at COP21)

Africa contributes less than 4% to global GHG emissions

Climate Change: the position of African authorities

Africa contributes less than 4% to global GHG emissions and requires substantial resources to adapt to a climatic situation not of its making. The continent's adaptation needs have been estimated at USD 7-15 billion per year by 2020, and may increase to $50 billion by 2050. The Paris Agreement on Climate Change strongly recommends developed countries scale up balanced (mitigation and adaptation) financial support to developing countries, and calls on developed countries to honour the USD 100 billion per year commitment to support developing countries including in Africa and Small Island Developing States (SIDSs) to adapt to climate change (Dia, 2015). Africa can champion a low carbon development trajectory at COP21, but to achieve beneficial outcomes from the negotiations, African countries must prepare extensively and design a clear strategy that is based on regional collaboration. Countries from the continent should aim to achieve a number of targets (Denton, 2015).

Most African countries have such low levels of greenhouse emissions that mitigation is not a priority. And unlike industrialised nations that were party to the Kyoto Protocol, African countries did not have binding targets, to which to reduce their GHG emissions (Shanahan et al., 2013). However, all countries are now expected to identify Nationally Appropriate Mitigation Actions (NAMAs), which might attract international investments or donors.

African governments work through a number of regional and global institutions to strengthen their response to climate change. They coordinate their regional positions and national policies on climate change through the African Ministerial Conference on the Environment (AMCEN), whose secretariat is provided by the Nairobi-based UN Environment Programme (UNEP). Another important regional forum is the New Partnership for Africa's Development (NEPAD), which promotes projects and action plans relevant to climate change. At the global level, African countries can tap a variety of funds and institutions for support, including the Special Climate Change Fund and the Least Developed Country Fund created under the UNFCCC, the Adaptation Fund under the Kyoto Protocol, the Global Environment Facility, the World Bank, and other UN and intergovernmental organizations and programmes. African countries can also participate in the Clean Development Mechanism (CDM), an innovative market-based instrument of the Kyoto Protocol that finances sustainable development projects in developing countries, which can reduce greenhouse gas emissions (UN, 2006).

The African Group has become increasingly visible in climate negotiations in recent years. They emphasize the principle of common but differentiated responsibilities and respective capabilities. It aims at parity between mitigation, adaptation and enhancing support, while referring to the increased burden that adaptation and loss and damage placed upon developing countries (Moosmann et al., 2017).

According to Mr Aliou Dia, Team Leader, Disaster Risk Reduction and Climate Change, UNDP, "Africa, under the leadership of the African Group of Negotiators, African countries successfully advocated for a balanced agreement that addresses both mitigation and adaptation in equal measure, in a departure from the Kyoto Protocol which focused significantly on mitigation. Adaptation is critical for African countries that are highly vulnerable to climate change due to heavy reliance on the agricultural sector, and being the least contributors to global CO_2 emissions".

The Paris Agreement also urges all countries to submit adaptation needs, priorities and plans, which developed countries will support. While the Agreement confirms a target of keeping the rise in temperature below 2°C above pre-industrial levels, the African Group in collaboration with other country groupings including the Least Developed Countries (LDCs), G77, SIDS, and Alliance of Small Island States (AOSIS) were successful in ensuring that the Agreement established, for the first time, the aim of keeping global temperatures even lower, at 1.5°C. Africa's continental Adaptation and Loss and Damage Initiative will play a critical role in international collaboration on adaptation, as mentioned in the Agreement. Loss and damage refer to the irreparable loss and damage to the territory, species, assets, etc., as a result of climate change (UNDP, 2015).

African nations have responded to climate change with different degrees of ambition. Some developed national climate change strategies while others have plans to relate to the specific sector such as agriculture or water. The following examples draw from a 2012 report from the Chatham House Africa Programme, which has more detailed information on

African leadership – national and subnational, and from governments, business and civil society (Dewer, 2012):

- Nigeria has produced policy frameworks such as a Climate Change Commission Bill, adaptation plans and a REDD+ programme.
- Kenya developed its National Climate Change Action Plan 2013-2017 after 20 months of consultation. The 258-page document details Kenya's options for adapting to and mitigating climate change, and for adopting a low-carbon development pathway. It identifies the institutions, finance and human capacity that the country needs to do this, and outlines how the country can implement and monitor the work. Developing renewable energy with private-sector support is a national priority, including feed-in tariff policy, focus on geothermal (e.g. potential Menengai 400MW plant), solar and wind (e.g. project near Lake Turkana to produce 300MW).
- Mozambique published its green growth roadmap in 2012.
- Gabon unveiled its Green Gabon plan in 2011. It aims to consider climate change in all sectors of the economy, and noted that the new protected areas and reduced deforestation/degradation had avoided 450 million tonnes of carbon dioxide emissions in a decade. Under the plan Gabon commits to generate 80 per cent

of energy from renewable sources (mainly hydro), and reduce gas flaring by 60 per cent by 2015.

- The Democratic Republic of Congo's national development strategy highlights the importance of forests, their conservation, management and funding by REDD+.
- Ethiopia launched a Climate-Resilient Green Economy strategy in 2011. It aims to keep greenhouse gas emissions in 2030 to current levels. Under the plan Ethiopia will improve crops and livestock practices; protect and re-establish forests; expand renewable energy and adopt modern, energy-efficient technologies in transport, construction and industry.
- Rwanda launched a Green Growth and Climate Resilience strategy in 2011. This includes geothermal power generation, soil fertility management, and better design of cities for pedestrians and cyclists, irrigation infrastructure and roads.
- South Africa has a National Climate Change Response strategy with both mitigation and adaptation measures designed to enhance social, economic and environmental resilience, and emergency response capacity. It has pledged to reduce its greenhouse gas emissions by 34 per cent by 2020 and 42 per cent by 2025.

3
Agriculture and Climate Change

3.1. INFLUENCE OF AGRICULTURE ON CLIMATE CHANGE

Global greenhouse gas emissions were estimated to be 49 (±4.5) Gt CO_2 eq in 2010 (IPCC, 2014), with approximately 24 % (10.3–12 Gt CO_2 eq) of emissions coming from Agriculture, Forestry and Other Land Use (AFOLU) (Tubiello et al., 2015; IPCC, 2014). Annual non-CO_2 GHG emissions, primarily methane (CH_4) and nitrous oxide (N_2O) from agriculture were estimated to be 5.2-5.8 Gt CO_2 eq yr^{-1} in 2010 (FAOSTAT, 2014; Tubiello et al., 2015), with approximately 4.3–5.5 Gt CO_2 eq yr^{-1} attributable to land use and land-use change activities (IPCC, 2014).

The food we consume has been produced, stored, processed, packaged, transported, prepared and served. In each of these phases, greenhouse gases are released into the atmosphere. Greenhouse gas emissions

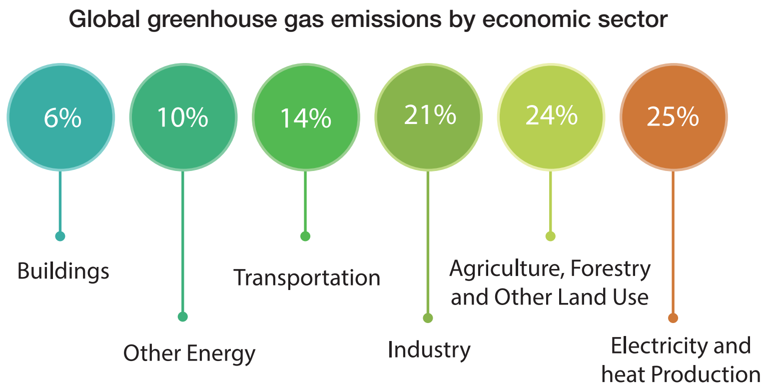


Figure 3.1. Global greenhouse gas emissions by economic sector. This estimate does not include the CO_2 offsets from soils. Source: IPCC (2014); based on global emissions from 2010.

from agriculture come mostly from the cultivation of crops and livestock, and deforestation (IPCC, 2014). In addition to $CO_{2,}$ agriculture, in particular, releases significant amounts of methane and nitrous oxide, two potent greenhouse gases. Methane is produced by livestock during digestion due to enteric fermentation and is released by belching. It can also be released by manure and organic waste stored in landfills. Nitrous oxide emissions are an indirect product of organic nitrogen and mineral fertilizers. Poorly drained soils tend to have higher levels of methane and nitrous oxide emissions.

Agricultural practices regulate soil nitrogen (N) and carbon (C) dynamics and thereby affect the fluxes of N_2O and CO_2 (Adviento-Borbe et al., 2007; Mutegi et al., 2010). Natural factors also affect or interact with farming practices, thereby influence N_2O, CH_4 and CO_2 emissions (Chatskikh et al., 2005; Čuhel et al., 2010; Gu et al., 2013; Jansen, 2009; Vidon et al., 2016). In recent decades, many site-specific studies have been conducted to explore the impacts of fertilization (Tan et al., 2017; Yan et al., 2015), tillage (Wei et al., 2012), and crop residues (Hu et al., 2013; Huang et al., 2013).

Particularly in Africa, land use changes such as deforestation, overgrazing and burning of vegetation not only add to the carbon load but also cause a change in energy and moisture fluxes, with noticeable consequences on weather and climate patterns at local and regional levels (Ngaira, 2003). Greenhouse gas fluxes in Africa play an important role in the global GHG budget (Hickman et al., 2014; Valentini et al., 2014; Ciais et al., 2011; Bombelli et al., 2009). In recent years, conversion rates of African natural lands, including forest, grassland and wetland to agricultural lands have increased (Gibbs et al., 2010; FAO, 2010). The dominant type of land use change has been the conversion of forest to agriculture with average deforestation rates of 3.4 million ha per year (FAOSTAT, 2014). This land-use conversion results in an estimated release of 0.32 ± 0.05 Pg C yr^{-1} (Valentini et al., 2014) or 157.9 ± 23.9 Gt CO_2 eq in 1765 to 2005 (Kim and Kirschbaum, 2015), higher than fossil fuel emissions for the continent (Valentini et al., 2014).

For example, GHG emissions in the East Africa region, from the countries for which data are available, are primarily from the land-use change and forestry (LUCF) and agriculture sectors. Together, regional emissions from these two sectors are responsible for 81% (540 Mt CO_2 eq) of total regional GHG emissions (669 Mt CO_2 eq), with LUCF responsible for nearly half (324 Mt CO_2 eq) and agriculture nearly a third (216 Mt CO_2 eq) (USAID, 2015).

Agriculture is the region's second highest GHG emitting sector. It is the leading source of emissions in five countries: the Central African Republic (CAR), Djibouti, Ethiopia, Kenya, and Rwanda. Their combined emissions represent 69% of the region's agriculture sector emissions. In terms of emissions volume, the key countries are Ethiopia, Tanzania, Kenya, the CAR, and the Democratic Republic of Congo (DRC), whose emissions makeup 89% of the region's agriculture GHG emissions (USAID, 2015). Their emissions are shown in Fig. 3.3.

In Ethiopia, Tanzania, and Kenya, enteric fermentation is the top emitting agriculture subsector, which also

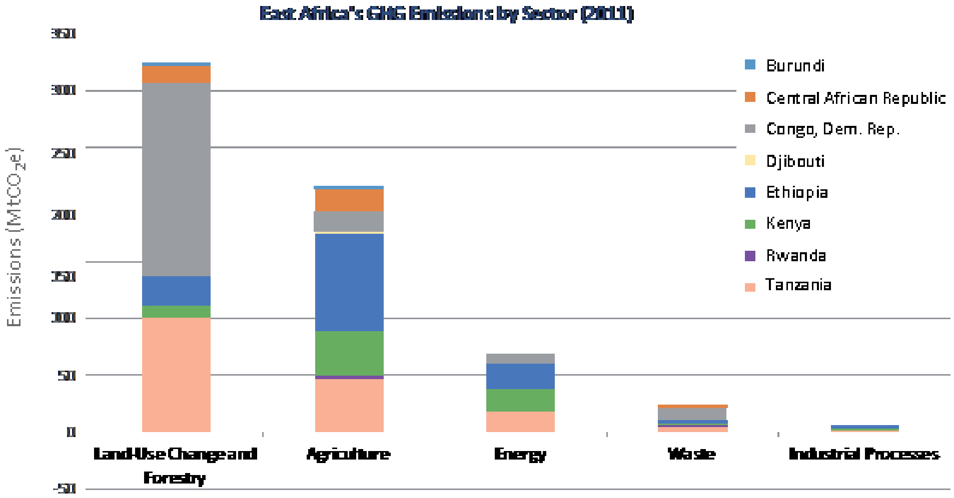
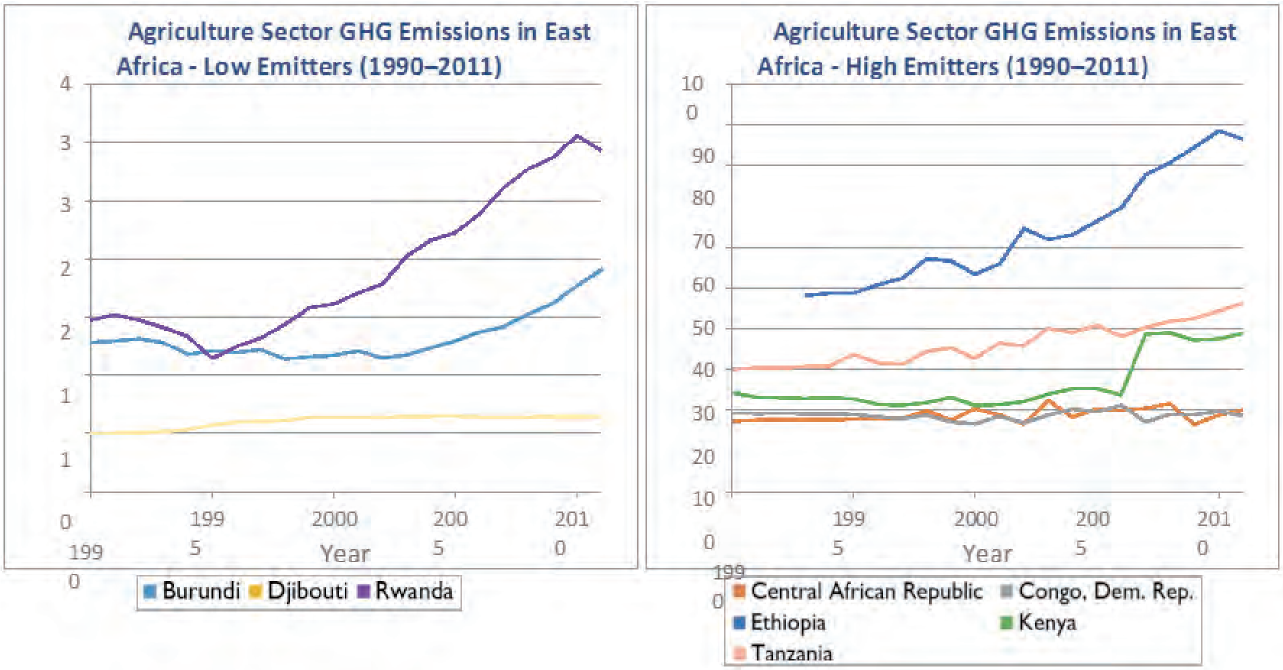


Figure 3.2.
East Africa's GHG emissions by sector (2011). Source: WRI CAIT 2.0, 2015 (WRI CAIT. GHG emissions data are not available for Somalia and South Sudan)

Figure 3.3.
Agriculture sector GHG Emissions in East Africa, Low and high emitters (1990-2011). Source: WRI CAIT 2.0, 2015



ranks among the top three sources of agriculture emissions in the CAR and DRC. In the CAR and DRC, the top emitting subsector is savanna burning, which is also a key source of GHGs in Tanzania. Manure left on pasture is among the top three emitting agriculture subsectors for all five countries (USAID, 2015). The agricultural sector is the primary source of livelihood and the most important economic sector for Ethiopia and Tanzania, with agriculture accounting for around 50% of the GDP. Agriculture accounts for roughly 25% of the GDP in Kenya. Countries have identified a range of needs to reduce emissions, including implementation of mixed farming, strategic supplementation, and manure management (Ethiopia); reduction of methane emission in crop and livestock production, switching to drought-resistant crops, and improvement of traditional irrigation schemes (Tanzania); and promoting climate-smart agriculture and livestock development (Kenya).

How agricultural soils and climate change are related: carbon dioxide and nitrous oxide

The strong link between agricultural soils and climate change might not be evident, but it certainly exists. How soils are managed in agricultural land has a direct effect on climate change, and a proper soil management is one of the best tools for climate change mitigation and adaptation (Lal, 2008). Soils are an important pool of active carbon and play a major role in the global carbon cycle and have contributed to changes in the concentration of GHGs in the atmosphere. Indeed, agricultural ecosystems can play a significant role in the production and consumption of GHGs, especially carbon dioxide (Gonzalez-Sanchez et al., 2016).

However, traditional or conventional agricultural practices are based on tillage, and they have been identified as one of the major causes of soil degradation (Kassam et al., 2017). Until a few decades ago, due to the scarce means available to farmers, tillage was not perceived as a serious problem for soil health. Formation and stability of soil aggregation are influenced directly by tillage, leading to effects on a wide range of soil parameters, including those affecting water holding capacity and gaseous exchange. It has been estimated that over the last 100 years, aggressive tillage may be primarily responsible for a 30–50% decrease in soil carbon worldwide. Tillage affects the soil carbon content directly by soil fracturing, which facilitates movement of carbon dioxide out of the soil immediately after cultivation; and indirectly by altering soil aggregation leading to reduced carbon adherence to clay surfaces and increased organic matter oxidation, and by accelerating carbon loss through water and wind erosion (Bradford and Peterson, 2000).

One of the consequences of agricultural systems based on tillage is the reduction of the soil sink effect, whose direct consequence is the reduction of the organic carbon content, the main component of organic matter. The sink effect is any process that can fix atmospheric C. Agriculture and forestry are virtually the only activities that can achieve this effect through photosynthesis and the C incorporation into carbohydrates. Crops capture CO_2 from the atmosphere during photosynthesis by converting C forms associated with soil organic matter

(SOM) for microbial decomposition processes (Johnson et al., 2007).

Reicosky (2011) argues that intensive agriculture has contributed to the loss of 30% to 50% of soil organic carbon in the last two decades of the 20th century. Soil carbon provides substantial benefits to plant growth by improving soil structure, increasing cation exchange capacity and nutrient retention, providing a source of energy for microbial growth and nutrient cycling, and improving the overall water capture and water holding capacity of a soil. Adopting management practices that reduce soil disturbance and increase the return of residues to the soil provide for a healthy soil environment. This, in turn, may improve productivity and provide the potential for increasing soil carbon stocks. From a greenhouse perspective, the most commonly held view is that reducing or avoiding tillage leads to carbon sequestration.

Another consequence of intensive tilling processes is the higher emissions of CO_2 into the atmosphere, both in short-term (immediately after tillage) and long-term (during the crop season). This is because the tillage stimulates the production and accumulation of CO_2 in the porous structure of the soil through processes of oxidation and mineralization of organic matter. The mechanical action of the tillage involves a breakdown of the soil aggregates, with the consequent release of CO_2 trapped inside the soil and its subsequent emission into the atmosphere. In that regard, and in order to quantify the sequestered CO_2 that represents the values of organic carbon fixed in the soil, Tebruegge (2001) states that through the microbiological oxidation processes in the soil, 3.7 tonnes of CO_2 are generated from 1 tonne of carbon. The soil capacity to act as a sink or a source of carbon will be mainly determined by a range of environmental factors that may, in fact, outweigh the ability of the farmer to adopt practices that could increase carbon stocks.

Emissions of nitrous oxide from soils may result from three separate microbial mediated processes. One is the oxidation of ammonia to nitrite via ammonium (a dissimilatory pathway) by a few genera of aerobic chemoautotrophic bacteria. This pathway is dependent on the availability of carbon dioxide and oxygen. Nitrous oxide production results from a reductive process in which the bacteria use nitrite as an alternative electron acceptor. This is especially favoured under conditions of oxygen limitation, typically when soil water content lies between 55 and 65% water-filled pore space (Bouwman, 2013). At elevated water contents, the aerobic exchange is reduced, and the nitrification process is restricted. Oxidation of nitrite to nitrate is generally carried out by classes of Nitrobacter.

The relative prevalence of the two pathways is determined directly by soil properties and external conditions. Nitrogen substrate which may ultimately limit nitrogen gas release is derived from both organic and inorganic sources, including fertiliser inputs and nitrogen-fixing plants; and generally increased soil nitrogen creates conditions conducive to increased nitrous oxide emissions (e.g. Goossens et al., 2001). Tillage has been shown in numerous papers to have a detrimental effect on the growth and activity of microbial populations (e.g. Carter and Mele, 1992) and this change can determine the extent to which nitrification and denitrification reactions proceed.

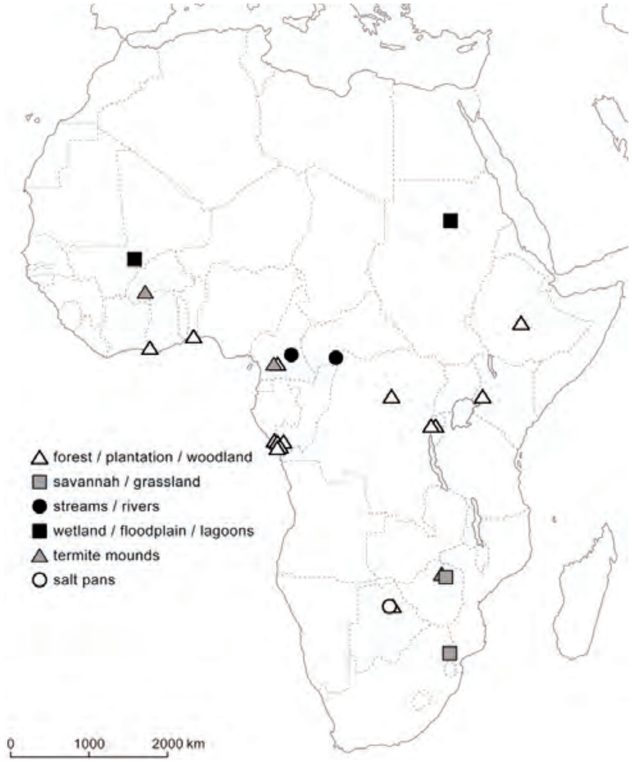


Figure 3.4.
Maps showing study sites of CO_2, CH_4 and N_2O fluxes. Source: Kim and Kirschbaum (2015).

Nitrogen fertilizer plays an important role in cultivation in terms of both economic and environmental aspects. Nitrogen fertilizer positively affects yield and the soil organic carbon level, but it also has negative environmental effects through nitrogen-related emissions from soil. Management practices may also affect N_2O emissions, although these relationships have not been well quantified. As mentioned, levels of N_2O emissions may be dependent on the type of fertilizer used, although the extent of the effect is not clear, as demonstrated by the wide range of emission coefficients for individual fertilizer types derived in experiments. Although high fertilizer application rates may cause higher N_2O emission rates, the relationship between fertilizer application rate and nitrous oxide emissions is not well understood yet. In a work of Kim and Kirschbaum (2015), 73 studies in 22 countries in sub-Saharan Africa (SSA) were revised (Fig. 3.4). Soil GHG emissions from African natural terrestrial systems ranged from 3.3 to 57.0 Mg carbon dioxide

Incorporation of crop residues to the soil has frequently been proposed to increase soil fertility

(CO_2) ha^{-1} yr^{-1}, −4.8 to 3.5 kg methane (CH_4) ha^{-1} yr^{-1} and 0.1 to 13.7 kg nitrous oxide (N_2O) ha^{-1} yr^{-1}. Soil GHG emissions reported from African croplands ranged from 1.7 to 141.2 Mg CO_2 ha^{-1} yr^{-1}, −1.3 to 66.7 kg CH_4 ha^{-1} yr^{-1} and 0.05 to 112.0 kg N_2O ha^{-1} yr^{-1}. Soil physical and chemical properties, rewetting, vegetation type, forest management and land-use changes were all found to be important factors affecting soil GHG emissions.

The effects of the amount and type of N input on N_2O emissions in croplands have been studied in several locations in Africa. In western Kenya, the rate of N fertilizer application (0 to 200 kg N ha^{-1}) had no significant effect on N_2O emissions (620 to 710 g N_2O-N ha^{-1} for 99 days) (Hickman et al., 2014), however another study from western Kenya, found a relationship between N input and N_2O emissions that was best described by an exponential model with the largest impact on N_2O emissions occurring when N inputs increased from 100 to 150 kg N ha^{-1} (Hickman et al., 2015).

Incorporation of crop residues to the soil has frequently been proposed to increase soil fertility (Malhi et al., 2011), however, incorporation of crop residues also affects CO_2 and N_2O emissions. In Tanzania, incorporation of plant residue into soil increased annual CO_2 fluxes substantially (emissions rose from 2.5 to 4.0 and 2.4 to 3.4 Mg C ha^{-1} yr^{-1} for clay and sandy soils, respectively), although a study in Madagascar showed that rice-straw residue application resulted in larger fluxes of CO_2 but reduced N_2O emissions due to N immobilization (Rabenarivo et al., 2014).

Adding an additional source of N (mineral or organic) when crop residues are incorporated into the soil could stimulate mineralization of crop residues, increase N-use efficiency and produce higher yields (Table 3.1). It was found that the application of mixed crop residue or manure and inorganic fertilizers resulted in a different response of CO_2 and N_2O emissions. In maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.) fields in Zimbabwe, application of inorganic fertilizer (ammonium nitrate, NH_4NO_3–N) with manure increased CO_2 emissions (26 to 73 %), compared to the sole application of manure (Nyamadzawo et al., 2014a). However, the mixed application resulted in lower N_2O emissions per yield (1.6–4.6 g N_2O kg^{-1} yield), compared to the sole application of inorganic fertilizer (6–14 g N_2O kg^{-1} yield) (Nyamadzawo et al., 2014a). Similarly, in a maize field in Zimbabwe, N_2O emissions were lower after the application of composted manure and inorganic fertilizer (NH_4NO_3–N) compared to the sole application of inorganic fertilizer.

The relationship between N input and N_2O emissions varied depending on N input level. N_2O emissions increase slowly up to 150 kg N ha^{-1} yr^{-1}, after which emissions increase exponentially up to 300 kg N ha^{-1} yr^{-1} (Fig. 3.5a). Consistent with van Groenigen (2010) N inputs of over 300 kg N ha^{-1} yr^{-1} resulted in an exponential increase in emission (Fig. 3.5b), slowing to a steady state with N inputs of 3000 kg N ha^{-1} yr^{-1}. Overall, the relationship between N input and N_2O emissions shows a sigmoidal pattern (Fig. 3.5c). The observed relationship is consistent with the proposed hypothetical conceptualization of N_2O emission by Kim et al. (2013) showing a sigmoidal response of N_2O emissions to N input increases. The results suggest that N inputs over 150 kg N ha^{-1} yr^{-1} may cause an abnormal increase of N_2O emissions in Africa.

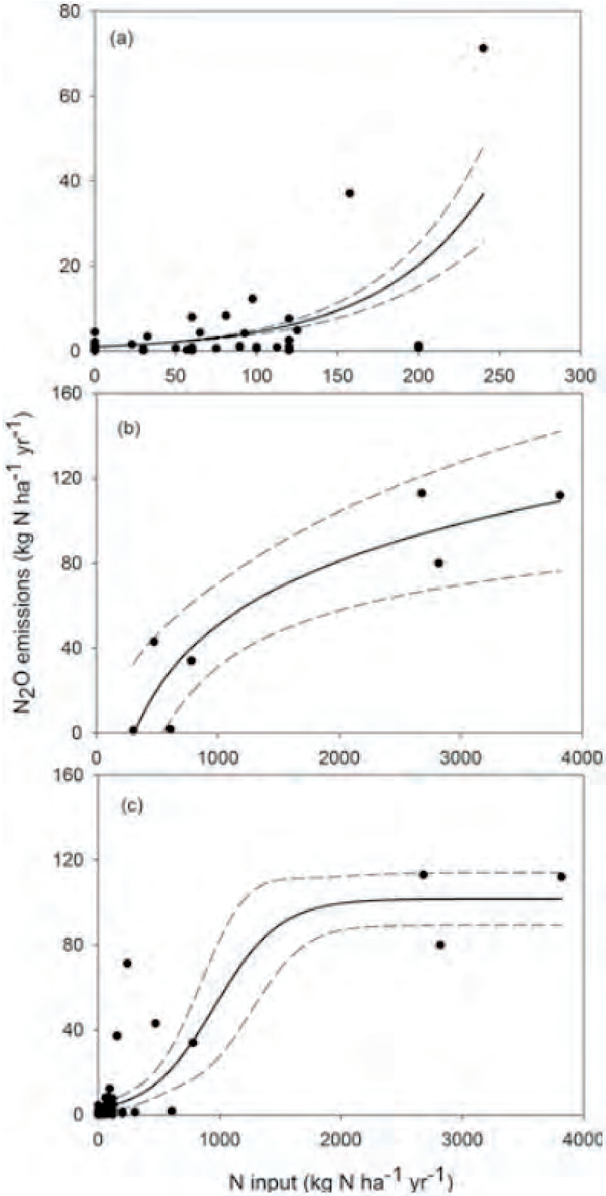


Figure 3.5.
The relationship between nitrogen (N) input and nitrous oxide (N_2O) emissions observed in Africa. N input ranged from 0 to 300 **(a)**, 300 to 4000 **(b)** and 0 to 4000 kg N ha^{-1} yr^{-1} **(c)**. The dashed lines indicate 95% confidence intervals. Source: Groenigen (2010).

The effects of crop type and management on GHG emissions have also been studied by several groups (Table 3.1). In Uganda, there were no significant differences in soil CO_2 effluxes from different crops (lettuces, cabbages, beans) (Koerber et al., 2009). However, in Zimbabwe, rape production resulted in greater N_2O emissions (0.64–0.93 % of applied N was lost as N_2O) than tomatoes (0.40–0.51 % of applied N was lost as N_2O) (Masaka et al., 2014). The results suggest that the effect of crop type on GHG emissions is difficult to predict and more research is needed to elucidate the relationship between crops, crop management and GHG emissions.

Table 3.1.
Summary of the effect of management practices on GHG emissions in African countries. Source: Kim et al. (2016).

Land use/ ecosystem type	Management practices	Impact on GHG			Country	Data Source
		CO_2	N_2O	CH_4		
Forest/ plantation/ woodland	Burning	+			Ethiopia	Anderson et al., 2004
	Thinning	+			Ethiopia	Yohannes et al., 2013
	Land uses change (cleaning and conversion to cropland)	+	+	+	Zimbabwe	Mapanda et al., 2010, 2012
	Flooding			+	Cameroon	McDonald et al., 1998
				+	Republic of Congo	Tathy et al, 1992
				+	Mali	Delmas et al, 1991
Savannah/ grassland	Burning	+	+	+	Republic of Congo	Castaldy et al, 2010; Delmas et al., 1991
					South Africa	Zepp et al., 1996
	Land uses change (cleaning and conversion to cropland)	+			Republic of Congo	Nouvellon et al, 2012
Croplands	Increase in N fertilisation rate		+		Kenya	Hickman et al., 2015
	Type of synthetic fertiliser		+		Madagascar	Rabenarivo et al., 2014
	Application of plant residues		-		Tanzania	Sugihara et al., 2012
			-		Madagascar	Rabenarivo et al., 2014
		+	+		Kenya	Kimetu et al., 2006
		+	+		Ghana	Frimpong et al., 2012
	Crop residues + N Fertiliser		+		Zimbabwe	Nyamadzawo et al., 2014a,b
			-		Zimbabwe, Gahna and Kenya	Gentile et al., 2008
	Combination of synthetic & organic fertilisers	+	-		Zimbabwe	Mapanda et al., 2011
			-		Mali	Dick et al, 2008
	Crop type				Uganda	Koerber et al., 2009
			-		Zimbabwe	Masaka et al., 2014
	Introducing N fixing crops in rotation		-		Mali	Dick et al., 2008
	Direct seeding mulch-based		-		Madagascar	Chapuis-Lardy et al., 2009
	Hand-ploughing after harvesting		-		Madagascar	Chapuis-Lardy et al., 2009
	Intensive grazing	+			Botswana	Thomas, 2012
Vegetable gardens	Plastic cover for ruminant manure		-		Niger	Predotova et al., 2010
	Incorporation of fallow residues		+		Kenya	Bagg et al., 2006; Millar and Bagg, 2004; Millar et al., 2004
Agroforestry	Improving fallow with N-fixing crops		+		Zimbabwe	Chikowo et al., 2004
	Cover crops		+		Kenya	Millar et al., 2004
	N-fixing tree species	+	+		Malawi	Kim, 2012; Makumba et al., 2007
		+	+		Senegal	Dick et al., 2006

Land-use change affects soil GHG emissions due to changes in vegetation, soil, hydrology and nutrient management (e.g., Kim and Kirschbaum, 2015) and the effects of land-use change on soil GHG emissions have been observed in woodlands and savanna. In Zimbabwe, clearing and converting woodlands to croplands increased soil emissions of CO_2, CH_4 and N_2O (Mapanda et al., 2012) and soil CO_2 emissions from the converted croplands were higher than *Eucalyptus* plantations established in former natural woodlands (Mapanda et al., 2010). In the Republic of Congo, early-rotation changes in soil CO_2 efflux after afforestation of a tropical savanna with *Eucalyptus* were mostly driven by the rapid decomposition of savanna residues and the increase in *Eucalyptus* rhizospheric respiration (Nouvellon et al., 2012).

Respect to the soil, adoption of no-till farming practices have improved soil structure, through enhanced soil porosity and aggregation (Carter et al., 1994), leaving a more friable textured soil surface profile making it easier to sow a crop. Retaining plant residues, by not burning and leaving them standing on the surface, also improves soil structure by increasing microbial processes that lead to soil aggregation. This improved soil texture requires less shear force to move tined implements through the soil.

Summarising, the studies presented in this chapter lead to the conclusion that it would be possible to reduce greenhouse gas emissions from agriculture. The approach should be based on improved soil management practices, and nitrogen fertiliser management that considers both the biophysical interactions within the soil and the use of no or minimum mechanical soil disturbance practices.

3.2. IMPACTS OF CLIMATE CHANGE IN AGRICULTURE

Agriculture contributes to both climate change and is affected by climate change. Even if agriculture would not be the only productive sector affected by global warming, the impacts on it would definitely have negative effects on food security and social welfare. Crops need adequate land, water, sunlight and heat to grow and complete their production cycles. Global warming has already altered the duration of the growing season in some areas. The periods of flowering and harvest of cereals are already several days ahead. It is foreseeable that these changes may continue to occur in many regions (EEA, 2016).

Changes in temperature patterns and precipitation, and an increase in the concentration of atmospheric CO_2, will significantly affect crop development. Nowadays, the global climate variabilities are estimated to be responsible for 32% to 39% of yield variability (Ray et al., 2015), so even higher CO_2 levels can affect crop yields more deeply.

Elevated CO_2 levels can increase plant growth. However, other factors, such as changing temperatures, ozone, and water and nutrient constraints, may counteract these potential increases in yield. For example, if the temperature exceeds a crop's optimal level, if sufficient water and nutrients are not available, yield increases may be reduced or reversed. Also, elevated CO_2 has been associated with reduced protein and nitrogen content in alfalfa and soybean plants, resulting in a loss of quality.

The flow of the impacts of climate change on the agricultural sector can be illustrated as shown in Figure 3.6.

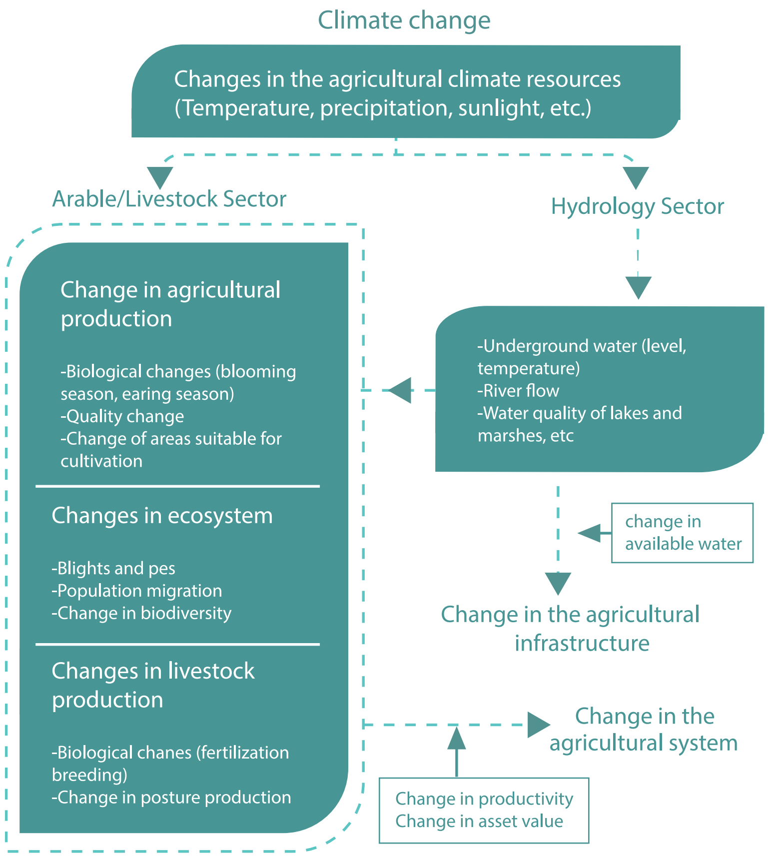


Figure 3.6.
Flow of the climate change impact on the agricultural sector.
Source: Kim et al. (2009).

The impacts of climate change on crops include the change of flowering and harvesting seasons, quality change, and shift of areas suitable for cultivation Kim et al. (2009). Climate change affects the agricultural ecosystem, giving rise to blights and pests and causing population movement and change in biodiversity.

As the impacts of climate change on the agricultural sector vary with the related variables, it is difficult to generalize certain analytical results. Therefore, what is attempted here is to classify the impacts of climate change into positive and negative ones based on the results that researches have gathered thus far in the related productive capacity of crops. Obviously, the potential positive and negative effects will not occur in all regions, but will largely depend on the variation produced by climate change with regard to the baseline conditions of each region (Table 3.2).

Among the positive impacts of global warming include the increase in crop productivity due to fertilization effect caused by the increase in carbon dioxide concentration in the atmosphere, expansion of the areas available for production of tropical and/or subtropical crops,

Region	Projection	Wheat	Rice	Maize	Sorghum	Groundnut
Northern Africa	worst	-14,53	-6,62	-6,79	-15,33	-9,19
	median	-7,71	-1,73	-1,11	-4,29	-0,38
	best	-2,72	3,7	7,42	6,18	8,77
Western Africa	worst	-11,03	-5,92	-9,64	-5,51	-16,6
	median	-1,26	-1,91	-3,51	-0,19	-7,32
	best	9	0,75	1,09	4,65	-2,01
Central Africa	worst	-8,33	-6,52	-4,18	-16,69	-8,14
	median	-1,76	-1,9	-1,39	-4,02	-2,54
	best	4,82	1,23	0,7	5,56	1,51
Eastern Africa	worst	-4,75	-3,24	-5,78	-7,17	-2,52
	median	5,45	3,31	-0,97	0,84	2,9
	best	17,73	12,27	4,42	6,23	10,72
Southern Africa	worst	-32,34	0,39	-46,56	-16,86	-8,09
	median	-15,79	5,23	-28,49	-1,49	2,21
	best	-4,78	12,05	-12,27	14,66	13,2

Table 3.2.
Comparison of relative production changes for a variety of African crops under climate change in different regions. The results are probabilistic projections of production impacts in 2030 as a percentage of 1998 to 2002 yields. Red (very negative), brown (negative), light green (positive) and dark green (very positive). Source: Pereira (2009).

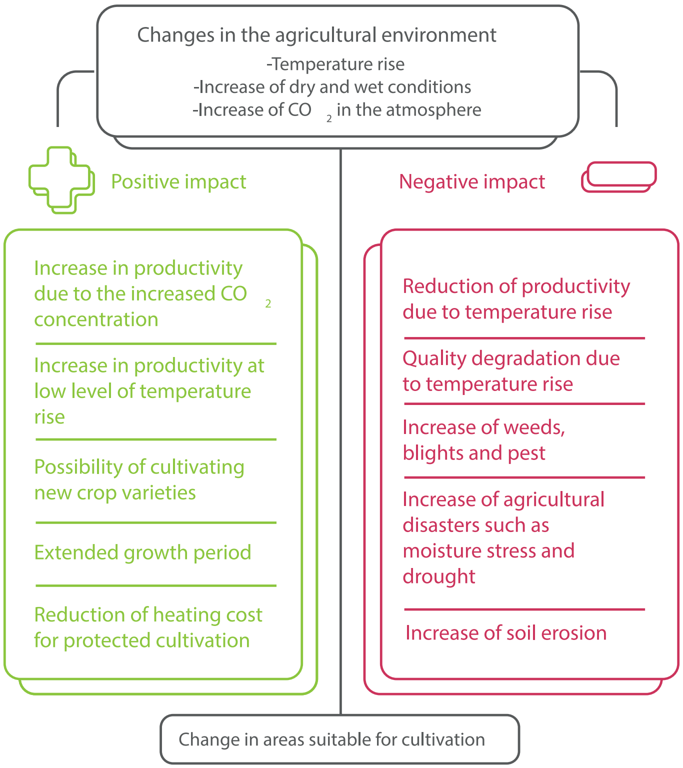


Figure 3.7.
Potential impacts of global warming on the agricultural sector. Source: Kim et al. (2009).

expansion of two-crop farming due to the increased cultivation period, reduction of damages of winter crops by low temperature, and reduction of heating cost for agricultural crops grown in the protected cultivation facilities.

Negative impacts of global warming include reduced crop quantity and quality due to the reduced growth period following high levels of temperature rise; reduced sugar content, bad coloration, and reduced storage stability in fruits; increase of weeds, blights, and harmful insects in agricultural crops; reduced land fertility due to the accelerated decomposition of organic substances; and increased soil erosion due the increased rainfall.

In addition, each crop requires different climate and environmental conditions to grow. So, if climate change like temperature rise occurs, the boundary and suitable areas for cultivation move further north or further south and thus the main areas of production also change. The change in the main areas of production might be as a crisis for certain areas but might be an opportunity for other areas, so overall it cannot be classified either as a positive or as a negative impact.

However, according to the IPPC (2014), there will be more regions that will be negatively impacted by climate change than the benefited ones (Figure 3.8). Feeding a growing global population in a changing

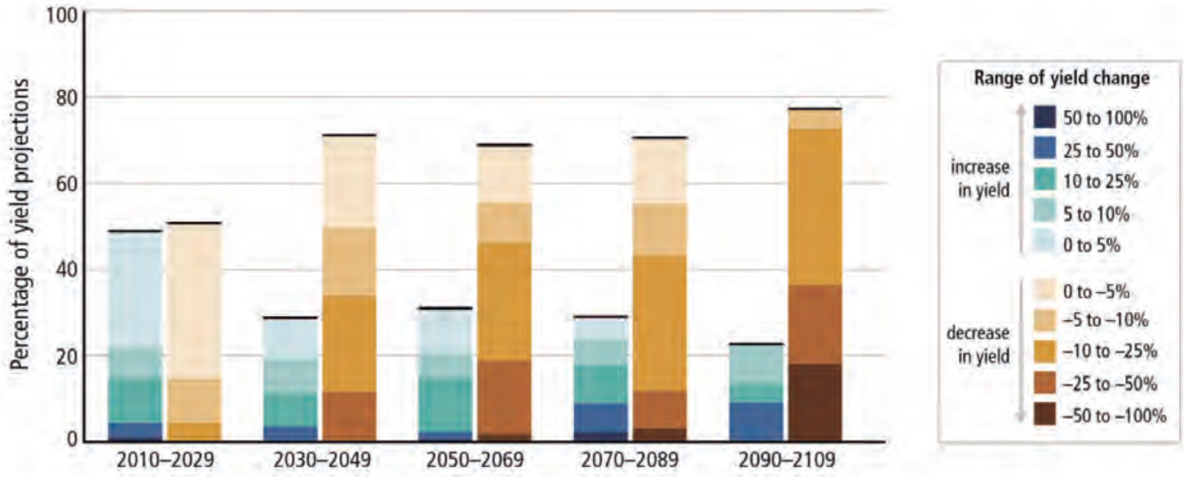


Figure 3.8.
Summary of projected changes in crop yields (mostly wheat, maize, rice and soy), due to climate change over the 21st century. Data for each timeframe sum to 100%, indicating the percentage of projections showing yield increases versus decreases. The figure includes projections (based on 1090 data points) for different emission scenarios, for tropical and temperate regions and for adaptation and no-adaptation cases combined. Changes in crop yields are relative to late 20th century levels. Source: IPPC, 2014.

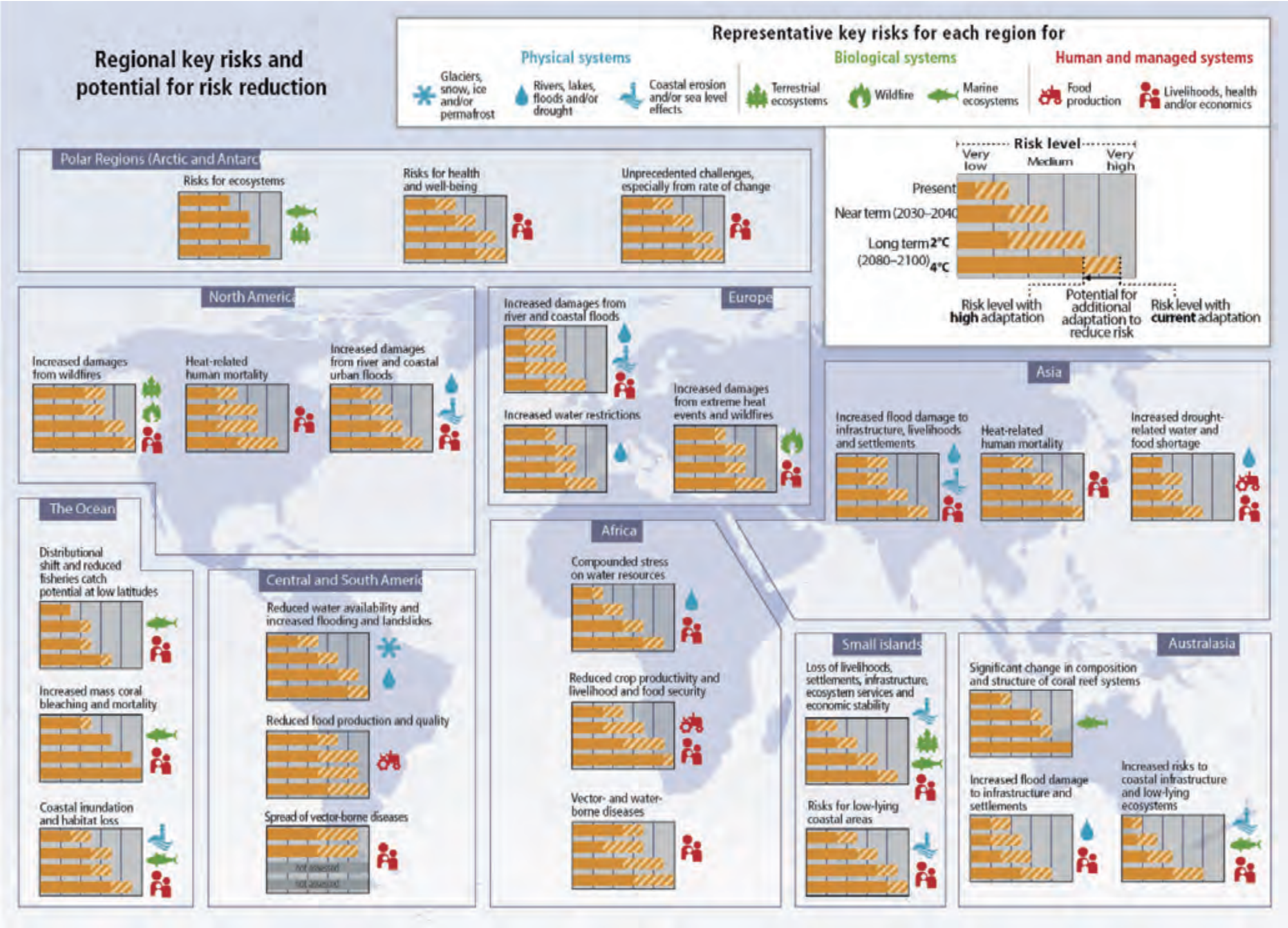


Figure 3.9.

Representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation. Each key risk is assessed as very low, low, medium, high or very high. Risk levels are presented for three time frames: present, near term (here, for 2030–2040) and long term (here, for 2080–2100). In the near term, projected levels of global mean temperature increase do not diverge substantially across different emission scenarios. For the long term, risk levels are presented for two possible futures (2°C and 4°C global mean temperature increase above pre-industrial levels). For each timeframe, risk levels are indicated for a continuation of current adaptation and assuming high levels of current or future adaptation. Risk levels are not necessarily comparable, especially across regions. Source: IPCC, 2014.

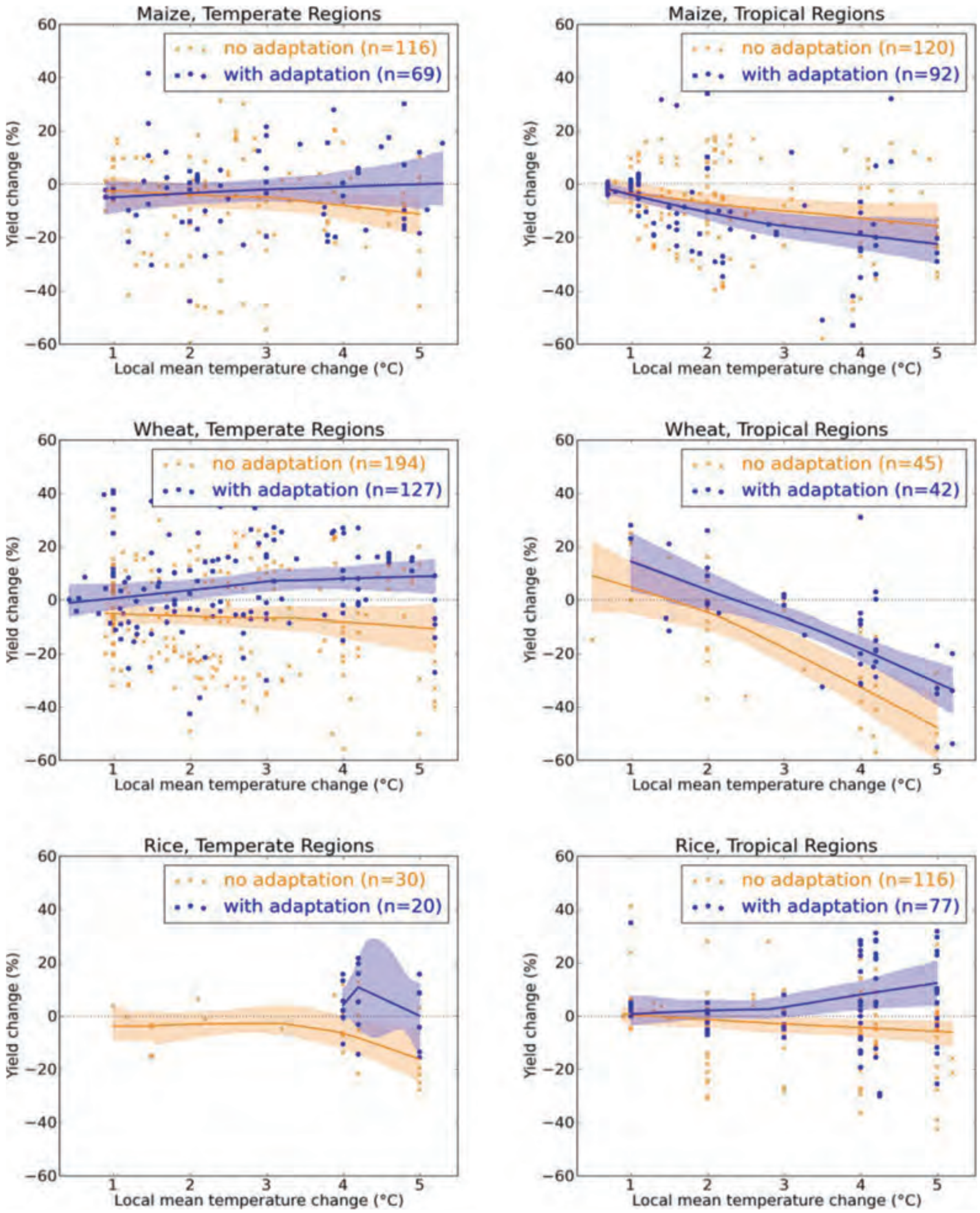


Figure 3.10. Percentage yield change as a function of temperature for the three major crops and for temperate and tropical regions for local mean temperature changes up to five degrees (n=1048 from 66 studies). Source: Challinor et al. (2014)

climate presents a significant challenge to society. Therefore, the projected yields of key crops under a range of agricultural and climatic scenarios are needed to assess food security prospects.

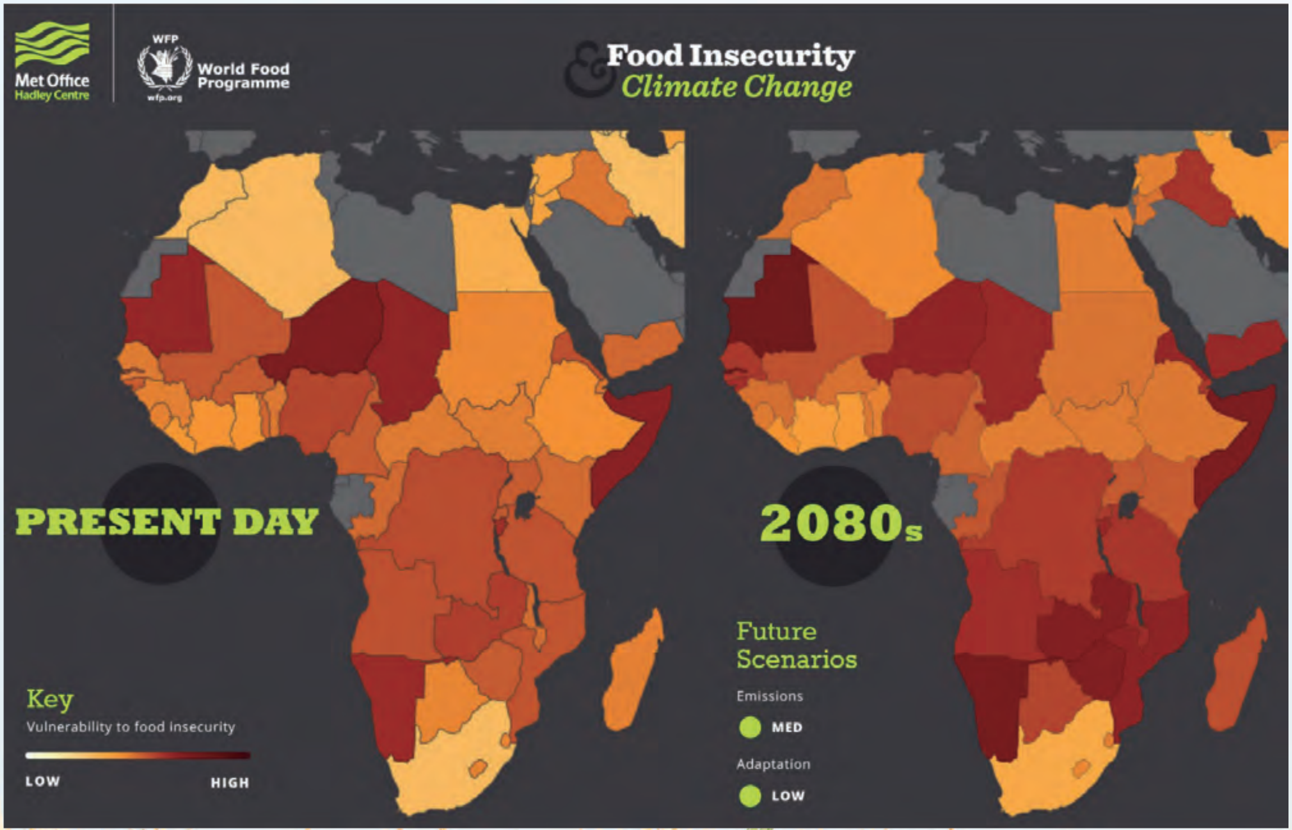
Representative key risks for each region, including the potential for risk reduction through adaptation and mitigation, as well as limits to adaptation, are presented in Figure 3.9. Without adaptation, losses in aggregate production are expected for wheat, rice, and maize in both temperate and tropical regions by 2°C of local warming (IPCC, 2014).

Challinor et al. (2014) developed a dataset of over 1700 published simulations to evaluate yield impacts of climate change and adaptation (Figure 3.10). Crop level adaptations increase simulated yields by an average of 7-15%, with adaptations more effective for wheat and rice than maize. Yield losses are greater in magnitude for the second half of the century than for the first. Consensus on yield decreases in the second half of the century is stronger in tropical than temperate regions, yet even moderate warming may reduce temperate crop yields in many locations.

Influence of climate change in African agriculture

According to the UN Environment, no continent will be struck as severely by the impacts of climate change as Africa. Given its geographical position, the continent will be particularly vulnerable due to the considerably limited adaptive capacity and exacerbated by widespread poverty. Climate change is a particular threat to continued economic growth and to the livelihoods of vulnerable populations (UN Environment,

Figure 3.11.
Comparison of current food insecurity and that expected in the 2080's (considering medium emissions and low adaptation).
Source: Global Food Insecurity Index (Met Office and World Food Program).

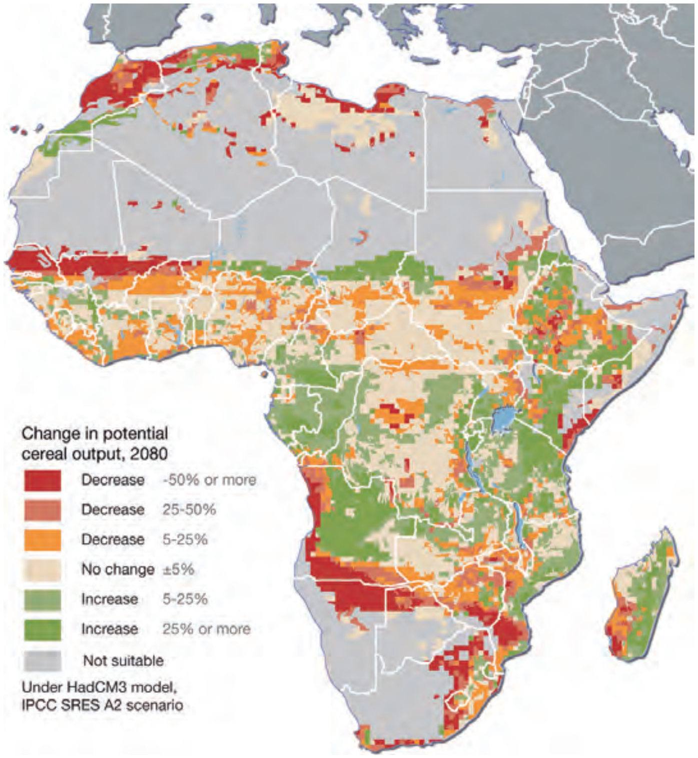


2018). In addition, African countries would be more affected by climate change because of their reliance on agriculture as well as their lower financial, technical, and institutional capacity to adapt to it (Nordhaus, 2006; Rose, 2015; Singh and Purohit, 2014; Huq et al., 2004). Eastern African countries (that is, Burundi, Eritrea, Ethiopia, Kenya, Uganda, Tanzania, Rwanda, and Somalia) were among the vulnerable countries to the effects of drought due to its dependency on rainfed agriculture. Feyssa and Gemeda (2015) alerted that climate change mainly affects the rainfed agricultural sectors in technological and economically less developed countries in Africa. Due to drought, by 2100, arid and semi-arid regions of Africa are expected to expand by 5-8%, or 60-90 million hectares, resulting in agricultural losses of between 0.4-7% of gross domestic product (GDP) in Northern, Western Central and Southern Africa (IPCC, 2007).

The IPCC's most recent regional report certainly raises the spectre of rising mortality. It predicts a minimum 2.5°C increase in temperature in Africa by 2030; drylands bordering the deserts may get drier, wetlands bordering the rainforests may get wetter. The panel suggests the supply of food in Africa will be "severely compromised" by climate change, with crop yields in danger of collapsing in some countries. In this sense, a model of Met Office (UK), designed to predict global food supply security (Figure 3.11), shows, in general, an increase in food supply insecurity in Africa in the future.

Rattani (2017) identifies a few reasons why climate change impacts are more pronounced in Africa. One, agriculture is largely rainfed and underdeveloped; two, 90 % of the farms are small yet contribute to 80 % of the total food production; and three, a majority of the farmers have few financial resources, limited access to infrastructure and extremely limited access to weather and technological information.

Figure 3.12. Model of climate change effects on cereal crops in Africa. Source: Geothinking (2012).



The type of crops and cropping calendars and production levels in Africa are very diverse. The effects of changes in both temperature and precipitation may be different for the different farming systems, i.e. irrigated or rainfed crops, large-scale and small-scale farms. The increasingly unpredictable and erratic nature of weather systems on the continent have placed an extra burden on food security and rural livelihoods (FAO, 2009).

As an example, the continental scale of cereal production in Africa (Figure 3.12), it could be seen that climate change will increase crop yields in the equatorial area. On the other hand, in tropical areas crop yields are projected to decrease. At first glance, the effects seem to be balanced, but in fact, tropical areas are very vulnerable because they are already arid (perimeters of the Sahara and Kalahari deserts). Reducing harvests in these areas could pose a significant risk to the food supply (Geothinking, 2012). Projections on yield reduction show a drop of up to 50% and crop revenue is forecast to fall by as much as 90% by 2100 (Rattani, 2017).

In summary, climate change is expected to be harmful to crop farming in Africa. However, there may be expected to be gains and losses specific to each farming system and each agroclimatic region. Policy makers should identify where the gains and losses might be, and direct the appropriate policies and adaptation strategies to these areas.

4
Core principles of Conservation Agriculture

Conservation Agriculture (CA) is one of the most studied and most developed agro-sciences in the world (Lichtfouse et al., 2010). FAO defines Conservation Agriculture as an approach to managing agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment. CA is characterised by the practical application of three linked principles, along with other complementary good agricultural practices of crop and production management, namely (FAO, 2018):

- Principle 1: Continuous no or minimal mechanical soil disturbance (implemented by the practice of no-till seeding or broadcasting of crop seeds, and direct placing of planting material into untilled soil; no-till weeding and causing minimum soil disturbance from any cultural operation, harvest operation or farm traffic);
- Principle 2: Maintenance of a permanent biomass soil mulch cover on the ground surface (implemented by retaining crop biomass, root stocks and stubbles and cover crops and other sources of ex-situ biomass); and
- Principle 3: Diversification of crop species (implemented by adopting a cropping system with crops in rotations, and/or sequences and/or associations involving annuals and perennial crops, including a balanced mix of legume and non-legume crops).

Conservation Agriculture is not a single technology but a systems approach to farming based on a set of linked complementary practices that should be implemented in combination with other good technologies and practices by the farmers in order to obtain full benefits. These practices cover a large range of expertise from equipment and machinery to soil management, residue management and cover crops to pest and diseases management to nutrient and water management including crop and cropping system management.

Why is Conservation Agriculture needed?

Conventional farming practices, in particular, tillage and crop residue burning, have substantially degraded the soil resource base (Montgomery, 2007; Farooq et al., 2011), with a concomitant reduction in crop production capacity. Under conventional farming practices, continued loss of soil is expected to become critical for global agricultural production (Farooq et al., 2011). In conventional farming, farmers plough and hoe to alter the soil structure and control weeds. But in the long term, they actually destroy the soil structure and function and contribute to declining soil fertility and productivity.

However, until now, agricultural intensification based on intensive tillage systems, generally has had a negative effect on the quality of many of the essential natural resources such as soil, water, terrain, biodiversity and the associated ecosystem services provided by nature (Montgomery, 2007; Kassam et al., 2013; Dumanski

Conservation Agriculture aims at reducing and/or reverting many negative effects of conventional tillage farming practices et al., 2014). This degradation of the land resource base has caused crop yields and factor productivities to decline and promoted the search for an alternative paradigm that is sustainable as well as profitable (Goddard et al., 2006; Jat et al., 2014; Farooq & Siddique, 2014). Conservation Agriculture involves changing many conventional farming practices as well as the mindset of farmers to overcome tillage-based agriculture.

Conservation Agriculture aims at reducing and/or reverting many negative effects of conventional tillage farming practices such as soil erosion (Putte et al. 2010), soil organic matter (SOM) decline, water loss, soil physical degradation, and fuel use (Baker et al. 2002; FAO 2008). For instance, soil erosion, water losses from runoff, and soil physical degradation may be minimized by reducing soil disturbance and maintaining soil cover (Serraj and Siddique, 2012). Using organic materials as soil cover and including legumes in rotations may help to address the decline in SOM and fertility (Marongwe et al., 2011). With less soil disturbance less fuel is needed, resulting in lower carbon dioxide emissions (West and Marland, 2002; Hobbs and Gupta, 2004; Govaerts et al., 2009). CA helps improve biodiversity in the natural and agro-ecosystems (Friedrich et al., 2012). Moreover, yield levels in CA systems are comparable and even higher than traditional intensive tillage systems (Farooq et al., 2011; Friedrich et al., 2012) with substantially less production costs.

Africa faces unprecedented challenges for food security. It is estimated that production should increase by 70% as a whole, but 100% in developing areas, in order to feed its population in the year 2050 (FAO, 2010) without damaging natural resources. CA is increasingly promoted as a concept of crop production to a high and sustained production level to achieve acceptable profit, while. Conservation Agriculture is a holistic system that complemented by other known good practices, including the use of quality seeds, and integrated pest, nutrient, weed and water management, conform the basis for sustainable agricultural production intensification, able to save resources along with conserving the environment (FAO, 2011).

What is not Conservation Agriculture?

Agricultural practices based on the reduced use of the plough have been adopted from diverse scientific sources and countries, even before FAO established the definition of CA. This has led to the lack of accuracy of CA perception, which still happens nowadays. For instance, from the standpoint of machinery manufacturers, the interpretation of CA principles has resulted in conceptual problems such as the use of incorrect terms. As an example, small mouldboard ploughs that penetrate soil less than 15 cm, shallower than the traditional over 25 cm, are presented as a valid "conservation" equipment (Ovlac, 2014). Similarly, combination cultivator seed drill that prepares seedbeds with only one tillage operation, disturbing soil and leaving less than 30% of crop residue, is sometimes wrongly considered as a no-tillage equipment. Table 4.1 shows several common techniques and their synonyms with an indication of whether they can be considered eligible as a CA practice.

Table 4.1. Agricultural practices, their synonyms and eligibility within Conservation Agriculture. Adapted from: González-Sánchez et al. (2015).

Crops	Technique	Synonyms	Can be considered as a CA practice?	Observations
Annual	No-tillage	Zero tillage	Yes	Normally more than 30% of the surface is covered with previous crop biomass cover after sowing
	Minimum tillage	Reduced tillage	No	Minimum tillage usually includes 3 or more plough passes, which do not leave more than 30% of the soil covered. All field is ploughed.
	Strip-till		Yes	Shallow tillage done only in the rows of planting. Less than 25% of soil is disturbed. It is practised on coarse grain crops (corn, sunflower,…).
Woody/ Permanent	Groundcovers		Yes	More than 30% of the soil is covered by a vegetal groundcover.

History and development of Conservation Agriculture in the world

Agricultural intensification based on tillage-based agriculture, has, at all levels of economic development, had a negative effect on the quality of the essential natural resources such as soil, water, terrain, biodiversity and the associated ecosystem services provided by nature (Kassam et al., 2018).

In the 1930s, tillage, the mechanical disturbance of soil, was questioned because in the central plains of the USA, after years of extreme drought started events of very intense wind erosion known as Dust Bowl, where millions of tonnes of soil were lost. These events were recorded by filmmaker Pare Lorentz for the United States Department of Agriculture (USDA) in the short documentary film "The Plow That Broke the Plains", where the tillage was already related to soil erosion (Lorentz, 1936). With time, the concept of protecting soil, by reducing tillage and keeping the soil covered, gained popularity. In response, seeding machinery developments allowed then, in the 1940s, to seed directly without any soil tillage. Another important fact was the creation of the US Soil Conservation Service in 1935. During the 1940s, universities, the USDA and farming companies began an intense research plan that resulted in several advances. In 1946, the University of Purdue developed the first seeded for NT (M-21). In the 1950s the corrugated cutting disc was introduced as well as the treatments with atrazine and paraquat. In the 1960s, NT was presented as a viable technique for farming (McKibben, 1968). Increased fuel prices during the 1970s attracted farmers to shift towards resource-saving farming systems (Haggblade and Tembo, 2003). In this scenario, commercial farmers adapted CA to combat drought-induced soil erosion together with the fuel saving (Haggblade and Tembo, 2003).

During the early 1970s, no-tillage was introduced in Brazil and no-tillage and mulching were tested in West Africa (Greenland, 1975; Lal, 1976). The CA experience in the USA helped motivate the CA movement in South Africa and South America (Haggblade and Tembo, 2003). Nonetheless, CA took more than 20 years to reach significant adoption levels in South America (Friedrich et al., 2012). During this time, farm equipment and agronomic practices in no-tillage systems were improved and developed to optimize crop performance and machinery, and field operations (Friedrich et al., 2012).

In the early 1990s, the spread of CA hastened, which revolutionized farming systems in Argentina, southern Brazil, and Paraguay (Friedrich et al., 2012). During this time, several international organizations became interested in the promotion of CA. Participation of these organizations in the promotion of these conservation farming systems led to the adoption of these systems in Africa (Tanzania, Zambia, and Kenya) and some parts of Asia (Kazakhstan, China, India, and Pakistan). CA systems then made their way to Canada, Australia, Spain, and Finland.

Over the past 40 years, farmer-led empirical evidence and scientific evidence from different parts of the world has been accumulating to show that CA concepts and principles have universal validity, and that CA practices, devised locally to address prevailing ecological and socio-economic constraints and opportunities, can work successfully to provide a range of productivity, socio-economic and environmental benefits to the producers and the society at large (Goddard et al., 2008; Reicosky, 2008; Derpsch & Friedrich, 2009a; 2009b; Kassam et al., 2009, 2017; FAO, 2008, 2010).

Summary, in a nutshell, since the 1930s, farming communities have gradually shifted towards no-tillage systems for potential fossil-fuel savings, reduced erosion, and runoff, and to minimize SOM loss. The first 50 years was the start of the conservation tillage movement and, today, a large percentage of agricultural land is cropped following CA principles (Hobbs et al., 2008; Kassam et al., 2018). Sustained governmental policies and institutional support may play a key role in the promotion of CA both in rainfed and irrigated cropped lands by providing incentives and required services to farmers to adopt CA practices and advance them over time (FAO 2008; Friedrich and Kassam, 2009; Friedrich et al., 2009; Kassam et al., 2009; Friedrich et al., 2012). Table 4.2 summarizes key milestones in the history of Conservation Agriculture.

Table 4.2. History of Conservation Agriculture. Adapted from Farooq and Siddique (2015).

Year	Milestone	Reference
1930	Great dust bowl and start of conservation agriculture in the USA	Hobbs et al. (2008)
1940	Development of direct seeding machinery, first no-till sowing	Friedrich et al. (2012)
1943	Book on no-till in modern agriculture entitled “Plowman’s Folly” by Faulkner	Faulkner (1943)
1950	No-till, direct-sowing of crops was first successfully demonstrated in the USA	Harrington (2008)
1956	Experiments on various combinations of tillage and herbicides were initiated	Lindwall and Sonntag (2010)
1960	Commercial adoption of no-till in the USA	Lindwall and Sonntag (2010); Friedrich et al. (2012)
1962	Paraquat was registered as first herbicide for broad-spectrum weed control	Lindwall and Sonntag (2010)
1962	Long-term no-till experiments were started in Ohio, USA; the experiments are still running	Perszewski (2005)
1964	First no-till experiments in Australia	Barret et al. (1972)
1966	Demonstration trials on direct drilling systems in Germany	Bäumer (1970)
1967	Demonstration trials on direct drilling systems in Belgium	Cannel and Hawes (1994)
1968	First no-tillage trials in Italy	Sartori and Peruzzi (1994)
1969	Introduction of CA in West Africa	Greenland (1975); Lal (1976)
1970	First no-till demonstration in Brazil	Borges (1993)
1970	Long-term no-till experiments were started in France	Boisgontier et al. (1994)
1970	First report on the development of herbicide resistance in weeds	Ryan (1970)
1973	Phillips and Young published the book “No-Tillage Farming.” This publication was a milestone in no-tillage literature, being the first one of its kind in the world	Derpsch (2007)
1974	First no-till demonstration in Brazil and Argentina	Friedrich et al. (2012)
1975	Book on CA entitled “One straw revolution” by Fukuoka	Fukuoka (1975)
1976	Glyphosate was registered for general broad-spectrum weed control	Lindwall and Sonntag (2010)
1980	Introduction and on-farm demonstration of CA in the subcontinent	Harrington (2008)
1980	Introduction of CA in Zimbabwe	Friedrich et al. (2012)
1981	The first National No-till Conference held in Ponta Grossa, Paraná, Brazil	Derpsch (2007)
1982	Introduction of no-till in Spain	Giráldez and González (1994)
1990	Development and commercial release of reliable seeding machines	Lindwall and Sonntag (2010)
1990	Commercial adaptation of CA in southern Brazil, Argentina, and Paraguay	Friedrich et al. (2012)
1990	Introduction of CA in India, Pakistan, and Bangladesh	Friedrich et al. (2012)
1992	Start of CA research in China	Derpsch and Friedrich (2009)
2002	Introduced no-tillage systems in Kazakhstan	Derpsch and Friedrich (2009)

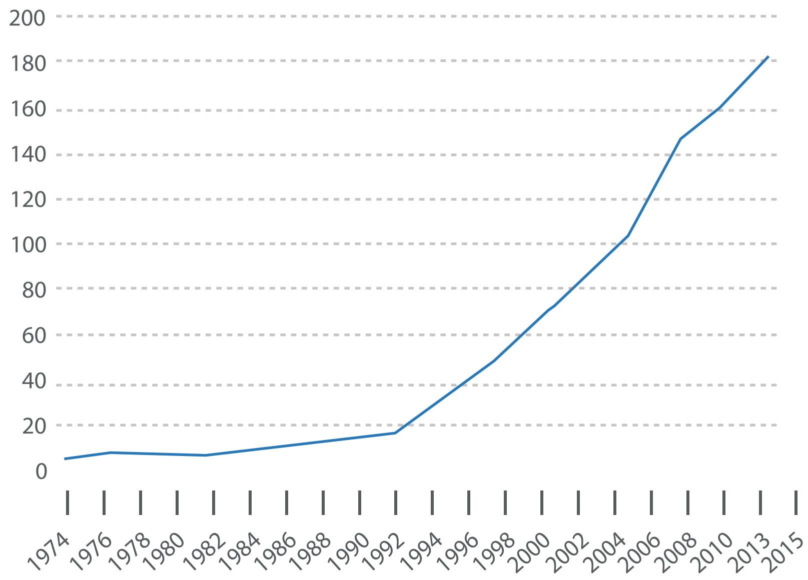


Figure 4.1.
Evolution of the adoption of Conservation Agriculture worldwide. Adapted from Kassam et al. (2018).

Adoption of Conservation Agriculture worldwide

The information below is mainly derived from the work of Kassam et al. (2018). Conservation Agriculture systems are now in existence in all continents in all land-based agriculture, supporting the notion that CA principles are universally applicable to all agricultural landscapes and land uses with locally formulated and adapted practices. Nowadays, CA is practised on over 180 million hectares across the globe.

Conservation Agriculture crop production systems are popular worldwide. There are few countries where CA is not practised by at least some farmers and where there are no local research results about CA available. The total cropland area under CA in 2008/09 was estimated to be 106 M ha. By 2010/11, the global spread of CA had to be corrected from the original estimates of 125 M ha to 145 M ha because it had not been possible to record all the increases. For 2013/14, the global total CA cropland area was initially estimated to be 155 M ha but was corrected to be 157 M ha because of the increase in CA area in Argentina which had not been reported at the time of the 2013/14 figures (see database at http://www.fao.org/ag/ca/6c.html). As reported by Kassam et al. (2018), the latest global estimate for CA cropland reported for 2015/16 is about 180 M ha.

Conservation Agriculture systems are widely adaptable. Their presence extends from the equatorial tropics (e.g., Kenya, Tanzania, Uganda) to the arctic circle (e.g., Finland) North and to about 50º latitude South (e.g., Falkland Islands); from sea level in several countries of the world to 3,000 m altitude (e.g., Bolivia, Colombia);

Table 4.3. Cropland under CA (M ha) by continent in 2015/16; CA area as % of global total cropland, and CA area as % of cropland of the countries. Source: Kassam et al. (2018).

Region	CA cropland area (M ha)	Per cent of global CA cropland area	Per cent of cropland area in the region
South America	69.9	38.7	63.2
North America	63.2	35.0	28.1
Australia & New Zealand	22.7	12.6	45.5
Asia	13.9	7.7	4.1
Russia & Ukraine	5.7	3.2	3.6
Europe	3.1	1.7	4.3
Africa	1.5	0.8	1.1
Global total	**180.4**	**100**	**12.5**

from heavy rainfall areas with 2,000 mm a year (e.g., Brazil) or 3,000 mm a year (e.g., Chile) to extremely dry conditions in the Mediterranean environments with 250 mm or less a year (e.g., Morocco, Syria, Western Australia).

Conservation Agriculture in Africa

Conservation practices are not new to African agriculture. In Africa's agricultural development, the 1960s and 1970s could be described as the mechanisation era, i.e. when most African countries, just after political independence, embarked on extensive agricultural mechanisation, particularly increasing agricultural output from increased area under cultivation.

African farmers developed conservation systems many centuries ago as it was considered the most natural way of agriculture. With the arrival of colonialism coming from occident and the introduction of the plough these conservation practices were stopped (Fowler, 2000). In the last two to three decades, there have been numerous efforts at some sort of conservation farming or sustainable farming practices. These range from practices directed and enforced by government legislation to agronomic recommendations developed and promoted by and through government and NGO agricultural extension services.

In the 1980s as limitations to sustain the mechanisation interventions become more apparent, with development organisations and NGOs more coming on the scene, efforts to promote increased performance in the agricultural sectors moved to embrace other strategies and technologies. Since the mid-1990s, FAO in association with non-governmental organizations, national governments and various research and development institutions, promoted the introduction of CA for agricultural development and the livelihoods of small farmers in Africa.

A key milestone was the establishment in 1998 of the African Conservation Tillage Network (ACT). This pan-African not-for-profit organization has evolved into an open platform for stimulating and facilitating the sharing of information and knowledge on experiences and

lessons on the promotion of CA. ACT brings together stakeholders in the public, private and civil sectors dedicated to improving agricultural productivity and resilience through the sustainable utilization of production inputs and of natural resources of land, water and biodiversity in Africa's farming systems. The thrust of ACT is to add strategic value to local, national and international efforts to introduce and scale CA for sustainable agriculture and rural development (ACT, 2018).

There are currently a number of national, regional and international initiatives supporting and/or facilitating the promotion of Conservation Agriculture in Africa. These include development efforts supporting direct technology development/adaptation and adoption to Networks, Projects and NGOs facilitating the exchange of experiences and information among stakeholders and players within and between countries/regions (Baudron et al., 2014; Kassam et al., 2017). One of the longer-term projects or programs, which began in 1996 and is still ongoing, has been a program of support for the CA initiated in collaboration by the governments of Norway and Zambia, which has achieved remarkable achievements. More recently, the Alliance for a Green Revolution in Africa (AGRA) sponsored by Gates Foundation and Rockefeller

Foundation began supporting CA in partnership with ACT from 2012 through their Soil Health Projects in Kenya and Tanzania. In addition, there are several national level NGOs that are promoting CA, namely: Kwa-Zulu Natal No-till Association in South Africa, CFU in Zambia, Foundation for Development in Zimbabwe, among others (Kassam and Mkomwa, 2017)

The private sector has also contributed significantly to the current situation of the CA in Africa. Major stakeholders include large-scale farmers (i.e. in South Africa, Kenya, Tanzania, Zambia and Zimbabwe), CA equipment manufacturers and distributors, and suppliers of agricultural inputs. The implementation of CA, especially in marginal and diverse conditions, has provided useful learning platforms for other farmers, responsible for formulating policies and development.

The focus of most CA initiatives has been on food security and livelihood development; participatory adaptive research with smallholder farmers for technology development for sustainable production, and advocacy for public and private sector support. Such initiatives are bound to have significant implications for adoption and spread of CA in the region and need to be supported and encouraged.

Finally, the Africa Congresses on Conservation Agriculture organized by ACT and their partners serve for raising awareness and exchange of information within the region. The African Conservation Tillage Network (ACT), the Government of Zambia and in close liaison with partners convened the 1st Africa Congress on Conservation Agriculture (IACCA) which was held in Lusaka, Zambia, in 2014 (Kassam et al., 2017). The Congress brought together 414 delegates from 42 African and other countries of the world to share experiences and lessons and facilitate alliances to unblock hindrances to expanded and scaled-up adoption of CA, especially among the smallholder farming systems and related industry in Africa. In order to achieve the CAADP goal of 6% growth of the agricultural sector, the participants made a 10 points declaration (http://www.africacacongress.org/) that support the upscaling of CA as a climate-smart technology in Africa. Another milestone will be the 2nd ACCA, which will be held in October 2018 in Johannesburg.

Adoption of CA in Africa

Conservation Agriculture has been shown to be relevant and appropriate for small and large scale farmers at all levels of farm power and mechanization, from manually-operated hand tools to equipment drawn by animals to operations performed by heavy machinery. However, despite the inherent benefits of CA, this form of agriculture is scarcely adopted in Africa in relation to other parts of the world (Table 4.3). Kassam and Mkomwa (2017) indicated the reasons for the slow spread adoption of CA compared to other continents: (i) continued promotion and development support of tillage-based agricultural systems by national and international, public and private institutions; (ii) weak policies and regulatory frameworks and institutional arrangements to support the promotion and mainstreaming of CA; (iii)

Figure 4.2.
No-till field in Africa.

inadequate awareness, knowledge and expertise of CA systems and the process of their adoption and spread among policymakers, academic, research, extension and technical staff; (iv) inappropriate CA technology packaging and dissemination; (v) inadequate CA-based enterprise diversification and integration in farming systems; (vi) inability of smallholders to diversify crop rotations, sequences and combinations; (vii) inadequate skills and competencies among farmers and other CA practitioners; (viii) farmers' inability to maintain year-round soil cover through the use of specially introduced cover crops, intercrops and crop residue; (ix) poor availability and access to the required CA equipment, machinery and inputs; and (x) absence of a strong continental body and strategic policy framework to guide the promotion and mainstreaming of CA across Africa.

The development of CA practices has not been uniform throughout the territory. As an example, its application in Kenya and Tanzania identified a relatively high CA adoption potential. The following factors, however, are noticed to require further improvement: accessibility of markets for CA products and inputs; adaptation of machinery and seeds to the CA practices; introduction of quality implementation measures; and a renewed motivation (interest) among CA service providers (Ndah et al., 2015).

Table 4.4 shows the current area under Conservation Agriculture in Africa. In 2008/09, CA was reported in

Conservation Agriculture has been shown to be relevant and appropriate for small and large scale farmers

Country	CA area 2008/09	CA area 2013/14	CA area 2015/16
South Africa	368.00	368.00*	439.00
Zambia	40.00	200.00	316.00
Kenya	33.10	33.10*	33.10#
Zimbabwe	15.00	90.00	100.00
Sudan	10.00	10.00*	10.00#
Mozambique	9.00	152.00	289.00
Tunisia	6.00	8.00	12.00
Morocco	4.00	4.00	10.50
Lesotho	0.13	2.00	2.00
Malawi	-	65.00	211.00
Ghana	-	30.00	30.00#
Tanzania	-	25.00	32.60
Madagascar	-	6.00	9.00
Namibia	-	0.34	0.34#
Uganda	-	-	7.80
Algeria	-	-	5.60
Swaziland	-	-	1.30
Total	**485.23**	**1,235.34**	**1,509.24**
Difference %		**154.6 since 2008/09**	**211.0 since 2008/09 22.2 since 2013/14**

*from 2008/09 update; # from 2013/14 update

Table 4.4.
Extent of CA adoption ('000 ha) in Africa in the 2008/09, 2013/14 and 2015/16 updates.

nine countries, but in 2013/14 there were 14 countries with area under CA, and in 2015/16, 17 countries. The total area of CA in Africa in 2015/16 is more than 1.5 M ha, an expansion of some 211% since 2008/09, from 0.48 M ha. From expert knowledge expressed at the 1st Africa Congress on Conservation Agriculture in March 2014, CA is expected to increase food production with fewer negative effects on the environment and energy costs, and to result in the development of locally-adapted technologies consistent with CA principles (Kassam et al., 2018).

In Africa, innovative participatory approaches are being used to develop supply- chains for smallholders to access CA equipment. Similarly, participatory learning approaches such as those based on the principles of farmer field schools (FFS) and lead-farmer networks are being encouraged to explain the ecological principles underlying CA and to make it attractive for use in local farming (Kassam et al., 2018).

Conservation Agriculture is spreading in eastern and southern Africa, and North Africa, using indigenous and scientific knowledge, and equipment

Figure 4.3. Two-wheel tractor equipped with a no-till seeder.

design from Latin America. There is now also a collaboration with China, Bangladesh and Australia, and CIMMYT, ICARDA, ICRISAT, ICRAF, CIRAD, ACT, FAO, IFAD, AfDB and NGOs. These have all stimulated the trend to have local practices and local equipment, with advantages in maintenance and repair. Farmers in at least 22 African countries are promoting CA (Kenya, Uganda, Tanzania, Rwanda, Sudan, Ethiopia, Swaziland, Lesotho, Malawi, Madagascar, Mozambique, South Africa, Namibia, Zambia, Zimbabwe, Ghana, Burkina Faso, Senegal, Cameroon, Morocco, Tunisia, Algeria). CA has also been incorporated into the regional agricultural policies by NEPAD, and it is recognized as a core element of climate-smart agriculture (Kassam et al., 2018).

Conservation Agriculture systems help Africa's resource-poor farmers to maintain subsistence with sustainability, so as to meet the challenges of climate change, high energy costs, environmental degradation, and labour shortages. The CA area is still relatively small, mainly because of the small land holdings as well as greater attention being paid to the promotion of conventional tillage agriculture, without much success. But there is now a developing trend, a CA movement of some two million small-scale farmers on the continent (Kassam et al., 2018).

5
Conservation Agriculture: a sustainable intensification of agriculture

There is a need to eradicate hunger and food insecurity in this world including in Africa and a sustainable intensification of agriculture, with a focus on soil and water conservation, is part of the solution (Conway, 2012). Sustainable intensification is a common term in discussions around the future of agriculture and food security. Sustainable intensification has been defined as a form of production wherein "yields are increased without adverse environmental impact and without the cultivation of more land" (MacDermott et al., 2010). The concept is thus relatively open, in that it does not articulate or privilege any particular vision of agricultural production (Garnett and Godfray, 2012; Smith, 2013). It emphasizes ends rather than means and does not pre-determine technologies, species mix or particular design components. However, we would emphasise the intensification of yields while reducing the application of production inputs.

"Sustainable intensification of agriculture" denotes an aspiration of what needs to be achieved, rather than a description of existing production systems, whether this is conventional high-input farming, or smallholder agriculture, or approaches based on organic methods (Pretty, 2014). While the intensification of agriculture has long been the subject of analysis (Boserup, 1965), sustainable intensification is a more recent concern (FAO, 2018). Compatibility of the terms 'sustainable' and 'intensification' was hinted at in the 1980s (e.g. Raintree and Warner, 1986; Swaminathan, 1989), and then first used in conjunction in a paper examining the status and potential of African agriculture (Pretty, 1997). Until this point, 'intensification' had become synonymous for a type of agriculture that inevitably caused harm whilst producing food (e.g. Collier *et al*., 1973; Poffenberger and Zurbuchen, 1980; Conway and Barbier, 1990). Equally, 'sustainable' was seen as a term to be applied to all that could be good about agriculture. The combination of the terms was an attempt to indicate that desirable ends (more food, better environment) could be achieved by a variety of means (Foresight, 2011; FAO, 2011).

During the green revolution era, the approach of "more inputs-more outputs" has been followed, which is considered as ecologically intrusive and economically and environmentally unsustainable against the suboptimal and inefficient use of inputs. The resource-intensive agricultural production system practised, especially during the post-green revolution era, has led to challenges like declining factor productivity, soil health deterioration, multiple nutrient deficiencies, depleting water table at an alarming rate, loss of biodiversity due to monotonous crop rotations, etc., rendering the agricultural production system unsustainable (Jat et al., 2016). Therefore, intensification of the agricultural system through efficient resource use remains the only available option to enhance production with no additional land expansion, as competition for land and water is increasing from the non-farm sectors. This warrants a paradigm shift in agronomic management optimization, not only to produce more but with a higher efficiency of use of production inputs while sustaining the natural resource base and reducing environmental footprints (Jat et al., 2016).

Sustainable intensification can be distinguished from former conceptions of 'agricultural intensification' as a result of its explicit emphasis on a wider set of drivers, priorities, and goals than solely productivity enhancement (Table 5.1).

CA is often described as a key toolbox in the transition of farming systems to higher levels of productivity without overusing natural resources

	Conventional forms of agricultural intensification	Sustainable intensification
Primary goals of farmers	Increase crop and livestock yields.	Improve yields and incomes, improve natural capital in on- and off-farm landscapes, build knowledge and social capital.
Knowledge development	Tends to be solely 'expert' driven.	Collaborations between 'experts' and other stakeholders as key to the emergence of agroecological design; participatory research and development lead to new technologies and practices.
Knowledge dissemination	Conventional extension chain from public or private research to farmers.	Conventional extension combined with participatory dissemination via peer-to-peer learning.
Stewardship of ecosystem services	Emphasis on provisioning services derived from agricultural landscapes; use of external inputs to substitute for regulating and supporting services; interactions with surrounding non-agricultural landscapes treated as externalities.	Greater appreciation of the contribution of multiple ecosystem services provided by agricultural landscapes and awareness of the two-way relationship between agricultural and non-agricultural components of landscapes.

Table 5.1. Differences between sustainable intensification and historically conventional forms of agricultural intensification. Source: Pretty and Bharucha (2014)

Conventional thinking about agricultural sustainability has often assumed that it implies a net reduction in input use, thus making such systems essentially extensive (requiring more land to produce the same amount of food). Organic systems often accept lower yields per area of land in order to reduce input use and increase the positive impact on natural capital. However, such organic systems may still be efficient if management, knowledge, and information are substituted for purchased external inputs. Recent evidence shows that successful agricultural sustainability initiatives and projects arise from shifts in the factors of agricultural production (e.g. from the use of fertilizers to nitrogen-fixing legumes; from pesticides to emphasis on natural enemies of pests; from ploughing or tillage to zero-tillage). A better concept is one that centres on the intensification of resources, making better use of existing resources (e.g. land, water, and biodiversity) and technologies (IAASTD, 2009; Royal Society, 2009; NRC, 2010; Foresight, 2011; FAO, 2011; Tilman *et al.*, 2011).

At present, there is a need for a paradigm shift in agronomic management practices to produce more and with higher efficient use of inputs. For this, conscious efforts must be made to replace unsustainable elements of the conventional-tillage-based monoculture production systems with high productivity in time and space and profitably sustainable intensification. Conservation Agriculture (CA) embraces the concept of sustainable intensification of agriculture, where not only social and environmental issues are involved, but also the economic profitability for farmers (Figure 5.1). Achieving real sustainable agriculture is possible through large-scale adoption of CA as a vehicle for

Figure 5.1. Three components of sustainability. Source: Authors' elaboration.

change. As a result of the measurable sustainability of CA, its principles are included in sustainability calculators, that comprise a holistic view of sustainability and productivity (INSPIA, 2018).

The impact of agriculture on ecosystems through erosion, pollution of water bodies and greenhouse gas emissions is also felt outside the actual agricultural area. However, CA together with other complementary "good agricultural practices" can significantly contribute to a reduction of this impact. Kassam et al. (2009) summarized the benefits as follow:

- Land: CA reverses soil degradation processes and builds up soil fertility and productive capacity. It facilitates a better infiltration of rainwater, enabling the recharge of groundwater resources while at the same time reducing the pollution of water bodies through reduced erosion and leaching. It also increases biodiversity in the agricultural production systems. CA conserves and enhances natural resources while maintaining and sustainably increasing production levels.
- Water: With this, it does not only contribute to a reduced displacement of soil, but it also reduces the pollution of water bodies.
- Air: Burning of crop residues is generally not practised under CA and also tillage and seedbed preparation, that creates considerable dust

problems in some parts of the world, are not practised. With this the air becomes cleaner.

- Landscape: The avoidance of ploughing or tillage in CA facilitates the introduction of trees and hedgerows into the agricultural landscape in a closer vicinity of field crops than under tillage-based agriculture. The greater diversity in the crop rotations also contributes to a more diverse and pest-free landscape.

- Climate Change: CA can contribute to reduced greenhouse gas emissions from agricultural crop production through reduced fuel use, better aeration of soils that reduces nitrous oxide emissions and, in no-till non-flooded rice (CA-SRI), methane emissions. In addition, it binds atmospheric carbon in the soil in the form of soil organic matter. With this, CA helps to mitigate climate change.

Many of the benefits under the no-till component and under the mulch cover component are not possible under tillage agriculture. Beneficial biological activity, including that of plant roots and soil microorganisms, thus occurs in the soil where it maintains and rebuilds soil architecture, competes with potential in soil pathogens, contributes to soil organic matter and various grades of humus, and contributes to capturing, retention, chelation and slow release of plant nutrients. The key feature of a sustainable soil ecosystem is the biotic actions on organic matter in suitably porous soil. Thus, 'conservation-effectiveness' encompasses not only conserving soil and water, but also the biotic bases of sustainability (Kassam et al., 2009).

The agricultural revolutions of the 20th century chiefly focused on reducing undernutrition, seeking to boost the availability of calories through increased production of cereals and other staples. Yet, at the global level, about 1 billion people remain undernourished, equivalent to one in eight of the global population (FAO, 2013; Conway, 2012), and many countries failed to meet the Millennium Development Goal target of halving the number of hungry people by 2015 (Gómez et al., 2013). The situation across the African continent remains particularly urgent. Of 34 countries requiring external food assistance in 2013, 27 were in Africa

Table 5.2.
Summary of productivity outcomes from case studies. Source: Pretty et al. (2010).

Thematic focus	Area improved (ha)	Mean yield increase (ratio)	Net multiplicative annual increase in food production (thousand tonnes year¹)	Countries represented
Crop variety and system improvements	391.000	2,18	292	Ghana, Etiopia, Kenya, Malawi, Mali, Mozambique, Tanzania, Uganda, Zimbabwe
Agroforestry and soil conservation	3.398.000	1.96	747	Burkina Faso, Cameroon, Malawi, Niger, Zambia
Conservation Agriculture	26.057	2,20	11	Kenya, Lesoto, Tanzania, Zimbabwe
Integrated pest management	3.327.000	2,24	1.416	Benin, Burkina Faso, Kenya, Mali, Niger, Rwanda, Senegal, Uganda
Horticulture and very small-scale agriculture	910	nd	nd	Kenya, Tanzania
Livestock and fodder crops	303,25	nd	nd	Burkina Faso, Kenya, Mali, Rwanda, Tanzania, Uganda
Novel regional and national partnerships and policies	5.319.840	2,05	3.318	Benin, Cameroon, Congo, Cote d' Jvore, Ghana, Kenya, Malawi, Nigeria
Aquaculture	523	nd	nd	Cameroon, Egypt, Ghana, Malawi, Nigeria
Total	**12.753.000**	**2,13**	**5.786**	

Table 5.3.
Comparison of different agricultural practices regarding environmental problems. * Abbreviations: CT: Conventional tillage; GC: Groundcovers; DS: Direct Seeding; MT: minimum tillage. GC 30%: Groundcovers present in 30% of the surface between the rows of trees; GC 60%: idem 60%; GC 90%: idem 90%. Effect on the environment: + slightly positive; +++++ very positive; - negative or indifferent. Source: Gonzalez-Sanchez et al. (2015).

Crops	Soil management	Erosion	Soil organic matter	Compaction	Climate change mitigation	Bio-diversity	Water quality	Safety of plant protection products application
Annual	CT	+	+	++	-	-	+	+
	MT	+	+	++	-	++	++	++
	DS	++++	++++	++++	++++	+++	++++	++++
	DS+GC	+++++	+++++	+++++	+++++	+++++	+++++	+++++
Permanent	GC 30%	++	++	++	++	++	++	+++
	GC 60%	+++	+++	+++	+++	+++	+++	++++
	GC 90%	+++++	++++	+++++	+++++	+++++	+++++	+++++

(FAO, 2013). Without significant effort, 500 million will still be food insecure in the region by 2020 (Shapouri et al., 2020; Smith, 2013).

In relation to Africa, despite the improvements made in African agriculture, continued population growth means that the per capita availability of domestically grown food has not changed at the continent-scale for 50 years and has fallen substantially in three regions (Pretty et al., 2011). As a result, hunger and poverty remain widespread in Africa. Of the 1.02 billion people hungry in 2009–10, it is estimated that 265 million are in sub-Saharan Africa and 642 million in Asia and the Pacific (FAO, 2009). For every 10% increase in yields in Africa, it has been estimated that this leads to a 7% reduction in poverty (more than the 5% in Asia) (World Bank, 2008; Wiggins and Slater, 2010).

Pretty et al. (2010), indicated that a review made from 40 projects and programmes from 20 countries of Africa where sustainable intensification has been developed, promoted or practised in the 2000s (some with antecedents in the 1990s). This analysis had a range of different themes, comprising crop improvements, agroforestry and soil conservation, CA, integrated pest management, horticulture, livestock and fodder crops, aquaculture, and novel policies and partnerships (Table 2). By early 2010, these 40 projects had documented benefits for 10.39 million farmers and their families and improvements on approximately 12.75 million ha.

CA is often described as a key toolbox in the transition of farming systems to higher levels of productivity without overusing natural resources (Kassam et al., 2009; Silici et al., 2011). It is an approach within the concept of sustainable intensification, which aims at producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services. CA is based on three pillars that include (a) a minimum to zero soil disturbance, (b) a permanent soil mulch cover via crop biomass retention on the soil surface, cover crops or agroforestry tree species, and (c) crop diversification through crop rotations and/or intercropping or associations involving annuals and perennials including legumes (Kassam et al., 2009; Mutua et al., 2014). Various benefits of CA include its potential to enhance soil fertility and counter soil degradation through increasing the share of soil organic matter and improving the soil's ability to conserve water and protect its surface. In practising CA, farmers can achieve a higher and more stable yield and income from their farm compared to conventional agriculture in the long term. Moreover, agronomic innovations based on CA may provide double benefits of bringing back to production additional farming areas including some of the degraded or marginalized lands.

Wherever CA has been adopted it appears to have had both agricultural and environmental benefits. In Lesotho, Kenya, Tanzania, and Zimbabwe, it has resulted in increased and more stable yields (Marongwe et al., 2011; Owenya et al., 2011; Silici et al., 2011). Conversely, tillage-based agriculture has led to widespread soil and ecosystem degradation globally. This is especially so in Africa where traditional and modern tillage-based agricultural practices have become unsustainable due to severe disturbance and exploitation of natural resources, with negative impacts on the environment and rural livelihoods.

In Africa, CA has the potential of reversing the current annual 3% decrease in agricultural production due to soil erosion and land degradation by providing more stability in crop production and better ratios of outputs over inputs (FAO, 2009). CA provides environmental services to communities such as contributing to atmospheric carbon sequestration, preserving biodiversity, managing watersheds and preventing soil erosion (Fowler et al., 2001). Communities and societies can also benefit from the adoption of CA through improved food and water security, more reliable water supplies (Fowler et al., 2001) and protection of ecosystem services (Kassam et al., 2009).

6
Mitigation of and adaptation to climate change through Conservation Agriculture

6.1. MITIGATION OF CLIMATE CHANGE THROUGH CONSERVATION AGRICULTURE

Introduction

For many developing countries, the main concern regarding agriculture relates to food security, poverty alleviation, economic development and adaptation to the potential impacts of climate change. Two-thirds of developing countries have implemented strategic plans to mitigate greenhouse gas (GHG) emissions from agriculture (Wilkes et al., 2013).

There are many factors involved in the release of GHG emissions from agricultural soil, such as: type of soil management, soil organic matter, degree of soil mechanical disturbance through tillage and soil

temperature and moisture conditions at the time of its release, crop phenological stage, weather conditions, biomass management, among others (IPCC, 2014). In the long-term, the interactions among these factors seem to determine the balance of CO_2 emissions.

Conventional farming globally is based on soil tillage, which promotes the mineralization of soil organic matter whilst increasing the release of CO_2 into the atmosphere due to carbon oxidation. Also, tillage operations can incorporate plant crop residues into soil layers where microorganisms and moisture conditions favour their decomposition and thus more carbon oxidation. Moreover, soil tillage physically breaks down soil aggregates and leaves them exposed to the action of soil microorganisms which were encapsulated and thus protected within the soil aggregates that existed prior to the performance of tillage (Reicosky et al., 2007).

One of the consequences of management systems based on tillage is the reduction of the soil sink effect, which has as a consequence which is the decrease in the content of organic carbon (OC). This decrease is the result of (1) the lower contribution of organic matter (OM) in the form of crop stubble and biomass from previous crops; (2) the higher rate of mineralization of soil humus caused by tillage. Tillage facilitates the penetration of air into the soil and therefore the decomposition and mineralization of humus, a process that includes a series of oxidation reactions, generating CO_2 as the main byproduct. One part of CO_2 gets trapped in the porous space of the soil, while the other part gets released into the atmosphere through diffusion mechanisms between zones of the soil with different concentration; (3) the higher rate of erosion, which causes significant losses of OM and minerals. In conventional agriculture, the preparation of soil for sowing leaves the soil exposed to erosive agents for a long period of time.

For all that reasons, many authors agree that soil disturbance by tillage is one of the main causes of organic carbon reduction in the soil (Balesdent et al., 1990; Six et al., 2004; Olson et al., 2005). Reicosky (2011) argues that intensive agriculture has contributed to the loss of between 30% and 50% of soil OC in the last two decades of the 20th century. Kinsella (1995) estimates that, in only 10 years of tillage, 30% of the original OM was lost.

Another consequence of the intensive disturbance on the soil in the tillage-based agriculture are the higher CO_2 emissions (Carbonell-Bojollo et al., 2011). Tillage has a direct influence on soil CO_2 emissions both in the short term (immediately after tillage) and in the long term (during the growing season). It stimulates the production and accumulation of CO_2 in the porous structure of the soil through the processes of mineralization of OM. The mechanical action of the tillage involves a breakdown of the soil aggregates, with the consequent release of CO_2 trapped inside the soil which is therefore emitted into the atmosphere. Among the first studies on CO_2 emissions during the tillage are those carried out by Reicosky and Lindstrom (1993) and Reicosky (1997) in the central area of the USA. These authors showed that the increase in CO_2 observed just after tillage was the result of changes in soil porosity and, therefore, it is proportional to the intensity of the tillage (generated by the depth and roughness of the soil).

Therefore, mitigation actions in the agricultural sector are aimed at fixing the carbon accumulated in the oxidized

The characteristics of CA make it one of the systems best able to contribute to climate change mitigation by reducing atmospheric GHG concentration.

compound in the soil, while reducing GHG emissions. Scientists all over the world agree that the less the soil is tilled, it absorbs and stores more carbon. In addition, it is verified that groundcovers and the mechanical non-disturbance of the soil, reduce the decomposition rate of stubble and biomass mulch on the soil surface. This occurs due to a decrease in the mineralization of the soil OM, due to a less aeration and a lower possibility of the microorganisms to access it, generating an increase in soil carbon. At the same time, no-tillage farming decreases the CO_2 released into the atmosphere, because the constant tillage oxygenates the land in excess, which favours the oxidation of carbon that is emitted as CO_2.

Current and potential mitigation through Conservation Agriculture in Africa

According to the Food and Agricultural Organization of the United Nations (FAO, 2018), Conservation Agriculture (CA) is a farming system that promotes continuous no or minimum soil disturbance (i.e. no-tillage for seeding and weeding), maintenance of a permanent soil mulch cover, and diversification of plant species. It enhances biodiversity and natural biological processes above and below the ground surface, so contributing to increased water and nutrient use efficiency and productivity, to more resilient cropping systems, and to improved and sustained crop production.

Conservation Agriculture is based on the practical application of three interlinked principles:

1. Avoiding or minimizing mechanical soil disturbance involving seeding or planting directly into untilled soil, eliminating tillage altogether once the soil has been brought to good condition, and keeping soil disturbance from cultural operations to the minimum possible.

2. Maintaining year-round biomass mulch cover over the soil, including specially introduced cover crops and intercrops and/or the mulch provided by retained biomass and stubble from the previous crop.

3. Diversifying crop rotations, sequences and associations, adapted to local environmental and socio-economic conditions, and including appropriate nitrogen-fixing legumes; such rotations and associations contribute to maintaining biodiversity above and in the soil, add biologically fixed nitrogen to the soil-plant system, and help avoid build-up of pest populations. In CA, the sequences and rotations of crops encourage agrobiodiversity as each crop will attract different overlapping spectra of microorganisms and natural enemies of pests.

The characteristics of CA make it one of the systems best able to contribute to climate change mitigation by reducing atmospheric GHG concentration. On the one hand, the changes introduced by CA in the carbon dynamics in the soil lead directly to an increase in soil C (Reicosky, 1995; Lal, 2008). This effect is known as ‘soil’s carbon sink’. At the same time, the drastic reduction in the amount of tillage and the mechanical

non-alteration of the soil reduce CO_2 emissions arising from energy saving and the reduction in the rates of the mineralization of soil organic matter. CA adoption requires a much lower level of capital investment and production inputs and is thus more readily applicable to smallholder farmers in developing countries (Kassam et al, 2017).

Soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. This process is primarily mediated by plants through photosynthesis, with carbon stored in the form of soil organic carbon (SOC) (Lal, 2008). In terms of climate change mitigation, CA contributes the increase of SOC, whilst reducing the emissions of carbon dioxide. On the one hand, the decomposition of the crop biomass on the soil surface increase soil organic matter and soil organic carbon. On the other hand, emissions are reduced as a result of less soil carbon combustion due to no-tillage, and less fuel burning because of fewer field operations. The sum of the first two processes, results in an increase in the carbon sink effect in the soil, leading to a net increase of soil organic carbon; this is measured in tonnes of carbon in soil per hectare and year (t ha^{-1} yr^{-1}).

Numerous scientific studies confirm that soils are an important pool of active carbon, and play a major role in the global carbon cycle. Since soils occupy about 30% of the global surface area, a major shift from tillage-based farming to climate-smart systems, such as CA, would have a significant impact on global climate and food security.

The results presented in this paper are based on a literature review of scientific articles published in peer-reviewed journals. The terms "Conservation Agriculture", "Africa", "climate change mitigation" have been consulted at the scientific databases *sciencedirect.com* and *webofknowledge.com*. Among the papers reviewed, those focused on the application of the interlinked three principles of Conservation Agriculture have been selected.

This review has been carried out based on the different climatic zones of Africa (Figure 6.1) and focused on CA management practices, carbon sequestration based on the current area of CA adoption in African countries, and potential of carbon sequestration based on the conversion of conventional agriculture to CA across Africa. No data for carbon sequestration in desert areas

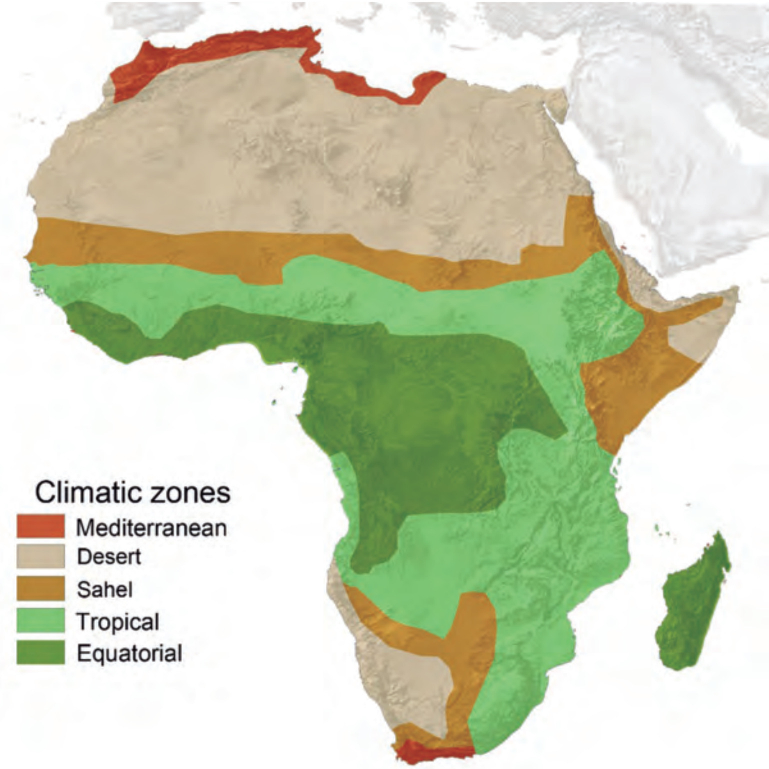


Figure 6.1.
Climatic zones of Africa. Source: Authors' diagram based on Ngaira (2007) and www.gifex.com

is presented, as no articles with a carbon sequestration rate of CA have been found, and there is little expectation of a significant carbon increase in those environments as a result of farming activities.

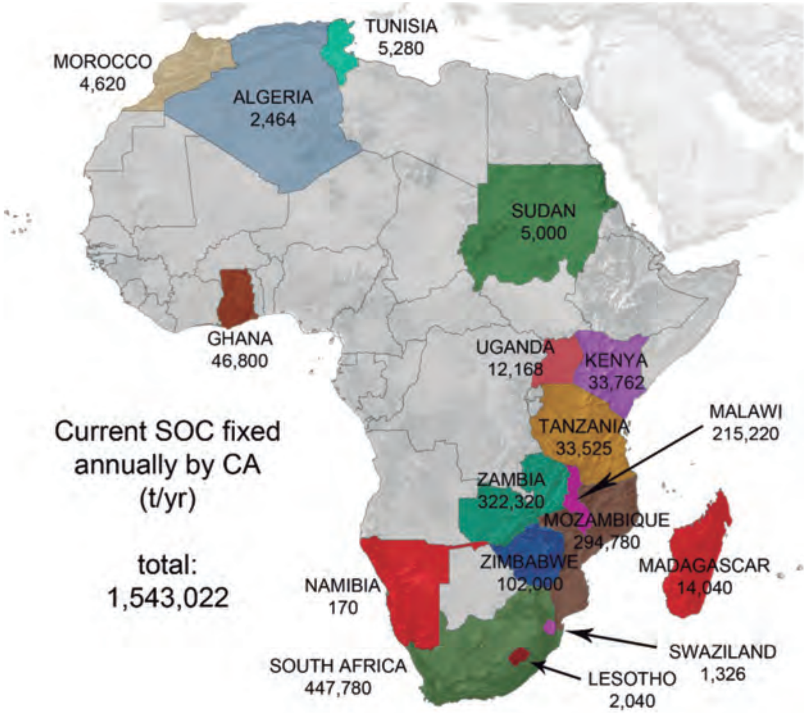
The description of the applied methodology to obtain potential areas of CA is as follows. Country statistics of crops were obtained from FAOSTAT (FAO, 2018b). Among the annual crops, those best adapted to no-tillage CA systems were selected: cereals, pulses, sunflower, rapeseed, cotton, among others. Most of the woody perennial crop areas were found suitable for CA production.

In climate change international agreements, emissions are referred to carbon dioxide; however, soil carbon studies refer to carbon. For transforming carbon into carbon dioxide, the coefficient of 3.67 was used. The atomic weight of carbon is 12 atomic mass units, while the weight of carbon dioxide is 44, because it also includes two oxygen atoms that each weigh 16. So, to switch from one to the other, one tonne of carbon equals 44/12 = 3.67 tonnes of carbon dioxide.

Farmers in almost 20 African countries are promoting and supporting CA, including in Algeria, Ghana, Kenya, Lesotho, Madagascar, Malawi, Morocco, Mozambique, Namibia, South Africa, Sudan, Swaziland, Tanzania, Tunisia, Uganda, Zambia and Zimbabwe (Kassam et al., 2018). CA has also been incorporated into the regional agricultural policies, and increasingly, has been 'officially' recognized as a core element of climate-smart agriculture (FAO, 2016, 2017; Kassam et al., 2017).

The latest figures of adoption of CA for annual crops in Africa (season 2015/16) totalled to 1.5 M hectares. This corresponds to some 211%

Figure 6.2.
Current soil organic carbon (SOC) fixed annually by CA cropland systems compared to systems based on tillage agriculture in Africa. Authors diagram



increase from 0.48 M ha in 2008/09 (Kassam et al., 2018). This significant increase is because of the many years of research showing positive results for CA systems, plus increasing attention being paid to CA systems by governments, NEPAD (New Partnership for Africa's Development), and NGOs such as ACT (African Conservation Tillage), and the private sector, international organizations and donors.

Average rates of carbon sequestration by CA in agricultural soils for each climatic zone in Africa are presented in Table 6.1. The total carbon sequestration estimated for the whole of Africa, of 1,543,022 t C yr^{-1} is shown in Figure 6.2. On average, the carbon sequestered for Africa due to CA is thus around 1 t C ha^{-1} yr^{-1}, corresponding to a total amount of 5,657,747 t CO_2 yr^{-1}. This relatively high figure is because degraded soils are 'hungry' for carbon, as the degradation caused by years of tillage and crop biomass removal has resulted in a drastic reduction of soil's organic matter (Reicosky, 1995; Jat et al., 2014; Kassam et al., 2017). However, the increase of C is not permanent in time, and after a number of years, a plateau is reached. The time to reach the plateau is considerable, and may take over 10-15 years before a deceleration in the rate of carbon increase is observed (González-Sánchez et al, 2012). Therefore, even if after 10-15 years C sequestration rates are lower, carbon is still being captured in the soil, which supports the value of long-term engagement with CA. Also, even when top soil layers may be reaching plateau levels, deeper soil layers continue to sequester C through the action of earthworms and biomass provided by deeper root systems.

In Figures 6.3 and 6.4, the potential area that could be shifted from conventional tillage agriculture to CA is presented, for both annual and permanent crop systems.

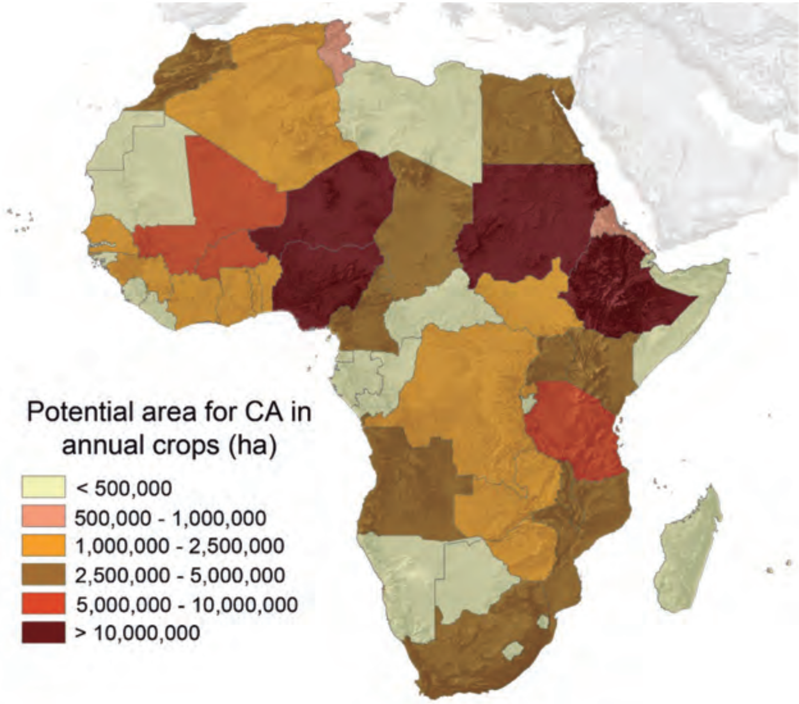


Figure 6.3.
Potential application surface of CA in annual crops in Africa in 2016. Source: Authors diagram based on FAOSTAT, 2018

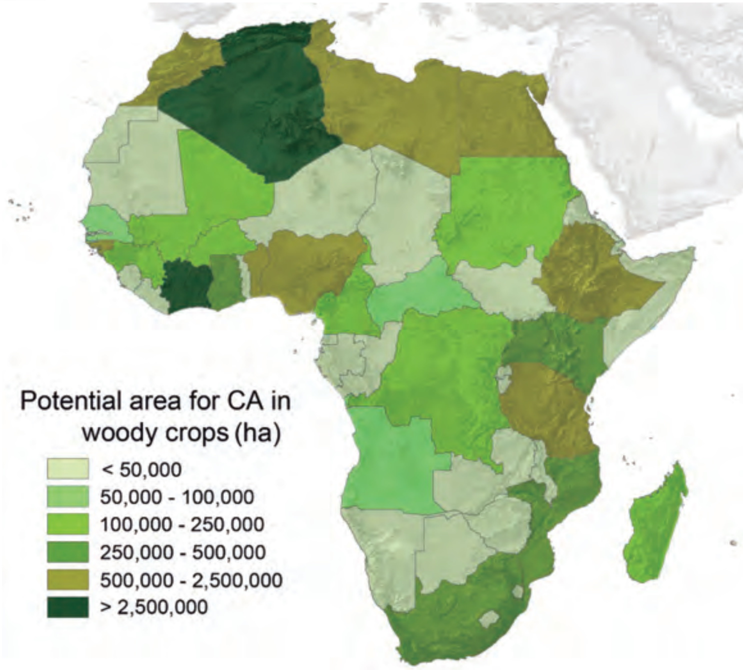


Figure 6.4.
Potential application surface of groundcovers in woody perennial crops in Africa in 2016. Source: Authors diagram based on FAOSTAT (2018).

Table 6.1.
Carbon sequestration rates in Conservation Agriculture (CA) for each climatic zone. Source: Authors diagram based on the papers reviewed and listed in the references.

	Carbon sequestration rate for CA in annual crops (t ha-1 yr-1)	Carbon sequestration rate for CA in woody crops (t ha-1 yr-1)
Mediterranean	0.44	1.29
Sahel	0.50	0.12
Tropical	1.02	0.79
Equatorial	1.50	0.26

Multiplying the rates of C sequestration presented in Table 6.1 by the potential areas per country and per type of crop (Figures 6.3 and 6.4) permits estimates of the potential carbon sequestration following the application of CA in the agricultural lands of Africa. Where more than one climate affects a single country, the climate of the major cropping area has been selected, i.e. Algeria's rate of C sequestration has been that of the Mediterranean, as most of its cropland is affected by that climate. In cases where there were two co-dominant climates, two rates of C sequestration have been applied.

Finally, Figure 6.5 shows the total amount of potential carbon sequestration for Africa, for each climatic region, with respect to current carbon sequestration status. In total, the potential estimate of annual carbon sequestration in African agricultural soils through CA amounts to 145 M t of C per year, that is 533 M t of CO_2 per year. This figure represents about 95 times the current sequestration rate. To put this figure into context, according to the United Nations Framework Convention on Climate Change, South Africa, the world's 13th largest CO_2 emitter, national emissions by 2025 and 2030 will be in a range between 398 and 614 M t CO_2–eq per year (UNFCCC, 2018).

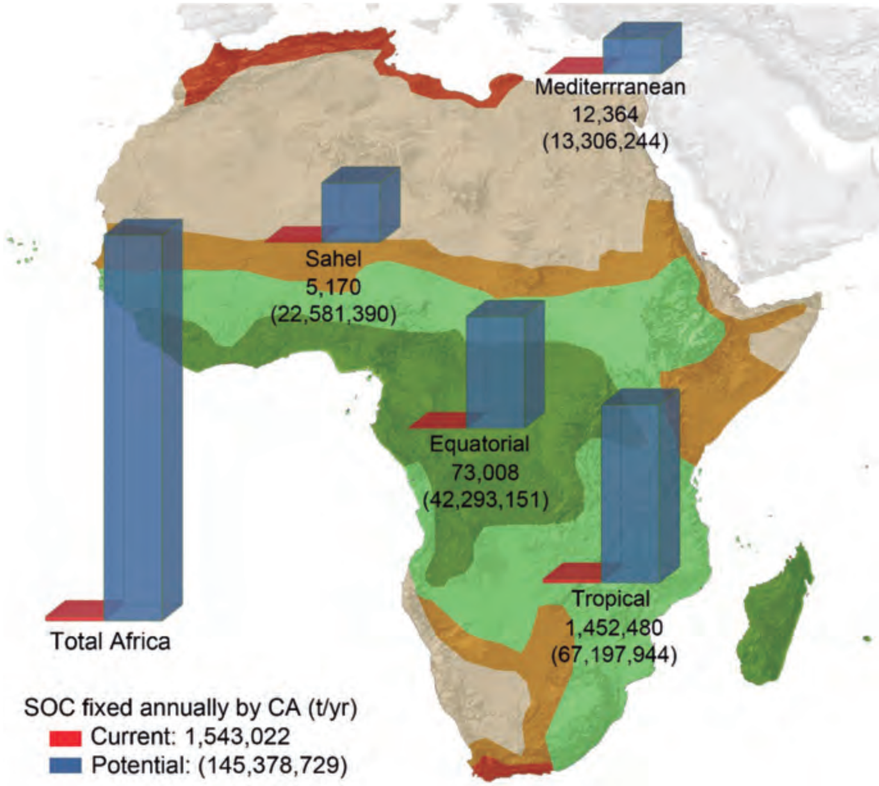


Figure 6.5.
Potential soil organic carbon (SOC) fixed annually by CA cropland systems compared to systems based on tillage agriculture in Africa. Authors diagram.

Summary

Currently, the total amount of African carbon sequestration due to CA adoption of 1.5 M ha is over 5.6 M t CO_2 yr^{-1}. The potential effect of the application of CA on carbon sequestration is to increase this to 533 M t of CO_2 per year, nearly a 100 times greater.

Conservation Agriculture is thus more than a promising sustainable agricultural system, as it can effectively contribute to mitigating global warming, being able to offset agricultural CO_2 emissions.

6.2. ADAPTATION TO CLIMATE CHANGE THROUGH CONSERVATION AGRICULTURE

Increase resilience of agriculture to climate change

The term "adaptation" refers to all adjustments that need to be made in a system (in our case, the agricultural system) to respond to actual or anticipated changes resulting from climate change, thus reducing their vulnerability and taking advantage of the opportunities given by the new climatic scenarios. The term "resilience" refers to the responsiveness of the medium to a disturbing agent or a harmful condition, minimizing the impact of such a situation and adapting to it.

As described in previous chapters, climate change has effects on all types of ecosystems, especially on agrarian ones. In addition to the environmental consequences that this phenomenon generates, it has a great impact on the economic and social areas, taking into account the great interrelation they have with human activities. Therefore, not only it is important to adopt strategies to mitigate phenomena which increase climate change, but it is also necessary to adopt practices which increase the resilience of agricultural ecosystems to be able to deal more easily with the consequences of global warming, and which favour the adaptation of crops to the new climatic scenarios predicted by the atmospheric circulation models.

Adaptation strategies must be related to the expected changes according to the considered climatic zone because the measures that

	WATER	SOIL	BIODIVERSITY	CROPS
Actions to increase resilience	Increase infiltration Reduce runoff Optimization of water use Improvement of soil water balance	Reduced runoff Increase in Organic Carbon Improvement of structure Increase soil fertility	Increase in the epigeal fauna Improvement of conditions for the habitability of steppe birds Increase in pollinating species	Increase resistance to drought Escape from water stress Reduction of weed invasion Reduce incidence of pests and diseases
Conservation Agriculture practices	**Conservation Agriculture**	**Conservation Agriculture**	**Conservation Agriculture**	**Crop rotation**
Another agricultural techniques	Deficit irrigation Precision farming Improvement of irrigation Green filters Multifunctional margins	High flotation tires Soil health cards	Use of integrated fighting Green filters Multifunctional margins	Use of varieties resistant to drought Advancement of planting date Use of native varieties Crop cycle variation

Figure 6.6.
Possible actions to increase the resilience of agrarian ecosystems and agricultural techniques whose application involves adaption of these actions. Source: González-Sánchez et al. (2017).

can be adopted in a region of arid and semiarid zone will be different from those adopted in the equatorial zone. Adaptation means looking for strategies at the local level to respond to a global problem. The options for adapting crops to the scenarios caused by climate change will increase the resilience of the ecosystems in which they are developing.

Taking into account the expected effects, it is possible to undertake various actions aimed at improving the quality of natural resources and biodiversity, which will result in an increase in the resilience of agricultural ecosystems, improving conditions for better adaptation of crops to climate change (Figure 6.6).

In many cases, as will be seen *a posteriori*, many of these actions can be carried out using the interlinked Conservation Agriculture practices, thus constituting not only a feasible tool to mitigate the effects of climate change, but also as a measure of adaptation to its effects. In Africa, around 1.5 million ha are under CA, on both largescale commercial farms and a multitude of small farms, in at least 20 countries. Five countries, South Africa, Zimbabwe, Zambia, Mozambique and

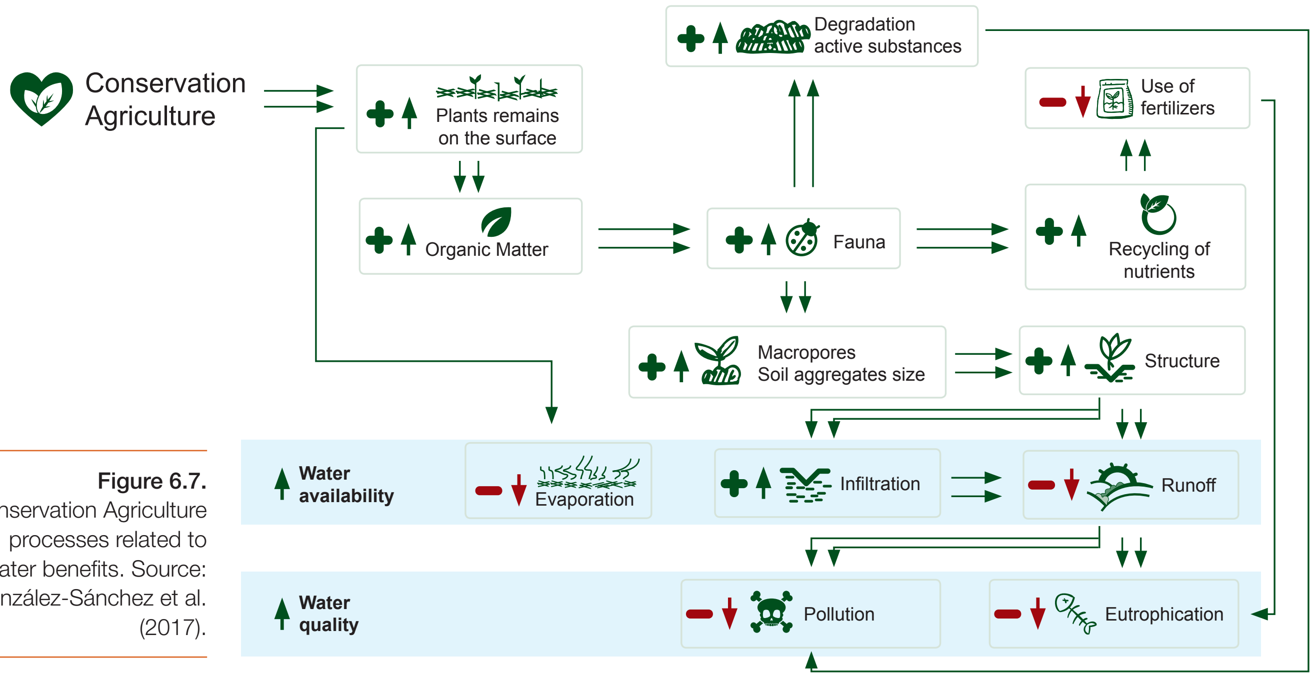


Figure 6.7. Conservation Agriculture processes related to water benefits. Source: González-Sánchez et al. (2017).

Malawi, account for 90% of Africa's CA area. (Kassam et al., 2018).

Conservation Agriculture and water resource improvement

As water is a scarce and in many cases a limiting resource, it is fundamental to manage the agricultural production system for the maximum harnessing of available water. So, in irrigated agricultural production systems, both agronomic and hydraulic strategies should aim to improve aspects such as the distribution and efficiency of applied water, while in the dryland, these strategies should be focused on maximizing the uptake of water and water used by plants.

The adoption and development of Conservation Agriculture practices lead to a number of benefits in the water supply system within the agricultural ecosystems, such as greater availability of this resource for the crop and improvement of its quality (Figure 6.7).

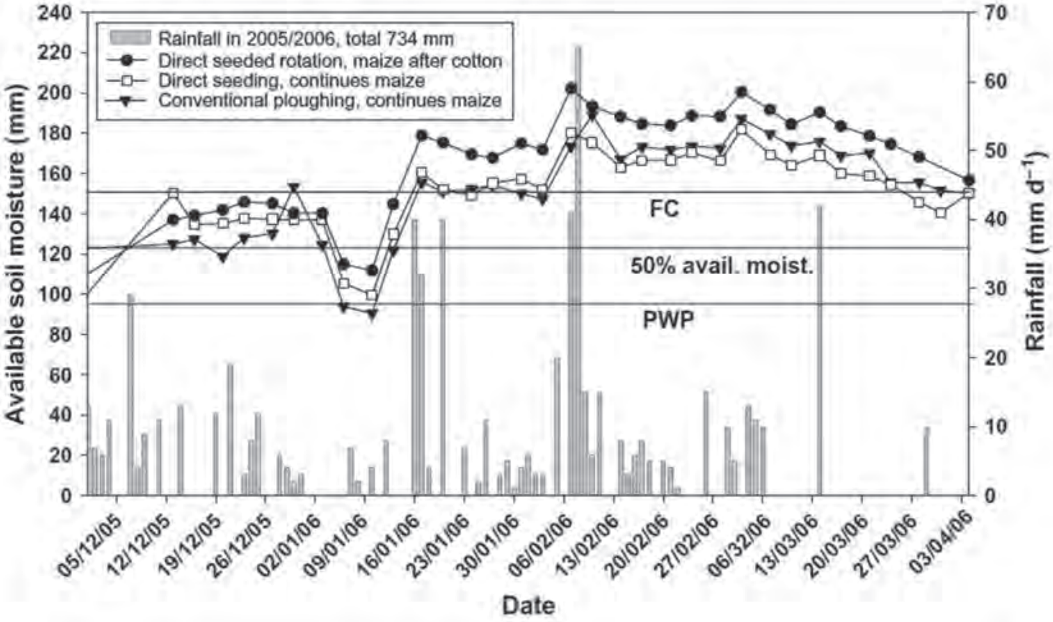
Regarding advantages offered by Conservation Agriculture related to adaptation to climate change, this management system will be particularly interesting in ecosystems with a decrease in availability of the water resources or in those regions, in which, due to the increase of extreme precipitation events, the phenomena of runoff are increased.

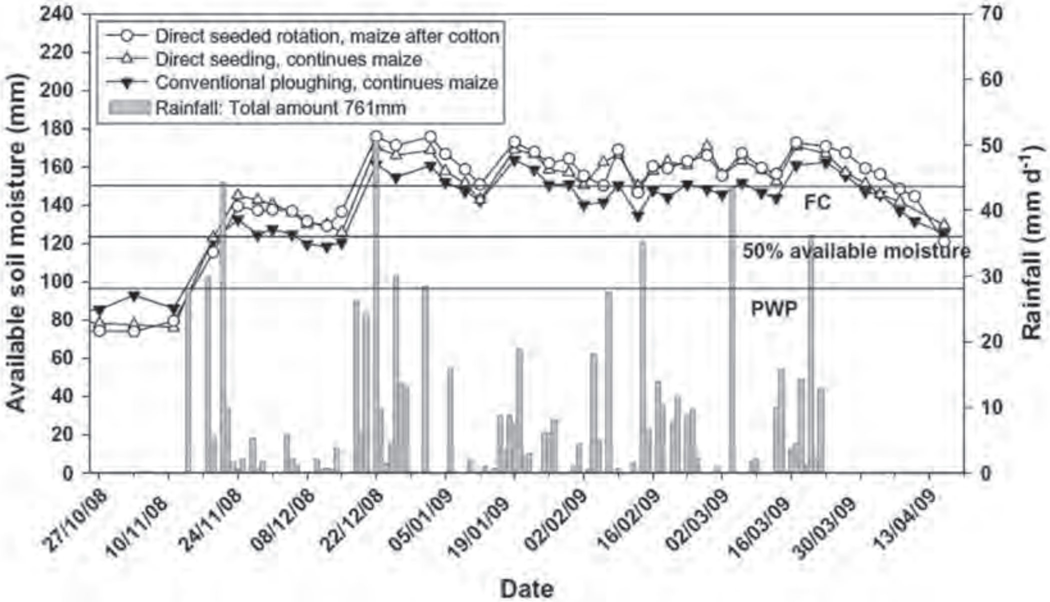
As to water balance of the soil-cropping system, the existing studies determine that CA systems improve the uptake, conservation and better use of available water in the soil by the crops, because of the fact that it favours infiltration, reduces runoff, increases water holding capacity and reduces evaporation. On the other hand, the increase in the infiltration rate that occurs in the soils managed by Conservation Agriculture practices improves water availability after periods of rain which is not the case in the soils managed under a system based on the tillage. Therefore, several studies have analysed the effects of soil management on dynamics and conservation of water.

According to López-Garrido (2010), in the soils under Conservation Agriculture practices, the volumetric content of the first 20 cm is higher than in soils under tillage practices. In addition, Muriel et al. (2005) concluded that CA techniques not only allow a greater retention of water in the soil profile, especially in the first 30 cm of depth but also slow down the water discharge rate, which has a positive impact on the development of spring-summer crops, where the limiting factor of production is undoubtedly the availability of water.

Figure 6.8 shows the evolution of moisture contents for three soil management systems in Zambia (Thierfelder and Wall, 2010). Not only it shows higher water recharge given in NT system, but also greater soil discharge in the second part of the campaign, because in that case, and due to the greater availability of water, the crop is able to better satisfy the growing evapotranspiration demand which occurs in spring.

Figure 6.8. Evolution of moisture content in three soil management systems, in two different agricultural campaigns in Monze Farmer Training Centre (MFTC), Zambia. FC=field capacity; 50% available moisture=50% available moisture content; PWP=permanent wilting percentage. Source: Thierfelder and Wall (2010).





Conservation Agriculture systems reduce water evaporation as they prevent the direct incidence of radiation on moist soil and reduce the turbulent transfer of vapour into the atmosphere. As a result, crops in drylands can better withstand difficult conditions, as Moreno et al. (1997) and Murillo et al. (1998) found in Mediterranean zone, where spring and summer temperatures are very high. This positive effect is especially noticeable in dry years. Moret et al. (2006) observed, during three periods of long fallow (16-18 months), that soil, under an intensive tillage system with mouldboard plough, had lost by evaporation, in the 24 hours after the primary soil management practices, 14 times more water than in NT system. This improvement in water use efficiency is a key factor in adapting crops to future climatic scenarios with lower, more erratic precipitation and higher temperatures.

Conservation Agriculture and soil resource improvement

Global soil resources are finite, unequally distributed among biomes and geographical regions, affected by climate change and variability and vulnerable to degradation (e.g., physical, chemical, biological, hydrological) by land misuse and soil mismanagement; and, yet, restorable through conversion to judicious land use and appropriate management. Strongly interacting with soil, in the context of agronomic production in a changing and variable climate, is the supply and quality of water. Soils must be framed as a key factor when dealing with complex environmental problems (Bouma et al., 2013). Thus, pertinent issues with regards to soil and water resources are as follows (IAASTD, 2013):

1. Actual and potentially available soil resources;
2. Loss of soil resources to climate-induced degradation;
3. Degradation of soil by land use and soil mismanagement;
4. Determinants of soil resilience to abiotic and biotic stresses;
5. Strategies of soil restoration in the context of threshold levels of key soil properties and their dynamics;
6. Global and regional hot spots of soil degradation; and
7. Sustainable intensification of soils devoted to agroecosystems

One of the keys to increasing the resilience of the agricultural ecosystems that are possible due to the adoption of CA is the substantial improvement that occurs in the physical-chemical-hydrological properties of the soils on which these agricultural practices are used. Soils with a better structure and less erosion will respond better to events of intense rainfall. On the other hand, soils with a greater quantity of organic matter and greater natural fertility, are more and better prepared to respond to adverse climatic conditions that contribute to their degradation. Figure 6.9 shows the processes through which CA improves this resources.

Thus adaptation of soil management to climate change will entail increasing the infiltration capacity of the soil, increasing water holding capacity, improving soil structure and conditions for soil fauna and flora,

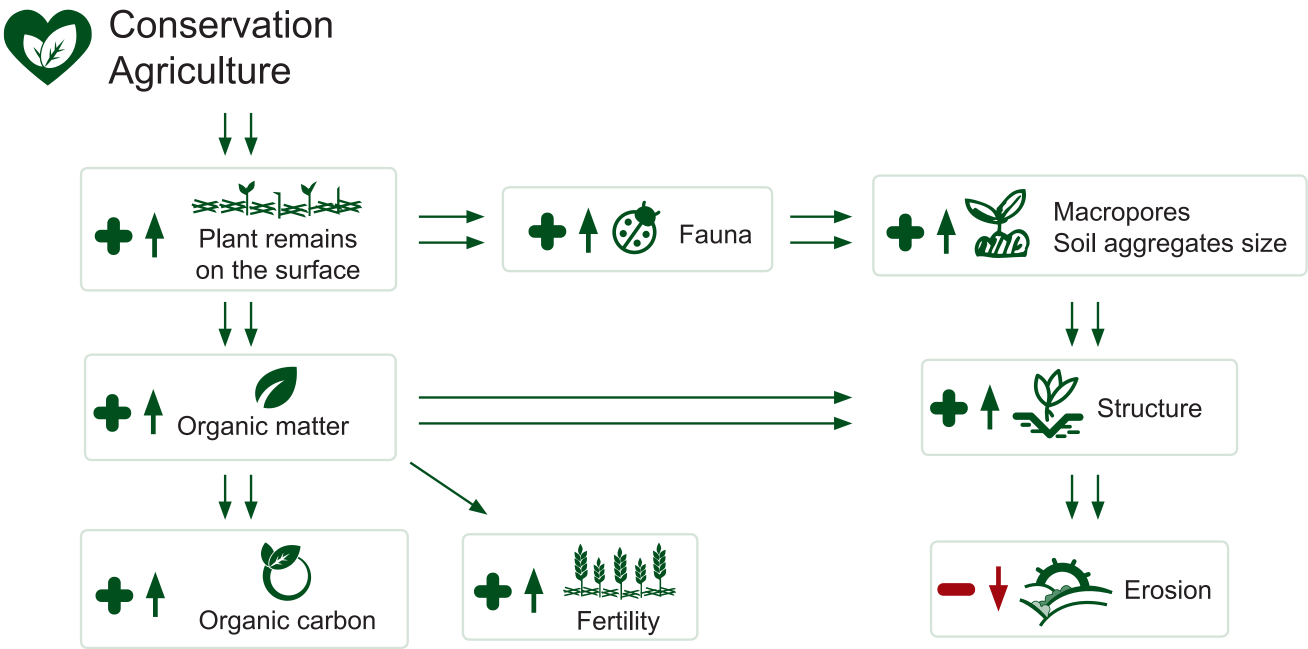


Figure 6.9.
Conservation Agriculture processes related to soil benefits. Source: González-Sánchez et al., 2017.

thereby increasing natural soil fertility. Implantation and development of CA lead to an increase in the organic matter content in the soil which, in addition, to being the basis of increases on:

- Carbon sink effect (Figure 6.10).
- Soil quality, because it releases nutrients to the vegetation.
- Chemical and physical fertility.
- Resistance to erosion.
- Water infiltration. (Figure 6.11).
- Cations retention and adsorb heavy and harmful elements.

Effects over resistance to erosion through CA may be the most important aspect in relation with the adaption of soils to climate change. CA maintains permanent soil covers which minimize the direct impact of the raindrops on the soil, reducing soil erosion. The greater the coverage of the soil, the more effective reduction of erosion is. Therefore, soil management operations should leave as much crop residue as possible on the soil surface, in order to protect it and prevent erosion.

Investigations carried out in different countries around the world certify erosion reductions of more than 90% in the case of no-tillage (NT) (Towery, 1998), and more than 60% in minimum tillage (Brown et al., 1996). More

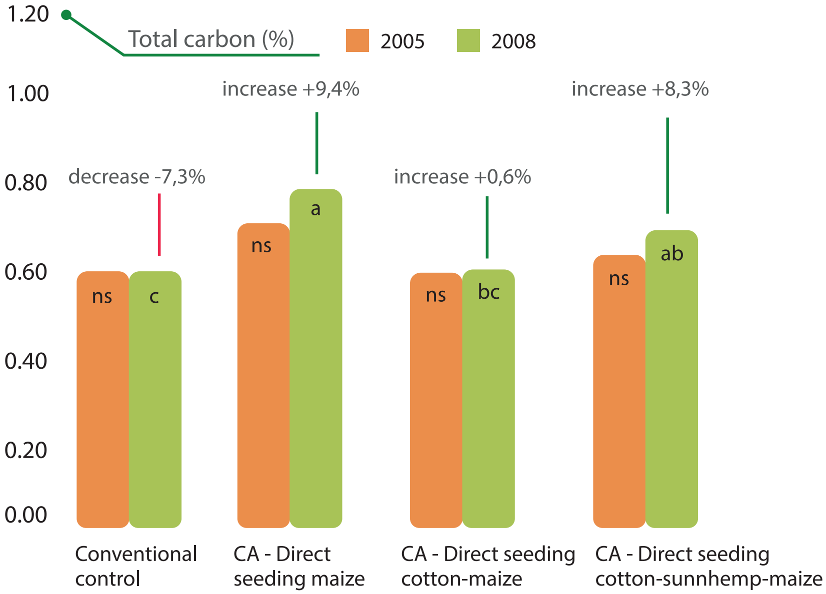


Figure 6.10.
Change in total carbon (%) measured at different times in one conventionally tilled and three conservation agriculture treatments. Monze, Zambia. Source: Thierfelder and Nyagumbo, 2011.

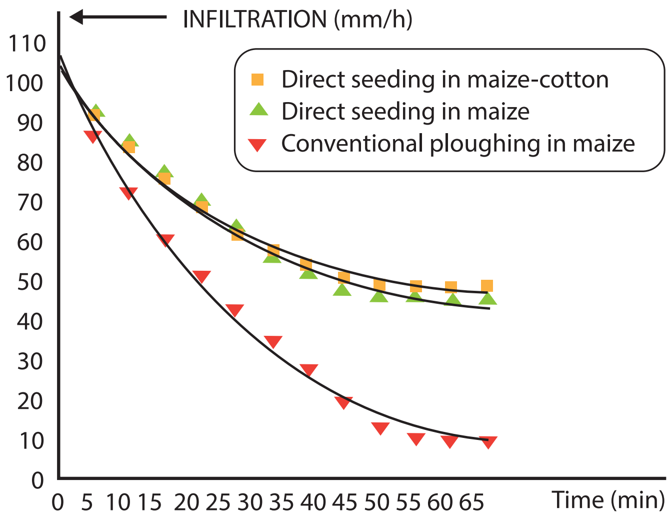


Figure 6.11.
Water infiltration (mm h^{-1}) measured at different times in one conventionally tilled and two conservation agriculture treatments. Monze, Zambia. Source: Thierfelder and Nyagumbo (2011).

recent studies (Kertész et al., 2010) show erosion reductions in NT of up to 98.3%. The maintenance of permanent soil covers also plays an important role in the reduction of wind erosion. According to the results obtained by Fryear (1985), in a soil whose surface was covered by 20% of crop residues, the soil loss was reduced by 57%. In soils whose surface was covered by 50%, erosion was reduced by 95%.

Soil conservation techniques are increasingly practised in Burkina Faso, Kenya, Senegal, and Niger (Akinnagbe and Irohibe, 2015). A study carried out by in Manyoni District of Tanzania revealed that farmers in Kamenyanga and Kintinku ensure proper timing of different farming activities, burying of crop residues to replenish soil fertility, burning crop residues to enhance quick release of nutrients and allowing livestock to graze on farmlands after harvesting crops so as to improve soil organic matter. In Tanzania, farmers used contour ridges as a strategy to minimize soil erosion to encourage better root penetration and enhance moisture conservation (Lema and Majule, 2009). In Senegal and Burkina Faso, local farmers have improved their adaptive capacity by using traditional pruning and fertilizing techniques to double tree densities in semi-arid areas. These help in holding soils together and reversing desertification. Nyong et al. (2007) noted that local farmers in the Sahel conserve carbon in soils through the use of zero tilling practices in cultivation, mulching and other soil management techniques. Biological mulches moderate soil temperatures and extremes, suppress diseases and harmful pests and conserve soil moisture.

A study carried out by Fapojuwo et al. (2012) explored farmers' awareness and practice of soil conservation techniques for climate change adaptation in southwest Nigeria. In the event of reducing yield, flooding and increasing soil temperature, farmers have resorted to adaptive strategies to reduce the effect of climate change. A sample of 102 annual crop farmers producing major staple crops, were selected and interviewed. The majority (81.4 %) of the people is male and 54.9 % fell within the age category of 31-50 years. Over half (80.6 %) of the farmers had formal education. Also, 60.8% of the farmers cultivated about 1-3 ha of land and had about 10 years of farming experience. The common climate adaptation soil strategies among the farmers were mulching, no-tillage practices, green and farmyard manuring, cover crops and mixed cropping, which have a direct effect on soil nutrient and crop performance.

Conservation Agriculture and the improvement of soil biodiversity

Soil biodiversity plays a key role in fertility, nutrient absorption by plants, biodegradation processes, the elimination of hazardous compounds and natural pest control. In other words, richer and more biologically diverse soils have a greater capacity to respond to extreme phenomena resulting from climate change that can worsen their degradation, such as the incidence of heavy precipitation, temperature increase or the geographical displacement of pests and diseases, among others.

One of the environmental benefits of the adoption of CA practices for agrarian ecosystems is the improvement

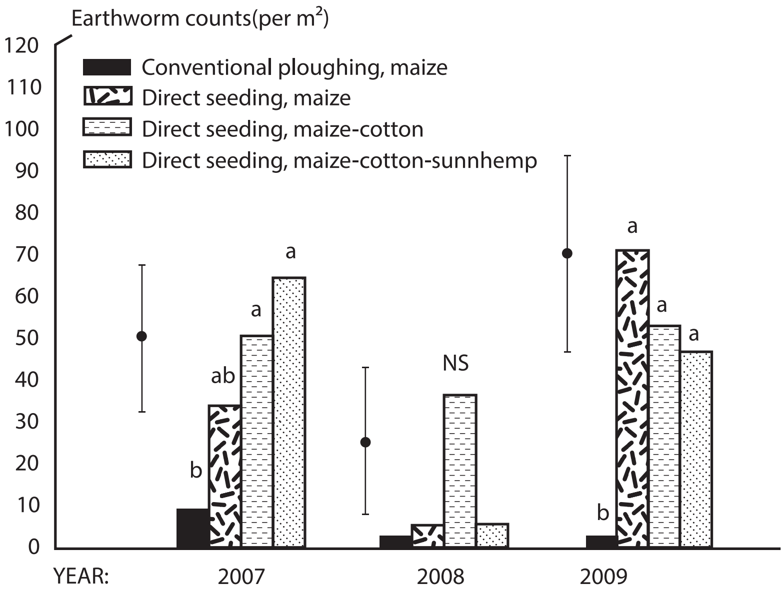


Figure 6.12.
Impact of conventional and conservation agriculture on earthworm counts (per m^2) in the first 30 cm in three consecutive years. Monze, Zambia. Source: Thierfelder et al., 2014.

of biodiversity in them in general, and in the soil in particular. Thus, under soil conservation practices, soil biota is enriched, allowing better recycling of nutrients and helping to control pests and diseases (Holland, 2004).

One of the populations benefited by the implementation of Conservation Agriculture is the microorganisms of various groups (bacteria, fungi, protozoa, nematodes, etc.) which live in no-tilled soils. Muñoz et al. (2007) found significant differences in the number of microorganisms from the beginning to the end of the study about microorganisms in the soil under several management systems, which were always in favour of conservation systems. Thus, according to the mentioned study, the soil maintained using no-till practices had 50% more microorganisms than the soil under conventional tillage. It should be noted that a direct consequence of the increase of microorganisms in the edaphic profile is the increase of the structural soil stability. Thus, large amounts of organic matter involved in the implementation of techniques such as no-tillage or groundcovers contribute to increasing microbial activity, which improves the stability of aggregates.

Another population benefited by the implementation of Conservation Agriculture and whose activity supposes an improvement of the fertility of the soil and its structural stability, are earthworms (Figure 12). These living beings have great importance especially in productive ecosystems, due to their influence on the decomposition of organic matter, soil structure development and nutrient cycle. In addition, earthworms reduce bulk density and increase water infiltration, with the consequent advantages discussed previously and related to the improvement of soil moisture content. It is verified that non-tillage increases the activity of earthworms, because of lower soil alteration and the increase in organic matter.

Conservation Agriculture and the improvement of productivity and crop quality

The increase in temperature that can occur in the critical periods of the crop, changes in the monthly distribution of precipitation and reduced soil water holding capacity because of climate change, reduce productivity and crop quality. Therefore, one of the measures that can be taken to deal with this risk is the application of CA and the diversification of crops using the crop rotation schedule on the farm, which is one of the fundamental pillars of implementation and development of no-tillage. In this way, pests and diseases are better controlled, breaking cycles that are maintained in monocultures, in addition to incorporating crops that can improve the natural fertility of the soil and biodiversity.

Conservation Agriculture not only brings benefits for the optimized management of water and soil moisture, but it also offers other advantages that help the agrarian ecosystem to be more and better prepared for the climatic scenarios caused by global warming, and, therefore, to be more sustainable. The rotation and diversification of crops promoted by Conservation Agriculure increases the resilience of the agricultural ecosystem, improving the soil properties in general, while increasing the crop potential to obtain higher yields (Figure 6.13).

An example of this adaptation to the food security of the population through the stability of the harvests has been visualized in an FAO project carried out in Zambia

of CA implantation. It is Conservation Agriculture Scaling Up Project (CASU). The project, of 11 million euros, has had a direct impact on 21,000 farmers and indirectly on another 315,000 (Figure 6.14). After a few years of benign weather conditions, in 2015, the El Niño phenomenon affected most of the African countries, leaving millions of people without food. But farmers who practised conservation agriculture thrived in this difficult context.

The surveys that monitored the project's follow-up evidenced a better nutrition of the households. There was also evidence of greater security in the level of income of those who practised conservation agriculture, with respect to the conventional. In fact, the economic improvement allowed families to invest in the purchase of livestock and even agricultural machinery. Increasing the profit margin to a greater extent and, subsequently, improving different aspects of the public health of local populations.

In the adaptation to climate change by agriculture, irrigated crops have an important role. Specifically,

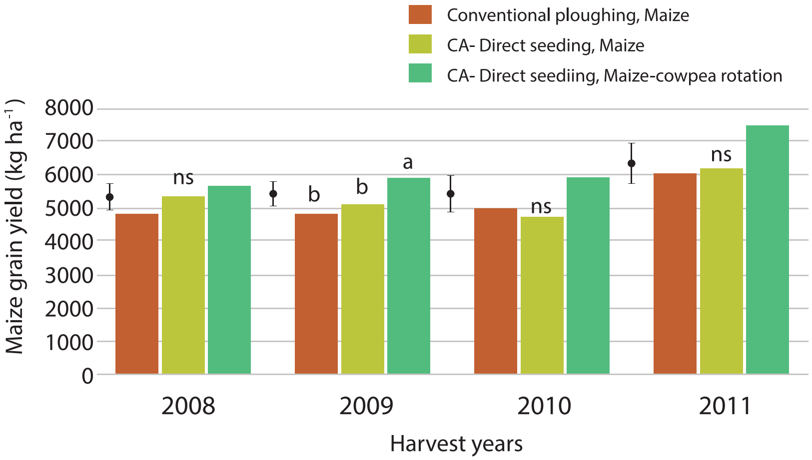


Figure 6.13.
Summary of maize grain yield at Chitedze, Malawi, 2007-2011. Source: Thierfelder and Nyagumbo (2011).

Figure 6.14.
Map of Zambia showing the number of farmers who have participated in the CASU project by region. Source: CASU Project (FAO, 2016).

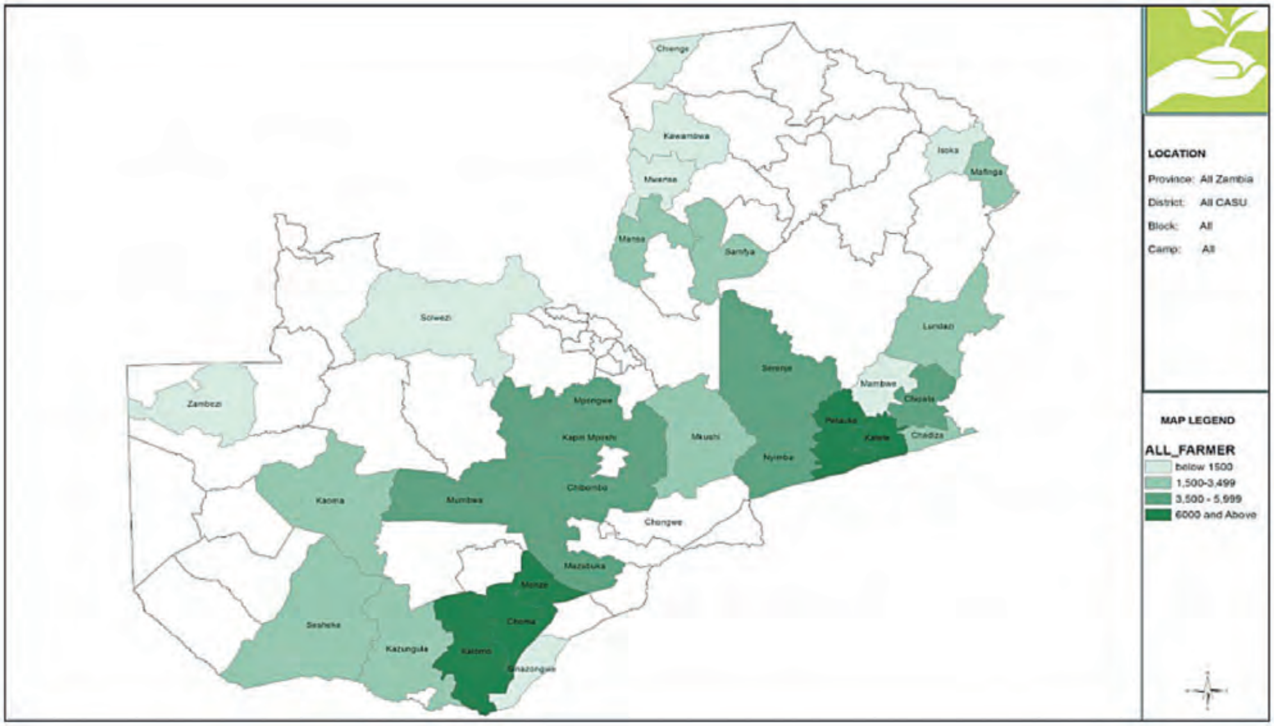
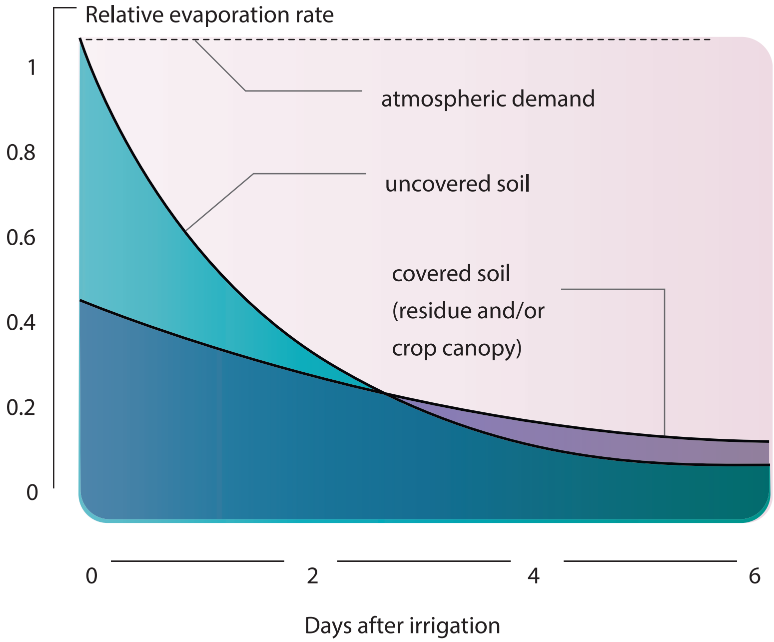


Figure 6.15.
Evaporation rates, relative to atmospheric demand, from covered and uncovered soil after an irrigation event. Source: Wortmann et al. (2008).

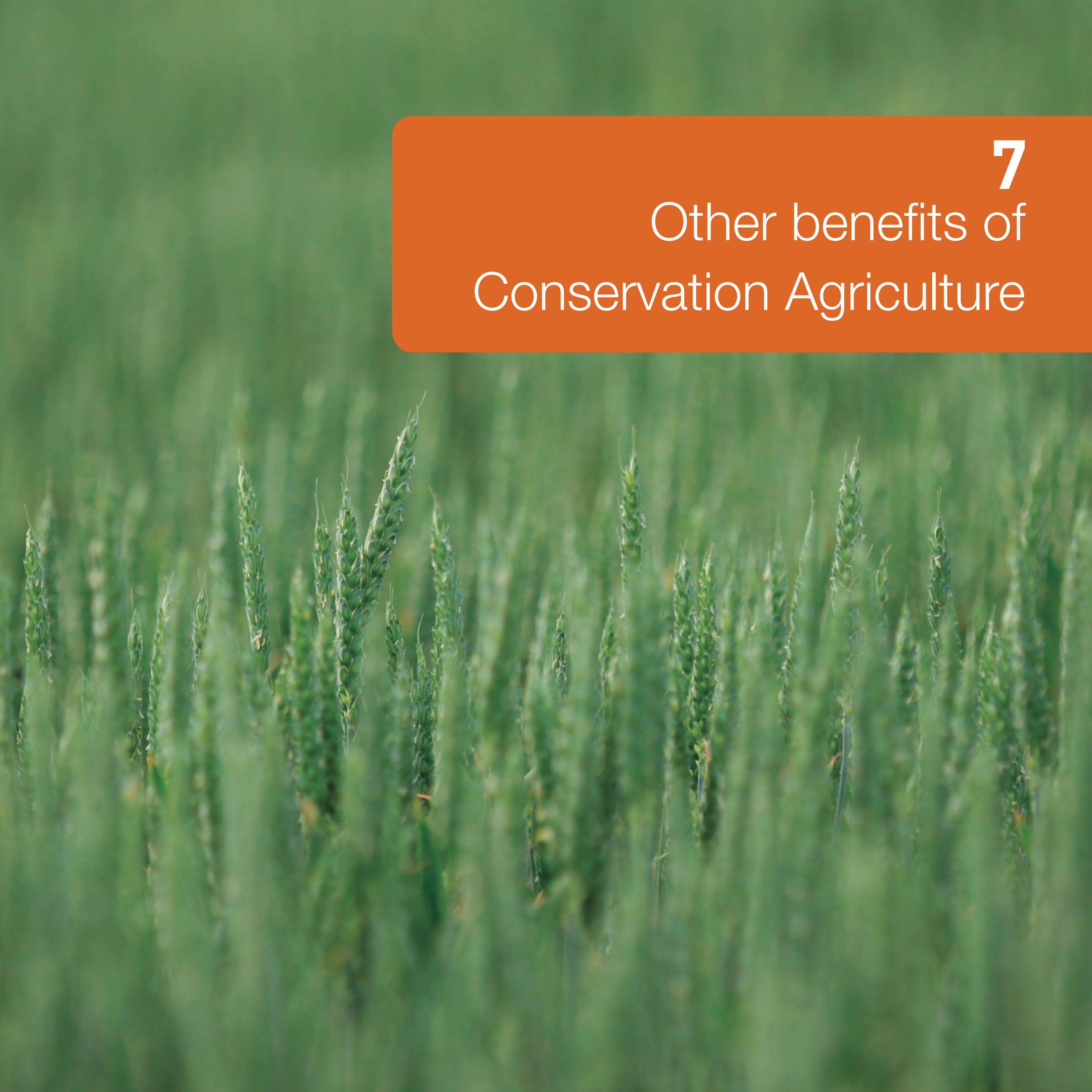


through improved irrigation efficiency (Akinnagbe and Irohibe, 2014). These authors highlight that the success of climate change adaptation depends on the availability of fresh water in drought-prone areas. In this sense, they tell that adaptation method to provide benefits even with the lower end of climate change scenarios, such as improved irrigation efficiency. As water becomes a limiting factor, improved irrigation efficiency will become an important adaptation tool, especially in dry season, because irrigation practices for the dry area are water intensive.

Conservation Agriculture can help reduce the amount of water needed for obtaining the same harvest – more crop per drop or more crop with less drops. This is because the vegetal remains that cover the ground act as a protective cover before evaporation (Figure 6.15). Evaporation of water from the soil is reduced because cover reduces solar energy reaches the soil surface and wind speed at the soil surface. When the soil surface is wet, evaporation from an uncovered soil occurs at a rate that equals the atmospheric demand (Wortmann et al., 2008). The evaporation rate will decrease drastically, because of a rapidly drying soil surface. In contrast, if the soil is covered, e.g. the residue insulates the soil from solar radiation and reduces air movement at the soil surface. This reduces the evaporation rate from a mulch-covered soil surface, compared to an uncovered or bare soil.

If we add to this the expected reduction in soil moisture due to climate change. CA is a win-win-win option for the limited freshwater availability (surface and groundwater) and reduced soil moisture during the dry season, while the crop water demand is expected to increase because of increased evapotranspiration.

7
Other benefits of Conservation Agriculture



Conservation Agriculture (CA) principles are universally applicable in all agro-ecological conditions and landscapes with necessary adaptation to the specific local and practical conditions. Advantages of CA, in comparison with conventional tillage agriculture, have been widely studied, and can be roughly divided as:

- Short-term advantages: increased water infiltration and improved soil structure, improved trafficability and lower compaction, reduced erosion by wind and water, reduced soil water evaporation, savings in fuel, mechanization, labour costs and time.
- Medium and longer-term advantages: increased soil organic matter (OM) content resulting in better soil structure, higher water holding and storage capacity, improved crop nutrition, higher and stable yields, optimised inputs, lower costs, increased biological activity, less pressure of weeds, insect pests and diseases.

Conservation Agriculture rehabilitates scarce resources (soil, water and biological) whilst minimising external inputs (Kertész et al., 2014; Kassam et al., 2013) and preventing soil degradation (Fereres et al., 2014). This chapter analyses the role of CA in agricultural sustainability, from different points of view, with a special focus on Africa.

Environmental benefits

Soil degradation is a serious problem in many parts of Africa. The main environmental problem caused by the current agricultural model based in tillage, bare soils and sub-optimal cropping systems is the degradation of agricultural soils and the resource base due mainly to erosion and compaction processes, and loss of soil functions and ecosystem functions and services. Croplands are susceptible to erosion because soil is repeatedly destructured through tillage and left without any protective vegetal cover and substrate for soil life. Montgomery (2007) pointed out the agricultural use of land with tillage as the root cause of higher erosion rates, over geologic erosion.

In Africa, large areas are already degraded physically, biologically and chemically (FAO, 2000). Some areas of South Africa have erodible soils and sodicity, and even salinity problems in the subsoil (Fey, 2010), leading to surface sealing and crusting if the topsoil is removed (Paterson et al., 2013). Studies have shown that such soils are classed as having high (25-60 t ha^{-1} yr^{-1}) to very high (60-150 t ha^{-1} yr^{-1}) water erosion risk (Le Roux et al., 1998). Nkonya et al. (2011) documented that cost of no-action to alleviate the problem of soil degradation exceeds that of a judicious action to prevent it or manage it. The per capita productive land areas and water resources are rapidly declining with the increase in population and conversion to other uses. Furthermore, the productivity of these lands is being severely jeopardized by accelerated erosion.

Some studies estimated soil losses with the use of Revised Universal Soil Loss Equation (RUSLE) such as Tamane & Le (2015) who calculated 35 and 75 t ha^{-1} yr^{-1} in average in the White Volta basin and Nile basin respectively, both in sub-Saharan Africa. In the tropics, erosion can be particularly threatening because of intense climatic inputs, low levels of fertilizer use and conservation activities, frequently fragile soils, and strong dependence on soil quality for livelihood (Cohen et al., 2005; Claessens et al., 2007). Data compiled by Labrière et al. (2015) in a review for humid tropics indicate erosion rates ranged from 0.1 to 16 t ha^{-1} yr^{-1} for cropland and 3 to 750 t ha^{-1} yr^{-1} for bare soils in Africa tropic.

According to Lal (1995) (Figure 7.1), estimated erosion rates are in excess of 75 t ha^{-1} $year^{-1}$ for a small proportion of the Maghreb region in the northwestern parts of Africa; 50 to 75 t ha^{-1} $year^{-1}$ for east African highlands, eastern Madagascar and parts of southern Africa; 25 to 50 t ha^{-1} $year^{-1}$ parts of north-west and southern Africa; 10 to 25 t ha^{-1} for coastal regions of eastern Africa, eastern Congo basin, and some parts of southern Africa; and <10 t ha^{-1} for most of the West African Sahel and eastern and southern Africa. This is considered unsustainable.

Many articles highlight the benefits of CA such as reduction of soil degradation and improvement of

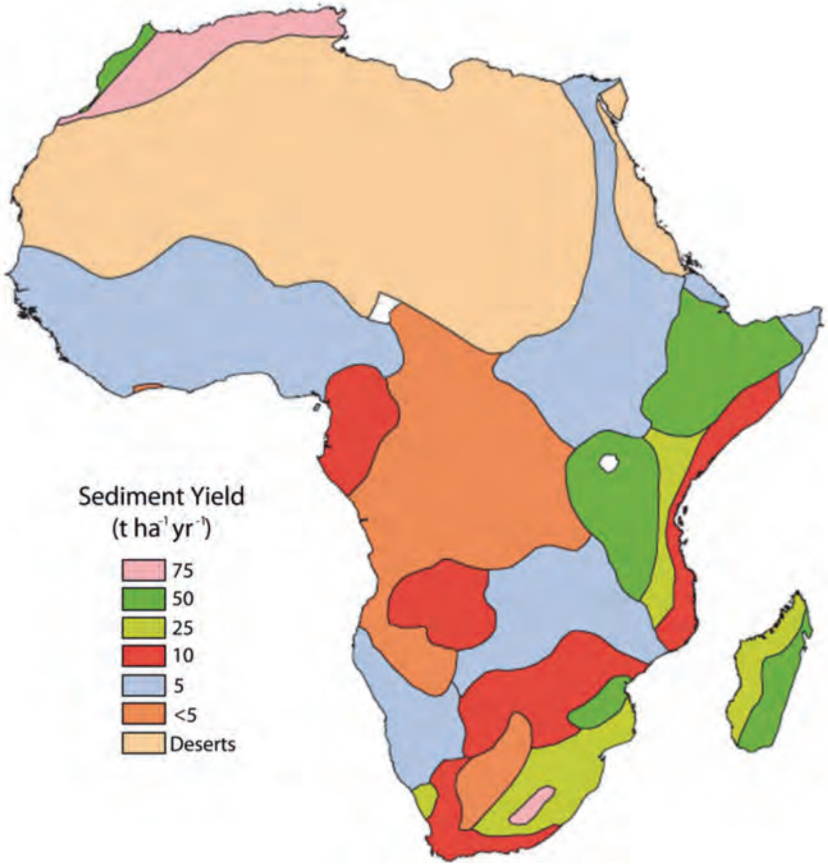


Figure 7.1.
Sediment transport, field erosion rate and accumulative soil loss for different regions in Africa. Source: Lal (1995).

sustainability. CA favours the soil conditions that result in reduced erosion and runoff and improved water quality compared to conventional practices (Palm et al., 2014). Although there are variations depending on soil type and local conditions, there is a general consensus in the scientific literature that CA techniques (no-tillage, groundcovers) reduce soil erosion up to 90-95% in comparison with conventional tillage (Towery, 1998).

The amount of surface crop residues has a decreasing relationship with the relative erosion (Figure 7.2). In addition, soils which are extremely sensitive to crusting do not present this problem under CA because the mulch cover avoids the formation of surface crusts (Derpsch et al., 2010). Although Vanlauwe et al. (2014) stated that fertilisation is a significant point to increase maize stover productivity above thresholds for minimal soil cover required for CA.

Sommer et al. (2013), observed in an experience carried out in Zimbabwe the increasing difference between the erosion that occurs with a treatment under conventional tillage and two soil conservation treatments (NT/direct seeding and ripline seeding) (Figure 7.3).

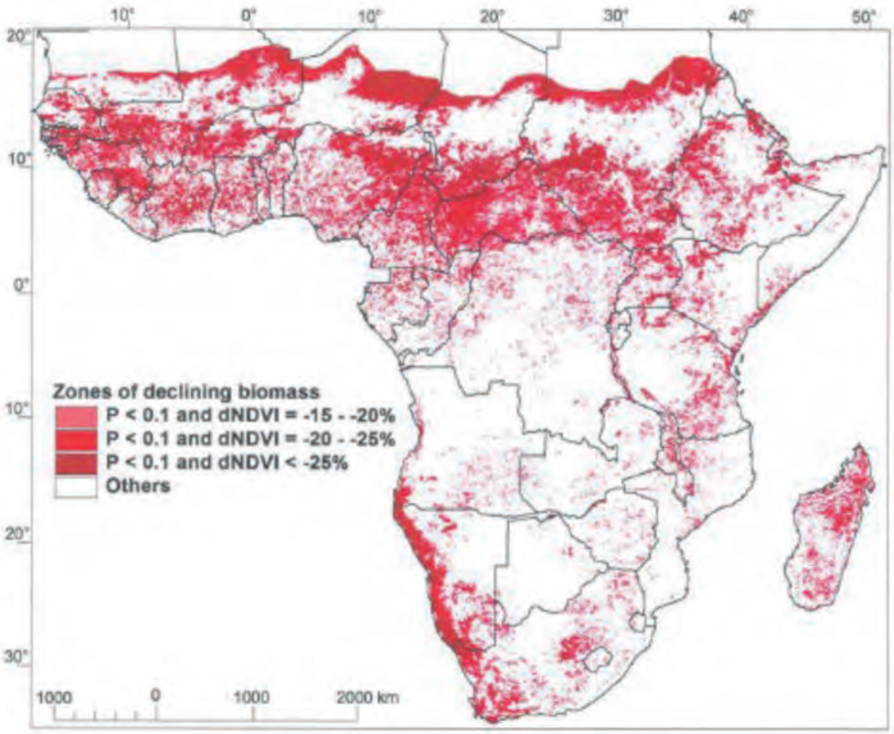
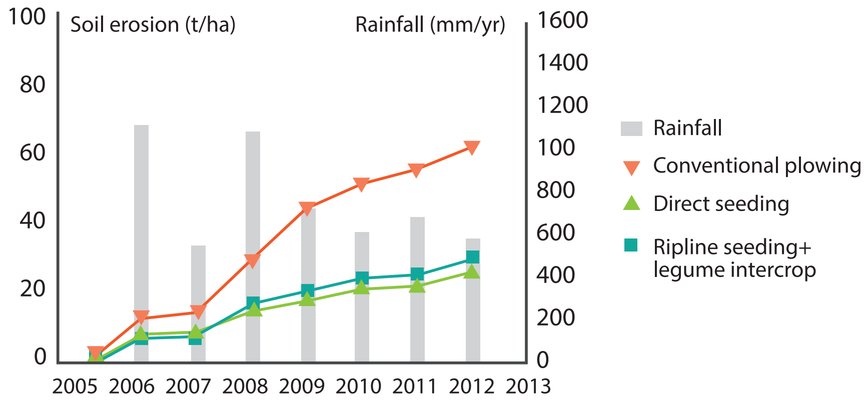


Figure 7.2.
Land degradation in sub-Saharan Africa based on declining biomass. Source: Kirui & Mirzabaev (2014) adopted from Vlek et al. (2010).

Figure 7.3.
Cumulative soil erosion and rainfall in two CA treatments (direct seeding and ripline seeding) in comparison with a conventionally ploughed control plot. Zimbabwe. Source: Sommer et al. (2013).



Conservation Agriculture helps increase the availability of cleaner water because pollution, erosion, and sedimentation of water bodies are reduced/avoided.

Agriculturally induced water pollution may occur from point sources (e.g. manure storage tanks, feedlots, overflows, tile drains) as well as through diffuse pollution from farmed land. The nutrients and agrochemicals applied to the fields may reach adjacent water bodies via overland flows and subsurface flows during precipitation events or, at a slower rate, reach surface water bodies through groundwater discharge. The change in land use and management associated with conservation-effective practices leads to a significant reduction in erosion, and thus to a reduction in water pollution and contamination (Palm et al., 2014). Some indicators show that CA improved water quality compared to conventional practices are:

- Reduction water turbidity and the concentration of sediments in suspension;
- Reduction total sediment loss and associated loss of nutrients;
- Reduction of water treatment costs

Conservation Agriculture helps increase the availability of cleaner water because pollution, erosion, and sedimentation of water bodies are reduced/avoided. Reduced erosion can lead to regional benefits such as reduced rate of siltation of watercourses and increased recharge of aquifers (Jarecki and Lal, 2003; Lal et al., 2007).

It is also being claimed that when practised over a considerable large area, CA may lead to more constant water flows in rivers/streams and improved recharge of the water table with the reemergence of water in defunct wells. In CA system, channels created by decaying plant roots are not disturbed (macroporosity is increased) which helps in increasing deep percolation of water (Green et al., 2003), leading to recharge of groundwater. CA helps in reducing flooding in downstream areas because most of the water is absorbed in the soil in-situ. Due to improved growing season moisture regime and soil quality, crops under CA are healthier, require less fertilizers and pesticides to feed and protect the crop, thus reduce chemicals into the water.

Thus, thanks to the maintenance of a soil cover, which can be either composed of residues of the previous crop, or of plant covers that maintain their root systems, the direct impact of raindrops is minimized, the infiltration is increased and the runoff is reduced. The greater the soil coverage, the greater is the decrease in runoff. Several studies at global level analyse the reduction of runoff occurring in Conservation Agriculture systems. Some studies address a runoff decrease of 67% in no-tillage (Kertész et al., 2010) and of 43% in groundcovers in perennial crops (Márquez-Garcia et al., 2013).

Most of the biodiversity of the soil is provided by microorganisms (bacteria, fungi, algae and protozoa). Soil bacteria are mostly saprophytes, since they feed on small residues of OM in the soil, recycling it to nutrient forms that can be assimilated to the rest of the soil biota and generating compounds that, when they join the mineral particles in the soil create stable aggregates. Bacteria, like the other components of soil biodiversity, undergo degradation under conventional farming conditions, losing the fertilizing capacity that their activity generates.

The fungi that inhabit areas of crops are adapted to the processes that occur in it, being nourished from biomass that remain in the soil after harvesting. Through their extensive network of hyphae, they collect and absorb the substances contained in these wastes and, therefore, their activity is greatly benefited by Conservation Agriculture techniques in which the remains of the previous crop are left on the ground. Like the bacteria, the fungi transform these remains into forms that can be assimilated to the rest of the soil organisms, as well as cementing them by forming stable aggregates.

The algae are less abundant than bacteria and fungi. Its presence contributes energy and nutrients to the edaphic subsystem, due to its autotrophic nature, which, in turn, forces them to be located in the most superficial layers of the soil. The role they have in the conservation of soils is relevant because they reduce the compaction and erosion of them.

Protozoa are somewhat more abundant than algae and stand out for their predatory nature on soil bacteria, assuming an important controlling agent of the processes that occur in the soil subsystem.

The application of CA measures entails an increase in the global biodiversity of microorganisms. López-Piñeiro et al. (2005) when implementing direct seeding instead of conventional tillage actions on corn crops under irrigation found that the microbial populations became more diverse. Andrade et al. (2001), obtained similar results in herbaceous crops in rotation under CA located in Brazil. This increase in the biodiversity of the soil microbiota increases the stability and resistance of the processes carried out by it, favouring the recycling and availability of nutrients for the rest of the soil subsystem. Within the biodiversity of microorganisms, there are studies that demonstrate the effectiveness of CA actions on a specific group. For example, Brito et al. (2010), in a rotation of annual crops, demonstrate that the application of these measures has a positive effect on the biodiversity and abundance of mycorrhizal fungi in the soil.

In general, the entire trophic chain is going to benefit, both the communities that live in the edaphic profile (earthworms (Figure 7.4), oribatids, nematodes, etc) (Piron et al., 2010). Like those who live on it (ants, spiders, beetles, etc.). In turn, the population increase of these groups will provide food for reptiles, birds and mammals. The benefit of increasing biodiversity is not restricted to the increase in wealth per se in species. The number of interrelations between them is also increased. What makes the agrosystem more stable, increasing soil quality, by increasing biological activity, and facilitating other processes such as pollination or in the fight against pests.

Agronomic benefits

A review of 324 articles on Conservation Agriculture in Africa carried out by Dubreil (2011) provides interesting data about agronomic advantages and recommendations of practices of this system. The number of articles and some of the highlighted results have been sorted out below according to their positive or no impacts and the climate considered in the experiment. The main classification has been performed depending on the influence on these factors:

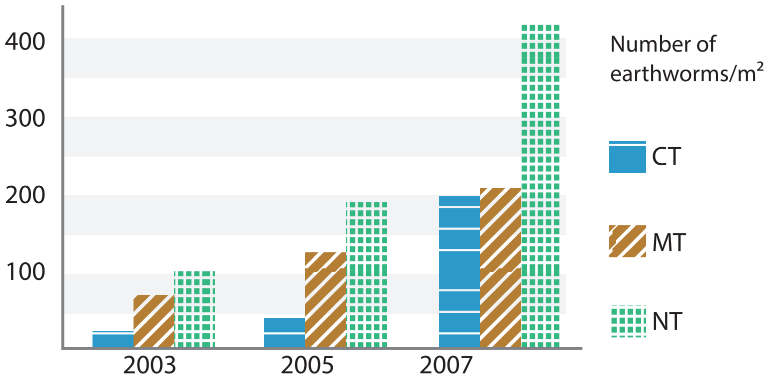


Figure 7.4.
Evolution of the population of earthworms under different management of corn cultivation. CT: Conventional Tillage; MT: Minimum Tillage; NT: No-Tillage. Adapted from Piron et al. (2010).

- soil nutrients and soil organic matter (OM)
- soil structure
- soil moisture
- crop performance

Thus, it can be seen from the review that CA has profound effects on soil quality through its positive effects on soil physical, chemical, and biological properties.

Soil nutrients and soil organic matter

Many articles point out the positive effect of CA on soil nutrient and OM. Ben Moussa-Machraoui et al. (2010) highlighted the higher nutrient content (N P K), OM, and CEC under NT compared to CT. SOC was largely increased with MT and NT in wheat/cotton rotations (Gwenzi et al., 2009) and with NT and several types of fallow (Nyamadzawo et al., 2008) in experiments carried out in Zimbabwe. Moreover, Chivenge et al. (2007) found differences in textural class, indicating significantly higher SOC in clay than sandy soils under tied ridging system.

The impact of mulch of crop residues on nutrient and OM was studied by many authors, whose experiment show positive effects on soil N (Rebafka et al., 1993; Larbi et al., 2002; Formowitz et al., 2009), soil P (Buerkert, et al., 2000; Du Preez, et al., 2001; Larbi et

Table 7.1.
Frequency of articles about CA in Africa and their impacts on four main factors sorted out by climate. Own elaboration from Dubreil (2011).

	Positive Impact		No Impact	
FACTORS	Semi-arid	Sub-humid	Semi-arid	Sub-humid
Soil nutrients and OM	20	10	13	8
Soil structure	3	2	3	
Soil moisture	10	8	9	4
Crop performance	36	16	10	5

al., 2002), soil K (Buerkert, et al., 2000; Du Preez, et al., 2001) and OM (Rebafka et al., 1993; Larbi et al., 2002: Zeleke et al., 2004)

As could be expected, the crop rotation that includes legumes, improved the soil N (Bationo & Ntare, 2000; Muhr et al., 2002; Stahl et al., 2002). In addition, arbuscular mycorrhizal fungi abundance is improved. Intercropping also improved the soil C and N in the long term (Myaka et al., 2006).

Soil structure

Crust thickness was significantly reduced with the combination of NT and surface mulch in the experiments of Gicheru et al. (2004). Mrabet (2002) showed higher water aggregate stability with NT comparing to CT in a review, which was also indicated by Nyamadzawo et al. (2007) in a 10-year experiment.

Soil moisture

Gicheru et al. (2004) and Mupangwa et al. (2007) showed the benefits of conservation tillage applied in combination with soil cover to soil moisture. Moreover, Munodawafa & Zhou (2008) found more runoff and drainage with conventional tillage than mulching. Kosgei, et al. (2007) also obtained higher moisture in NT and runoff in CT. The NT system can improve infiltration (Thierfelder & Wall, 2010) and hydraulic conductivity Osunbitan et al. (2005) comparing to conventional tillage. Across a set of experiments in semi-arid and dry sub-humid locations in east and southern Africa, Rockström et al. (2009) demonstrated that NT practices increased water productivity and crop yields, even when little or no mulch through crop residues was achieved.

The effect of residues on soils surface usually increases the water content in the soil profile. The soil moisture was significantly higher with mulch than control plot in the experiment of Buerkert et al. (2000). Naudin et al. (2010) improved the water balance with mulching in an experiment performed in cotton. The evaporative flux of water is reduced with the use of residues and the rainwater use efficiency can be improved (Zeleke et al., 2004).

Crop performance

Many publications have reported yield increases in semi-arid condition with CA, often due to increased water availability, mainly in drier years (Munodawafa & Zhou, 2008; Rockstrom et al., 2009; Kouyaté et al., 2000). Generally, crop residues resulted in an increase in yields, especially for the mulching practice, which improves soil fertility. Only a few studies showed non-significant results in dry conditions (Mupangwa et al., 2007; Kouyaté et al., 2000). However, in wetter conditions, mulch was not a successful strategy (Kolawole et al., 2004; Sinaj et al., 2001).

The impact of rotations was clearly positive on crop production. Nevertheless, rotation schemes should be selected locally according to climatic and soil conditions (Sileshi et al., 2010). Most of the publications showed that legume cover crops involved in rotations or intercropping systems have impact on subsequent yields (Bationo & Ntare, 2000; Kouyaté et al., 2000; Bado et al., 2006; Jeranyama et al., 2007; Ncube et al., 2007; Sileshi et al., 2008). Generally, the increase in production was due to the improvement of levels of soil N (Vesterager et al., 2008)

More evidence

Studies reveal that CA leads to significant improvement in soil quality over time. A successful adoption of CA can improve soil quality and thereby agronomic sustainability (Lal, 1995; Verhulst et al., 2010).

Soil organic matter is an integrator of several soil functions and as such is a key component of soil quality and the

delivery of many ecosystem services (Kassam et al., 2013; Palm et al., 2014). CA practices, especially NT and soil covers, are key to maintain or increase soil OM in the topsoil which in turn provides energy and substrate for soil biota activities, and their contributions to soil structure and nutrient cycling, as well as many other soil processes and ecosystem service (Brussaard, 2012).

Unlike in conventional systems, where OM content of the soil decreases over time, it increases under CA (González-Sánchez et al., 2012). 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 to good quality CA (following its three principles), CA system can outbalance degradation processes and turn them into a net build-up of new top soil. In more humid climates, the top soil under CA "grows" faster, i.e. at a rate of up to 1 millimetre per year. This process is ongoing until the saturation point for OM is reached, which is specific according to the soil and climate type. Under drier conditions, the build-up of the soil OM 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 physicochemical structure of the soil becomes stabilized.

In general, when the soil ceases to be tilled and crop biomass and stubble are integrated into productive management of crops and cropping systems, soil parameters that have been traditionally used to evaluate soil fertility (OM, nitrogen-phosphorus-potassium availability) evolve favourably. For all this, CA aims to improve soil fertility because the slow decomposition of ground covers produces surface layer rich in compost which, through its mineralization provide crops with nutrients (Roldán et al., 2003; Diekow et al., 2005). The figure below shows how tillage has been argued to alter the soil food web (Figure 7.5).

In terms of pH, Mousques & Friedrich (2007) reported improvements in CA, but also in OM and available nutrient contents in most of the farms compared to conventional tillage: organic matter content was raised by an average of 0.2%, the available N was raised by 20-25 mg kg^{-1} soil, available P increased by 10 mg kg^{-1} soil.

Soil microbial population and enzyme activities are greater under no-tillage and the amount of potentially mineralizable N in the surface of no-till soils averaged 35% greater than in conventional tillage, thereby indicating a greater conservation of N in CA plots (Nurbekov, 2008). Nhamo (2007) also reported that soil biota is more abundant and more active under maize-based CA cropping systems compared with conventional practice in the sandy soils of Zimbabwe.

Conservation Agriculture has been found to reduce soil compaction due to reduced traffic and maintenance of crop biomass soil cover. Besides, the deep root system of legumes used as cover crops in CA cropping systems improves soil improves soil architecture without affecting the delicate structure created by soil life and biology. In addition, the properties related to soil structure, such as aggregate size distribution, weighted average diameter and aggregation index are improved due to CA (López-Garrido et al., 2010). CA also improves the stability of aggregates 1-2 mm in diameter in wet conditions (Figure 7.6). Conversely, intensive mechanized agriculture with conventional tillage has been reported to cause soil compaction (Verhulst et al., 2010).

It is thought that due to improved growing season moisture regime and soil storage of water and nutrients, as well as legume cover crops and surface mulch and build-up of soil organic matter, crops under CA cropping systems require less fertilizer and pesticides to feed and protect the crops (Lafond et al., 2008; Crabtree, 2010; Lindwall & Sonntag, 2010). Good mulch cover provides 'buffering' against extreme temperatures at the soil surface which otherwise are

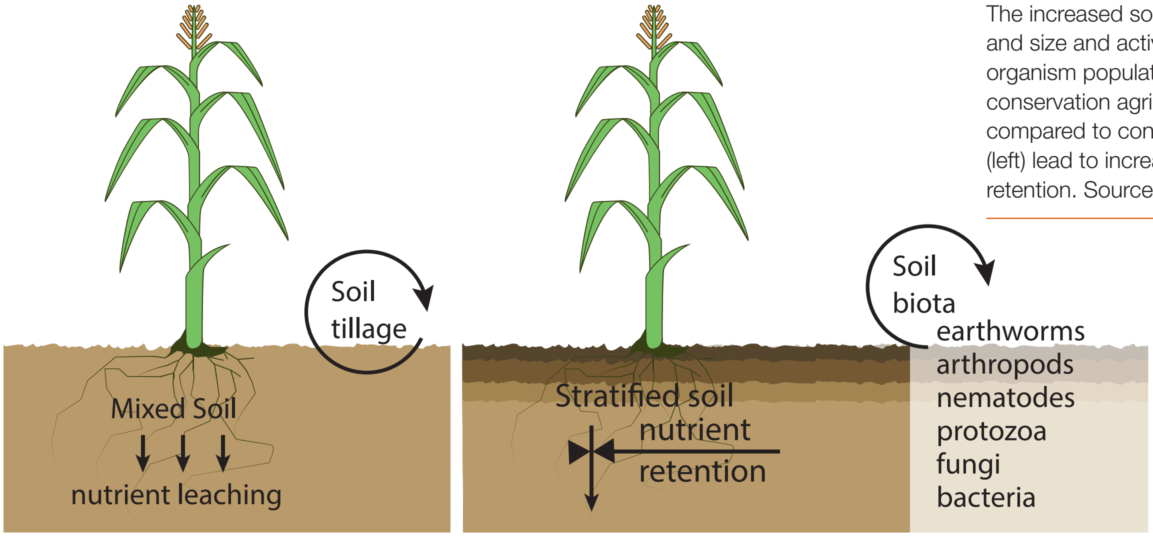


Figure 7.5.
The increased soil stratification and size and activity of soil organism populations under conservation agriculture (right) compared to conventional tillage (left) lead to increased nutrient retention. Source: Wander (2015)

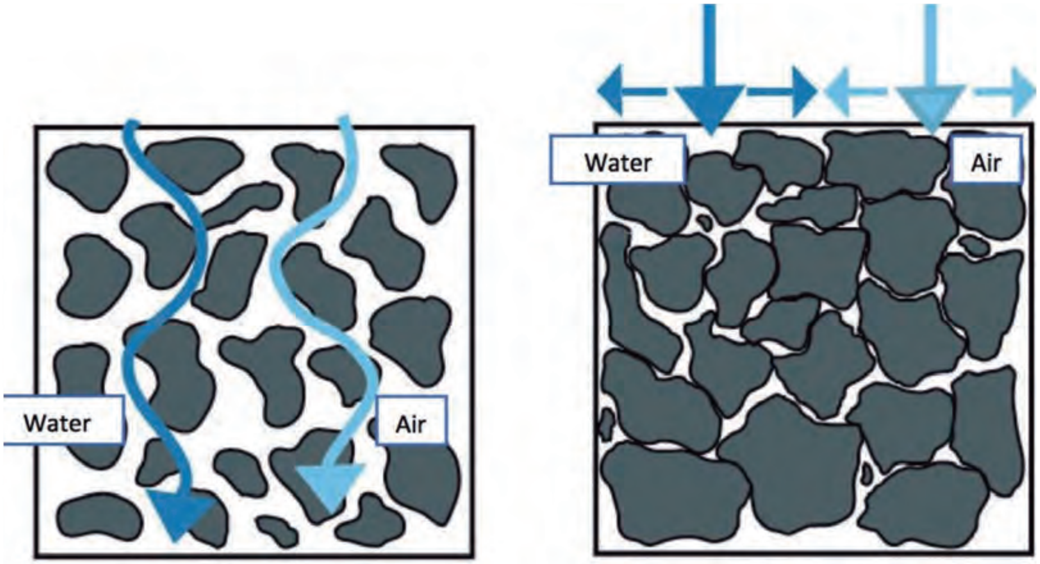


Figure 7.6.
Conservation Agriculture (left) improves soil structure by increasing organic matter, which improves infiltration rates and reduces sedimentation and nutrient runoff. Conventional tillage leaves soil vulnerable to compaction, which leads to sedimentation and increased nutrient runoff. Source: Graphics created by Fox Demo Farms.

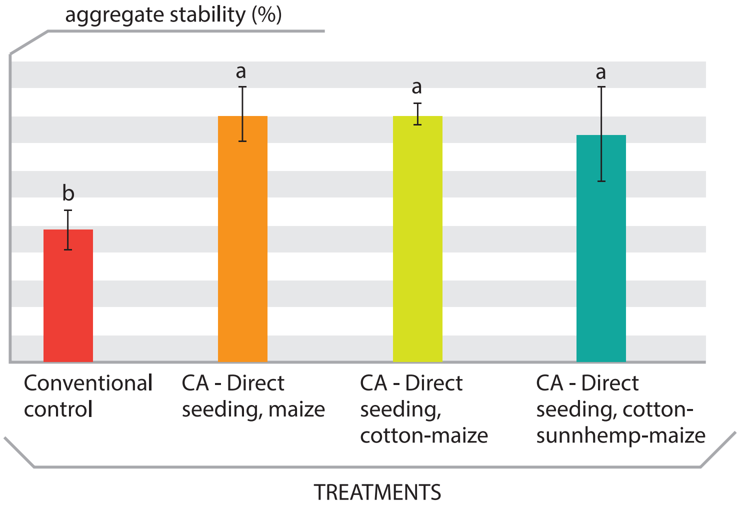


Figure 7.7.
Aggregate stability (%) measured at different times in one conventionally tilled and three conservation agriculture treatments. Monze, Zambia. Source: Thierfelder & Nyagumbo (2011).

capable of harming plant tissue at the soil/atmosphere interface, thus minimizing a potential cause of limitation of yields (Kassam et al., 2012).

Keeping crop biomass and stubble on the ground surface captures and traps water for uptake by the soil by providing shade and obstruction to horizontal water movement. The shade reduces water evaporation. In addition, surface biomass material acts as tiny 'dams', slowing runoff and increasing the opportunity for water to soak into the soil. Another way infiltration and percolation increases in CA soils are by the network of channels (macropores) created by mesofauna such as earthworms and termites and by old plant roots. In fact, continuous no-till can result in as much as two additional inches or more of water available to plants in late summer (CTIC, 2018), extending the growing season by two to three weeks.

The combination of no-tillage with sufficient crop biomass retention on the surface reduces evaporation from the topsoil and salt accumulation (Nurbekov, 2008; Hobbs & Govaerts, 2010). According to Govaerts et al. (2007) NT on its own does not induce better soil health, but the combination of NT with biomass retention is essential for desirable benefits in terms of improved soil quality and function.

Socio-economic benefits

The adoption of CA not only helps in improving soil quality and higher nutrient and rainwater use efficiency and productivity but also in the longer run provides a range of economic and environmental benefits to the farmers through reduced demand for chemical fertilizers, fuel, labour and pesticides (Machado and Silva, 2001; Sangar et al., 2004; Mariki & Owenya, 2007; Lindwall & Sonntag, 2010). In general, CA benefits can include: increased factor productivities and yields (depending on prevailing yield levels and extent of soil degradation);

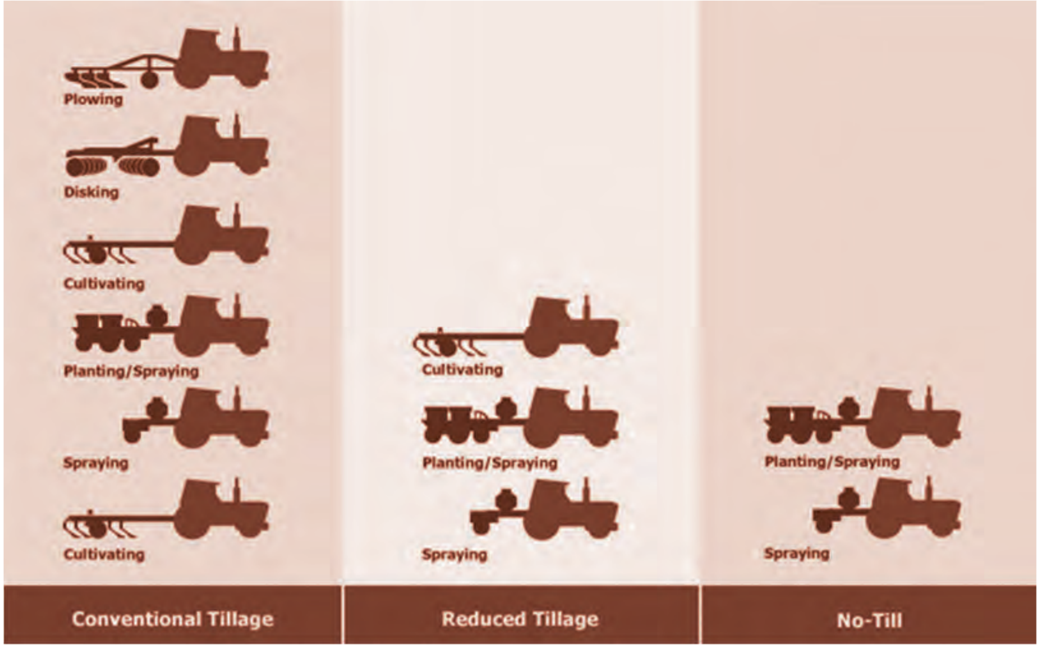


Figure 7.8. Moving from conventional to no-tillage system

up to 70% decrease in fuel energy or manual labour; up to 50% less fertiliser use; 20% or more reduction in pesticide and herbicide use; some 30% less water requirement; and reduced cost outlay on farm machinery. Further, with CA it is possible to enhance climate change adaptability of cropping systems, farms and landscapes because of improved soil-plant moisture relations while at the same time achieving greater carbon sequestration and lower emissions of greenhouse gases particularly CO_2, N_2O and CH_4. Also, due to higher rainfall infiltration and reduced runoff and soil erosion, CA also decreases flood risks, raises water resource quality and quantities, and can reduce infrastructure maintenance costs and water treatment costs (Friedrich et al., 2009; Kassam et al., 2009; Kassam et al., 2013). Experiences worldwide have shown that similar or higher yields can be obtained with no-tillage CA systems compared with conventional tillage systems (Crabtree, 2010; Derpsch et al., 2012; Thierfelder et al., 2013; Kassam et al., 2013, 2017).

The benefits of CA include reduction of the amount and costs of labour, energy and time required for land preparation and sowing due to the fact that the soil under CA becomes softer over time and easier to manage. Sowing directly into the soil without any prior tillage operations implies less labour requirement under CA.

In fact, the reduction in cost and time required are usually the most compelling initial reasons for farmers to adopt no-tillage (FAO, 2000). Farmers see NT systems as a less laborious and less risky procedure enabling fuel and machinery saving and cost reduction (Machado and Silva, 2001).

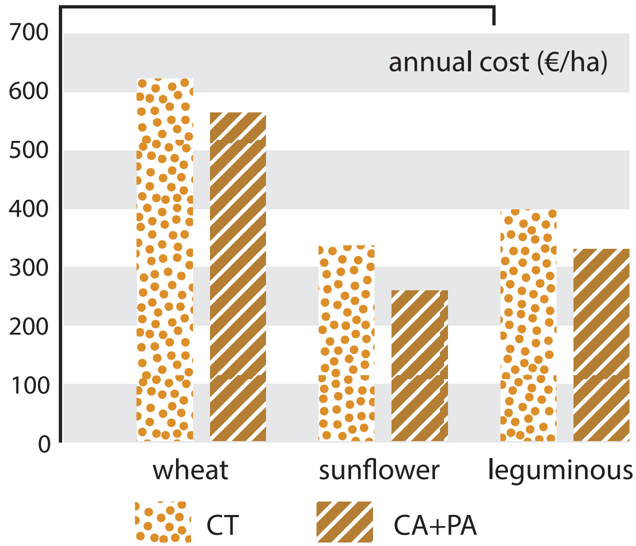


Figure 7.9.
Evaluation of costs (€ ha^{-1}) obtained in the plots under conventional tillage (CT) and No-till+Precision agriculture (CA+PA). (Source: González-Sánchez et al. (2017).

González-Sánchez et al. (2017) indicated that, within the framework of the LIFE+ Agricarbon project, the profitability obtained in a wheat-legume-sunflower crop rotation under CT and NT systems supported by precision agriculture (CA + PA) were evaluated. The profitability of the NT systems was considerable, because, while maintaining the yields, they showed cost savings compared to conventional management systems. In each campaign, the estimated cost savings were: 59.6 €/ha on wheat, 72.7 €/ha on sunflower and 62.0 €/ha on legumes. In percentages, the cost savings were 9.5% on wheat, 21.6% on sunflower and 15.4% on leguminous plants.

With respect to Africa, of the total energy used in crop production in North Africa in 1987, 69 per cent was derived from people, 17 per cent from animals, and 14 per cent from tractors (Twomlow et al., 1999). In sub-Saharan Africa, this ratio was 89:10:1. Findlay & Hutchinson (1999) estimated that 80-100 person-days/ha would be needed to prepare a land for planting with hand hoes. Animal-drawn mouldboard ploughing may take two or three days, whereas tractor ploughing may require only two or three hours. Although it is often recommended that farmers should plough immediately after harvest, most farmers wait until the first rains before commencing seedbed preparation. Because the majority of African farmers have no direct access to animal or motorised traction, seedbeds are often prepared too late, the cropping season shortened, and crop yields reduced (Ellis-Jones & Mudhara, 1997).

Conservation Agriculture reduces the energy (for example fuel for machines and calories for humans and animals) and time required. A large-scale trial at the IITA (International Institute of Tropical Agriculture) in Nigeria found that NT required 52 MJ energy and 2.3 h labour ha compared to 235 MJ and 5.4 h on CT (Wijewardene, 1979). Use of pre- and post-plant herbicides in no-till in Ghana required only 15% of the time required for seedbed preparation and weed control with a hand-hoe, while the reduction in labour days required in rice in Senegal was 53-60% (Findlay & Hutchinson, 1999).

The farmers' point of view is a central consideration in an adoption process because they will not change their practices if they do not see any benefits within a reasonable time period. Farmers are not against change but they are against taking unnecessary risks.

8 Conclusions

Climate Change

The impact of human activities, such as the burning of fossil fuels, tillage-based agricultural land use, burning of agricultural biomass, and deforestation are increasing the levels of GHG's in the atmosphere, causing global warming and climate change.

Africa has been the lowest source of GHG in the world. However, it is the most vulnerable continent to the impacts of climate change. It is expected that climate change will lead to the reduction in food and agricultural production due to changes in rainfall patterns and temperature regimes in Africa. Changing weather patterns in recent years are producing a detrimental impact on food security due to flooding, drought, land degradation and deforestation.

Agriculture and Climate Change

Greenhouse gas emissions from agriculture come mostly from crop and livestock production, and deforestation. The dominant type of land use change has been the conversion of forest to agriculture, and the dominant source of carbon emission from agriculture is from the soil due to oxidation of soil organic matter through mechanical tillage, turning soil into a source of carbon instead of a sink for carbon.

How soils are managed in agricultural land has a direct effect on climate change, and a proper soil management is one of the best tools for climate change mitigation and adaptation. Soils are an important pool of active carbon and play a major role in the global carbon cycle and have contributed to changes in the concentration of GHGs in the atmosphere.

Adopting management practices that reduce soil disturbance and increase the return of crop biomass to the soil provide for a healthy and productive soil environment. This, in turn, can improve actual productivity and provide the potential for increasing soil carbon stocks. Minimizing soil disturbance by avoiding tillage leads to carbon sequestration in the soil but also reduces N2O and CH4 emissions due to better drainage conditions in healthy porous soils with stable structure maintained under minimum soil disturbance conditions.

Thus, it would be possible to reduce greenhouse gas emissions from agriculture and lock it up in the soil. The approach should be based on improved soil management practices, and nitrogen fertiliser management that considers both the biophysical interactions within the soil, and the use of no or minimum mechanical soil disturbance practices, and leaving as much crop biomass on the soil surface to be incorporated into the soil by mesofauna and microorganisms.

Agriculture contributes to both climate change and is affected by climate change. Even if agriculture would not be the only productive sector affected by global warming, the impacts on it would definitely have negative effects on food security and social welfare.

No continent will be struck as severely by the impacts of climate change as Africa. Given its geographical position, the continent will be particularly vulnerable due to the considerably limited adaptive capacity, and exacerbated by widespread poverty. In addition, African countries would be more affected by climate change because of their reliance on agriculture.

Conservation Agriculture: A Holistic Approach to Climate Change Mitigation and Adaptability

Until now, agricultural intensification based on intensive tillage systems and increased agrochemicals, generally has had a negative effect on the quality of many of the essential natural resources such as soil, water, terrain, biodiversity and the associated ecosystem services provided by nature. This degradation of the land resource base has caused crop yields and factor productivities to decline and promoted the search for an alternative paradigm – Conservation Agriculture (CA) – that is sustainable as well as profitable.

CA comprises the application of three interlinked principles based on locally formulated practices, namely: no or minimum mechanical soil disturbance (no-till seeding and weeding), maintenance of soil mulch cover (crop biomass, stubbles, cover crops), and diversified cropping systems (rotations and/or

Conservation Agriculture aims at reducing and/or reverting many of the negative effects of conventional tillage farming practices associations with annuals and perennials including legumes).

CA involves changing many of the conventional tillage farming practices as well as the mind-set of farmers to overcome tillage-based agricultural thinking. CA thus aims at reducing and/or reverting many of the negative effects of conventional tillage farming practices such as soil erosion, soil organic matter (SOM) decline, water loss, soil physical degradation, and fuel use.

CA has been shown to be relevant and appropriate for small and large scale farmers at all levels of farm power and mechanization, from manually-operated hand tools to equipment drawn by animals to operations performed by heavy machinery. However, despite the inherent benefits of CA, its adoption in Africa is low compared with other parts of the world The reasons for the slow adoption and spread of CA compared to other continents are known and farmers are overcoming them in different ways. Since 2008/09, CA area in Africa has increased by 211% across some 22 countries.

Sustainable intensification has been defined as a form of production wherein "yields are increased without adverse environmental impact and without the cultivation of more land". Intensification of the agricultural system through efficient resource use remains the only available option to enhance production. This warrants a paradigm shift in agronomic management optimization, not only to produce more but with a higher efficiency of use of production inputs while sustaining the natural resource base and reducing environmental footprints.

CA embraces the concept of sustainable intensification of agriculture, where not only social and environmental issues are involved, but also the economic profitability for farmers. Achieving real sustainable agriculture is possible through large-scale adoption of CA as a vehicle for change. As a result of the measurable sustainability of CA, its principles are included in sustainability calculators that comprise a holistic view of sustainability and productivity. Many of the benefits under CA are not possible under tillage agriculture.

In Africa, CA has the potential of reversing the current annual 3% decrease in agricultural production due to soil erosion and land degradation by providing more stability in crop production and better ratios of outputs over inputs. CA provides environmental services to communities such as contributing to atmospheric carbon sequestration, preserving biodiversity, managing watersheds and preventing soil erosion. Communities and societies can also benefit from the adoption of CA through improved food and water security, more reliable water supplies and protection of ecosystem services

Currently, the total amount of African carbon sequestration due to CA adoption of 1.5 M ha is over 5.6 M t CO_2 yr^{-1}. The potential effect of the application of CA on carbon sequestration is to increase this to 533 M t of CO_2 per year, nearly a 100 times greater. To put this figure into context, according to the United Nations Framework Convention on Climate Change, South Africa, the world's 13th largest CO_2 emitter, national emissions by 2025 and 2030 will be in a range between 398 and 614 M t CO_2–eq per year. Thus, CA is more than a promising sustainable agricultural system, as it can effectively contribute to mitigating global warming, being able to offset agricultural CO_2 emissions.

It is important to adopt strategies to mitigate phenomena which increase climate change, but it is also necessary to adopt practices which increase the resilience of agricultural ecosystems to be able to deal more easily with the consequences of global warming, and which favour the adaptation of crops and cropping systems to the new climatic scenarios predicted by the atmospheric circulation models. CA does both.

Taking into account the expected effects of climate change, it is possible to undertake various adaptability actions aimed at improving the quality of natural resources, including soil, water and biodiversity resources, which will result in an increase in the resilience of agricultural ecosystems, improving conditions for better adaptation of crops to climate change, leading to improved crop productivity and quality. In most cases, many of these actions can be carried out using the interlinked CA practices, thus constituting not only a feasible tool to mitigate the effects of climate change, but also, as a measure of adaptation to its effects.

Conservation Agriculture principles are universally applicable in all agro-ecological conditions and landscapes to all land-based production systems with necessary adaptation to the specific local and practical conditions. Advantages of CA, in comparison with conventional tillage agriculture, cover productivity, environmental, economic and social benefits, and they can be roughly divided as: (a) Short-term advantages: increased water infiltration and improved soil structure, improved trafficability and lower compaction, reduced erosion by wind and water, reduced soil water evaporation, savings in fuel, mechanization, labour costs and time; and (b) Medium and longer-term advantages: increased soil organic matter (OM) content resulting in better soil structure, higher water holding and storage capacity, improved crop nutrition, higher and stable yields, optimised inputs, reduced energy and time requirement, lower costs, increased biological activity, less pressure of weeds, insect pests and diseases.

CA is a new paradigm of agriculture. It is referred to as being regenerative because it has many self-protective and self-repair features, and CA rehabilitates scarce resources (soil, water and biological) whilst optimising external inputs and preventing soil degradation. All these features contribute to climate change mitigation and adaptability while maximizing the sustainability of production.

9 References

Chapter 2. Climate change

Abebe, M.A. 2014. Climate change, gender inequality and migration in East Africa. Wash. J. Envtl. L & Policy, 4, 104.

Awojobi, O.N., Tetteh, J. 2017. The impacts of Climate Change in Africa: A review of the Scientific literature. Journal of International Academic Research for Multidisciplinary, 5.

Chidumayo, E., Okali, D., Kowero, G., Lawanou, M. 2011. Climate change and african forest and wildlife resources. Nairobi: African Forest Forum, Nairobi, Kenya. ClimDev-Africa. https://climdev-africa.org

Collier, P., Conway, G., Venable, T. 2008. Climate change and Africa. Oxford review of Economic Policy, 24(2), 337-353. https://doi.org/10.1093/oxrep/grn019.

Cruger, A.C., 2018. Africa and the Paris Agreementt. Nature Climate Change, 8, 365–366.

Denton, F. 2015. Africa's responses to climate change: policies to manage threat and create. Africa Programme Meeting Summary. The Royal Institute of International Affairs. Chatham House. https://www.chathamhouse.org

Dewer, B. 2012. Climate Change and Africa: Turning up the heat. Chatham House Africa Programme Paper. London. https://www.chathamhouse.org

Dia, A. 2015. What does the COP21 Paris Agreement mean for Africa? Available at: http://www.africa.undp.org/content/rba/en/home/ourperspective/ourperspectivearticles/2015/12/17/what-does-the-cop21-paris-agreement-mean-for-africa-.html

EPA. 2016. United States Environmental Protection Agency. Available at: http://epa.gov/ghgemissions/global-greenhouse-gas-emissions.

Funk, C., Senay, G., Asfaw, A., Verdin, J., Rowland, J., Michaelson, J., Choularton, R. 2005. Recent drought tendences in Ethiopia and equatorial-subtropical eastern Africa. Washington DC, FEWS-NET. Available at: http://pdf.usaid.gov/pdf_docs/Pnadh997.pdf.

Gemeda, D.O., Sima, A.D. 2015. The impacts of climate change on African continent and the way forward. Journal of Ecology and the Natural Environment, 7(10),256-262.

NOAA National Centers for Environmental Information, State of the Climate: Global Climate Report for Annual 2017, published online January 2018. Available at: https://www.ncdc.noaa.gov/sotc/global/201713.

Hulme, H.M., Doherty, R., Ngara, T., New, M., Lister, D. 2001. African climate change: 1900-2100. Climate Research, 17(2), 145-168. https://doi.org/10,3354/cr017145.

Hummel, D. 2015. Climate change, land degragadtion and migration in Mali and Senegal-some policy implications. Migration and Development, 5(2), 211-233. https://doi.org/10.1080/21632324.2015.1022972.

IPCC. 2014. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Moosmann, L., Neier, H., Mandl, Nand Radunsky, K. 2017. Implementing the Paris Agreement- New Challenges in view of the COP 23 Climate Change Conference, Study for the ENVI Committee. European Parlament, Policy department for Economic and Scientific Policy, Brussels.

NASA GISS, 2018. https://climate.nasa.gov/news/2683/january-2018-was-fifth-warmest-january-on-record/

Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., Padgham, J., Urquhart, P. 2014. Africa. In: Climate Change 2014: impacts, adaptation and vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. Available at: https:///www. Ipcc.ch/pdf/assessment-report/ar57wg2/WGIIAR5-Chap22_Final.pdf.

Rose, R.M. 2015. The impact of Climate Change on Human Security in the Sahel Region of Africa. Donnish Journal of African Studies and Developmnt, 1(2), 9-14.

Science for Environmental Policy. 2015. Migration in Response to environmental change. Luxembourg: Publications office. Available at: https://bookshop.europa.eu/uri?target=EUB:NOTICE:KHBA14006:EN:HTML

Shanahan, M., Shubert, W., Scherer, C., Corcoran, T. 2013. Climate Change in Africa: A guidebook for Journalist. Edited by UNESCO. ISBN 978-92-3-001234-2. UNDP Africa. 2015. http://www.africa.undo.org

United Nations for UN Climate Change Conference Nairobi 2006. https://unfccc.int

UNFCCC, United Nations Framework Convention on Climate Change, New York, 1992, available at: http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

UNFCCC, Kyoto Protocol to the United Nations Framework Convention on Climate Change, Kyoto. 1997. available at: http://unfccc.int/resource/docs/convkp/kpeng.pdf,

UNFCCC, Leaders Event and High Level Segment, 2015. Available at: http://newsroom.unfccc.int/cop21parisinformationhub/cop-21cmp-11-information-hub-leaders-andhigh-level-segment/

World Wide Fund for Nature. 2006. Climate Changes impacts on East Africa. World Wide Fund for Nature. Available at: https://repositories.tdl.org/tamugir/bitstream/handle/1969.3/288262/east_africa_climate_change_impacts-final

WMO. 2018. World Meteorological Organization's 2017 Annual Report. Services for Decision-Making. Available at: https://library.wmo.int/opac/doc_num.php?explnum_id=4604

Chapter 3. Agriculture and Climate change

3.1. Influence of agriculture on climate change

Adviento-Borbe, M.A.A., M.L. Haddix, D.L. Binder, D.T. Walters, and A. Dobermann. 2007. Soil greenhouse gas fluxes and global warming potential in four high-yielding maize systems. Glob. Change Biol. 13:1972–198. Andersson, M., Michelsen, A., Jensen, M., and Kjøller, A., 2004. Tropical savannah woodland: effects of experimental fire on soil microorganisms and soil emissions of carbon dioxide, Soil Biol. Biochem., 36, 849–858.

Baggs, E., Chebii, J., and Ndufa, J., 2006. A short-term investigation of trace gas emissions following tillage and no-tillage of agroforestry residues in western Kenya, Soil Till. Res., 90, 69–76.

Bender FA -M et al. (2006) 22 views of the global albedo - comparison between 20 GCMs and two satellites. Tellus 58A 320–330.

Bombelli, A., Henry, M., Castaldi, S., Adu-Bredu, S., Arneth, A., de Grandcourt, A., Grieco, E., Kutsch, W. L., Lehsten, V., Rasile, A., Reichstein, M., Tansey, K., Weber, U., and Valentini, R., 2009. An outlook on the Sub-Saharan Africa carbon balance, Biogeosciences, 6, 2193–2205, doi:10.5194/bg-6-2193-2009.

Bouwman, L., Goldewijk, K. K., Van Der Hoek, K. W., Beusen, A. H. W., Van Vuuren, D. P., Willems, J., Rufino, M. C., and Stehfest, E., 2013. Exploring global changes in nitrogen and phosphorus cycles in agriculture induced by livestock production over the 1900–2050 period, P. Natl. Acad. Sci. USA, 110, 20882–20887.Bradford, J.M. and Peterson, G.A., 2000. Conservation tillage, CRC Press, Boca Raton.

Carter, M.R, and Mele, P.M., 1992) Changes in microbial biomass and structural stability at the surface of a duplex soil under direct drilling and stubble retention in north-eastern Victoria. Australian Journal of Soil Research 30, 493–503. Carter, M.R., Angers, D.A., Kunelius, H.T., 1994. Soil structural form and stability, and organic matter under cool-season perennial grasses. Soil Sci. Soc. Am. J. 58, 1194–1199.

Castaldi, S., de Grandcourt, A., Rasile, A., Skiba, U., and Valentini, R. 2010. CO2, CH4 and N2O fluxes from soil of a burned grassland in Central Africa, Biogeosciences, 7, 3459–3471,

Cess, R.D,, 1976. Climate change: An appraisal of atmospheric feedback mechanisms employing zonal climatology. Journal of Atmospheric Sciences 33 1831–1843.

Chatskikh, D., Olesen, J.E., Berntsen, J., Regina , K., Yamulki, S., 2005. Simulation of effects of climate, soils and management on N2O emission from grasslands. Biogeochemistry 76, 395-419.

Chapuis-Lardy, L., Metay, A., Martinet, M., Rabenarivo, M., Toucet, J., Douzet, J. M., Razafimbelo, T., Rabeharisoa, L., and Rakotoarisoa, J., 2009. Nitrous oxide fluxes from malagasy agricul- tural soils, Geoderma, 148, 421–427.

Chikowo, R., Mapfumo, P., Nyamugafata, P., and Giller, K. E. 2004. Mineral n dynamics, leaching and nitrous oxide losses under maize following two-year improved fallows on a sandy loam soil in Zimbabwe, Plant Soil, 259, 315–33Ciais, P., Bombelli, A., Williams, M., Piao, S. L., Chave, J., Ryan, C. M., Henry, M., Brender, P., and Valentini, R. 2011. The carbon balance of Africa: synthesis of recent research studies, Philos. T. Roy. Soc. A, 269, 2038–2057.

Delmas, R. A., Marenco, A., Tathy, J. P., Cros, B., and Baudet, J. G. R., 1991. Sources and sinks of methane in African savanna. CH4 emissions from biomass burning, J. Geophys. Res., 96, 7287–7299.

Dick, J., Kaya, B., Soutoura, M., Skiba, U., Smith, R., Niang, A., and Tabo, R., 2008. The contribution of agricultural practices to nitrous oxide emissions in semi-arid Mali, Soil Use Manage., 24, 292–301.

FAO, 2010. Global Forest Resources Assessment, FAO Forestry Paper 163, Food and Agri- culture Organization of the United Nations, Rome, 340 pp., available at: http://www.fao.org/forestry/fra/fra2010/en/ (last access: 1 October 2017).

FAOSTAT, 2014. available at: http://faostat.fao.org/site/377/default.aspx#ancor (last access: 1 Octo- ber 2015).

Frimpong, K. A., Yawson, D. O., Agyarko, K., and Baggs, E. M., 2012. N2O emission and mineral N release in a tropical acrisol incorporated with mixed cowpea and maize residues, Agronomy, 2, 167–186.

Gentile, R., Vanlauwe, B., Chivenge, P., and Six, J., 2008. Interactive effects from combining fertilizer and organic residue inputs on nitrogen transformations, Soil Biol. Biochem., 40, 2375–2384.

Gibbs, H. K., Ruesch, A. S., Achard, F., Clayton, M. K., Holmgren, P., Ramankutty, N., and Foley, J. A, 2010.: Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s, P. Natl. Acad. Sci. USA, 107, 16732–16737.

González-Sánchez, E.J., Kassam, A., Basch, G., Streit, B., Holgado-Cabrera, A., Triviño-Tarradas, P, 2016. Conservation Agriculture and its contribution to the achievement of agri-environmental and economic challenges in Europe. AIMS Agriculture and Food, 1 (4), pp. 387-408.

Goossens A, De Visscher A, Boeckx P., 2001. Two-year field study on the emission of N2O from coarse and middletextured Belgian soils with different land use. Nutrient Cycling in Agroecosystems, 60, 23–34.

Gu, J., Nicoullaud, B., Rochette, P., Grossel, A., Hénault, C., Cellier, P., & Richard, G., 2013. A regional experiment suggest that soil texture is a major control of N2O emissions from tile drained winter wheat fields during the fertilization period. Soil Biology and Biochemistry, 60, 134–141.

Hickman, J. E., Palm, C., Mutuo, P., Melillo, J., and Tang, J. 2014. Nitrous oxide (N2O) emissions in response to increasing fertilizer addition in maize (Zea mays L.) agriculture in western Kenya, Nutr. Cycl. Agroecosys., 100, 177–187.

Hickman, J., Tully, K., Groffman, P., Diru, W., and Palm, C., 2015. A potential tipping point in tropical agriculture: Avoiding rapid increases in nitrous oxide fluxes from agricultural intensification in Kenya, J. Geophys. Res.-Biogeo., 120, 938–951,

HuX, YangW, Chen C (2013)Effects of returning maize straw tofield on soil nutrient and wheat yield. J Henan Inst Sci Technol 41:6–8.

Huang, K,, Ding, A., Liu, L., Liu, Q., Ding, K., Niu, X., Nie, W., Xu, Z., Chi, X., Wang, M., Sun, J., Guo, W. and Fu, C., 2016. Effects of aerosol–radiation interaction on precipitation during biomass-burning season in East China. Atmos. Chem. Phys., 16, 10063–10082.

International Panel on Climate Change (IPCC), 2007. Cambridge University Press; Cambridge, UK. Climate change: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

International Panel on Climate Change (IPCC), 2014: Summary for policymakers, in: Climate Change 2014, Mitigation of Climate Change, contribution of Working Group III to the Fifth Assessment Report of the Intergovernmen- tal Panel on Climate Change, edited by: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlomer, S., von Stechow, C., Zwickel, T., and Minx, J. C., Cam- bridge University Press, Cambridge, UK and New York, NY, USA, 1–30, 2014.

Janssen, S., Andersen, E., Athanasiadis, I.N., Van Ittersum, M.K., 2009. A database for integrated assessment of European agricultural systems. Environ. Sci. Pol., 12, 573-587.

Johnson, J.M, Franzluebbers, A.J., Lachnicht-Weyers, S., Reicosky, D.C., 2007. Agricultural opportunities to mitigate greenhouse gas emissions. Environ. Pollut. 150, 107-124.

Kassam, A., Basch, G., Friedrich, T., Gonzalez, E., Trivino, P., Mkomwa, S., 2017. Mobilizing greater crop and land potentials sustainably. Hungarian Geographical Bulletin, 66 (1), pp. 3-11.

Kim, D.-G., 2012. Estimation of net gain of soil carbon in a nitrogen-fixing tree and crop intercropping system in sub-Saharan Africa: results from re-examining a study, Agroforest. Syst., 86, 175– 184.

Kim, D.-G., Hernandez-Ramirez, G., and Giltrap, D., 2013. Linear and nonlinear dependency of direct nitrous oxide emissions on fertilizer nitrogen input: a meta-analysis, Agr. Ecosyst. Environ., 168, 53–65.

Kim, D.-G. and Kirschbaum, M. U., 2015. The effect of land-use change on the net exchange rates of greenhouse gases: a compilation of estimates, Agr. Ecosyst. Environ., 208, 114–126.

Kim, D.G., Thomas, A.D., Pelster, D., Rosenstock, T.S. and Sanz-Cobena, A., 2016. Greenhouse gas emissions in natural and agricultural lands in sub-Saharan Africa:

synthesis of available data and suggestions for further studies. Biogeosciences, 13, 4789–4809.

Kimetu, J., Mugendi, D., Bationo, A., Palm, C., Mutuo, P., Kihara, J., Nandwa, S., and Giller, K., 2007. Partial balance of nitrogen in a maize cropping system in humic nitisol of Central Kenya, Nutr. Cycl. Agroecosys., 76, 261–270.

Koerber, G. R., Edwards-Jones, G., Hill, P. W., Nyeko, P., York, E. H., and Jones, D. L., 2009. Geo-graphical variation in carbon dioxide fluxes from soils in agro-ecosystems and its implications for life-cycle assessment, J. Appl. Ecol., 46, 306–314.

Lal, R., Kimble, J.M., Follett, R.F., Stewart, B.A. (Eds.), 1998. Soil Processes and Carbon Cycle. CRC Press, Boca Raton, FL, 457 pp.

Lal R. 2008. Carbon sequestration. Philosophical Transactions of the Royal Society B 363, 815-830 (2008).

Makumba, W., Akinnifesi, F. K., Janssen, B., and Oenema, O., 2007. Long-term impact of a gliricidia- maize intercropping system on carbon sequestration in southern Malawi, Agr. Ecosyst. Env- iron., 118, 237–243.

Malhi, S., Nyborg, M., Solberg, E., Dyck, M., and Puurveen, D., 2011. Improving crop yield and N uptake with long-term straw retention in two contrasting soil types, Field Crop. Res., 124, 378–391.

Mapanda, F., Mupini, J., Wuta, M., Nyamangara, J., and Rees, R., 2010. A cross-ecosystem assessment of the effects of land cover and land use on soil emission of selected greenhouse gases and related soil properties in Zimbabwe, Eur. J. Soil Sci., 61, 721–733.

Mapanda, F., Wuta, M., Nyamangara, J., and Rees, R. M., 2011. Effects of organic and mineral fertil- izer nitrogen on greenhouse gas emissions and plant-captured carbon under maize cropping in Zimbabwe, Plant Soil, 343, 67–81.

Mapanda, P., Wuta, M., Nyamangara, J., Rees, R., and Kitzler, B., 2012. Greenhouse gas emissions from savanna (miombo) woodlands: Responses to clearing and cropping, Afr. Crop Sci. J., 20, 385–400.

Masaka, J., Nyamangara, J., and Wuta, M., 2014. Nitrous oxide emissions from wetland soil amended with inorganic and organic fertilizers, Arch. Agron. Soil Sci., 60, 1363–1387.

Macdonald, J. A., Eggleton, P., Bignell, D. E., Forzi, F., and Fowler, D., 1998. Methane emission by termites and oxidation by soils, across a forest disturbance gradient in the mbalmayo forest reserve, Cameroon, Glob. Change Biol., 4, 409–418.

Millar, N. and Baggs, E. M., 2004. Chemical composition, or quality, of agroforestry residues influ- ences N2O emissions after their addition to soil, Soil Biol. Biochem., 36, 935–943.

Millar, N., Ndufa, J., Cadisch, G., and Baggs, E., 2004. Nitrous oxide emissions following incorporation of improved-fallow residues in the humid tropics, Global Biogeochem. Cy., 18, GB1032, doi:10.1029/2003GB002114.

Nouvellon, Y., Epron, D., Marsden, C., Kinana, A., Le Maire, G., Deleporte, P., Saint-Andre', L., Bouillet, J. P., and Laclau, J. P., 2012. Age-related changes in litter inputs explain annual trends in soil CO2 effluxes over a full eucalyptus rotation after afforestation of a tropical savannah, Biogeochemistry, 111, 515–533.

Mutegi, J. K., Munkholm, L. J., Petersen, B. M., Hansen, E. M., and Petersen, S. O., 2010. Nitrous oxide emissions and controls as influenced tillage and crop residue management strategy, Soil Bio. Biochem., 42, 1701–1711.

Ngaira, J. K., 2003. The Climatology of Equatorial East Africa: Causes and impacts of rainfall anomalies, Climates in Transition (LC Nkemdirim ed) Washington DC. pp. 41-53.

Nyamadzawo, G., Wuta, M., Nyamangara, J., Smith, J. L., and Rees, R. M., 2014a. Nitrous oxide and methane emissions from cultivated seasonal wetland (dambo) soils with inorganic, organic and integrated nutrient management, Nutr. Cycl. Agroecosys., 100, 161–175.

Nyamadzawo, G., Shi, Y., Chirinda, N., Olesen, J.r., Mapanda, F., Wuta, M., Wu, W., Meng, F., Oelofse, M., de Neergaard, A., and Smith, J., 2014b. Combining organic and inorganic nitrogen fertilisation reduces N2O emissions from cereal crops: a comparative analysis of China and Zimbabwe, Mitig. Adapt. Strategies Glob. Chang., doi:10.1007/s11027-014-9560-9.

Pielke, R.A., Avissar, R., Raupach, M., Dolman, A.J., Zeng, X. and Scott, A., 1998. Interactions between the atmosphere and the terrestrial ecosystem: Influence on weather and climate. Global Change Biology 4 461–475.

Predotova, M., Schlecht, E., and Buerkert, A., 2010. Nitrogen and carbon losses from dung storage in urban gardens of Niamey, Niger, Nutr. Cycl. Agroecosys., 87, 103–114.

Rabenarivo, M., Wrage-Moennig, N., Chotte, J. L., Rabeharisoa, L., Razafimbelo, T. M., and Chapuis-Lardy, L., 2014. Emissions of CO2 and N2O from a pasture soil from Madagascar- simulating conversion to direct-seeding mulch-based cropping in incubations with organic and inorganic inputs, J. Plant Nutr. Soil Sc., 177, 360–368.

Reicosky, D.C., 2011. Conservation agriculture: Global environmental benefits of soil carbon management. In 'Fifth World Congress on Conservation Agriculture'. Vol. 1. pp. 3–12.

Smith, L.C., C.A.M. deKlein, and W.D. Catto., 2008. Effect of Dicyandiamide Applied in a Granular Form on Nitrous Oxide Emissions from a Grazed Dairy Pasture in Southland, New Zealand. New Zealand Journal of Agricultural Research, 51(4):387-3.

Tan Y., Xu C., Liu D., Wu W., Lal R., & Meng F., 2017. Effects of optimized N fertilization on greenhouse gas emission and crop production in the North China Plain. Field Crops Research, 205, 135–146.

Tathy, J., Cros, B., Delmas, R., Marenco, A., Servant, J., and Labat, M., 1992. Methane emission from flooded forest in central Africa, J. Geophys. Res., 97, 6159–6168.

Tebruegge, F., 2001. No-tillage visions- Protection of soil, water and climate and influence on management and farm income. García-Torres, L.; Benites, J.; Martínez.

Thomas, A. D., 2012. Impact of grazing intensity on seasonal variations in soil organic carbon and soil CO_2 efflux in two semiarid grasslands in southern Botswana, Philos. T. Roy. Soc. B, 367, 3076–3086.

Tubiello, F. N., Salvatore, M., Ferrara, A. F., House, J., Federici, S., Rossi, S., Biancalani, R., Condor Golec, R. D., Jacobs, H., Flammini, A., Prosperi, P., Cardenas-Galindo, P., Schmid-huber, J., Sanz Sanchez, M. J., Srivastava, N., and Smith, P., 2015. The contribution of agriculture, forestry and other land use activities to global warming, 1990–2012, Glob. Change Biol., 21, 2655–2660.

USAID, 2015. Greenhouse Gas Emissions in East Africa. Available from: https://www.climatelinks.org/sites/default/files/asset/document/GHG%20Emissions%20Factsheet%20East%20Africa_12%2031%202015_edited_rev08-19-2016_Clean.pdf

Valentini, R., Arneth, A., Bombelli, A., Castaldi, S., Cazzolla Gatti, R., Chevallier, F., Ciais, P., Grieco, E., Hartmann, J., Henry, M., Houghton, R. A., Jung, M., Kutsch, W. L., Malhi, Y., Mayorga, E., Merbold, L., Murray-Tortarolo, G., Papale, D., Peylin, P., Poulter, B., Ray- mond, P. A., Santini, M., Sitch, S., Vaglio Laurin, G., van der Werf, G. R., Williams, C. A.,and Scholes, R. J., 2014. A full greenhouse gases budget of Africa: synthesis, uncertainties, and vulnerabilities, Biogeosciences, 11, 381–407.

Van Groenigen, J., Velthof, G., Oenema, O., Van Groenigen, K., and Van Kessel, C., 2010. Towards an agronomic assessment of N_2O emissions: a case study for arable crops, Eur. J. Soil Sci., 61, 903–913.

Vidon P., Marchese S., Welsh M., & Mcmillan S., 2016. Impact of precipitation intensity and riparian geomorphic characteristics on greenhouse gas emissions at the soil-atmosphere interface in a water-limited riparian zone. Water Air & Soil Pollution, 227, 1–12.

Wei Y. H., Zhang E. P., Chen F., Zhang Y., & Zhang H. L., 2012. Effects of tillage systems on greenhouse gas emission of wheat-maize double cropping system in North China Plain. Advanced Materials Research, 524–527, 2526–2532.

WRI CAIT 2.0, 2015. Available at: https://www.wri.org/resources/websites/cait

Yan G., Yao Z., Zheng X., & Liu C., 2015. Characteristics of annual nitrous and nitric oxide emissions from major cereal crops in the North China Plain under alternative fertilizer management. Agriculture, Ecosystems & Environment, 207, 67–78.

Yohannes, Y., Shibistova, O., Asaye, Z., and Guggenberger, G.: Forest management influence on the carbon flux of cupressus lusitanica plantation in the Munessa forest, Ethiopia, Forest Res., 2, doi:10.4172/2168-9776.1000111, 2013.

Zepp, R. G., Miller, W. L., Burke, R. A., Parsons, D. A. B., and Scholes, M. C.: Effects of mois- ture and burning on soil–atmosphere exchange of trace carbon gases in a southern African savanna, J. Geophys. Res., 101, 23699–23706, 1996.

Chapter 3. Agriculture and Climate change

3.2. Impacts of climate change in agriculture

Challinor, A. J,, Watson, J., Lobell, D. B,, Howden, S. M,. Smith, D. R. and Chhetri, N., 2014. A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change, 4, 287-291.

EEA, 2016. European Environment Agency. Agriculture and Climate Change. Available from: https://www.eea.europa.eu/signals/signals-2015/articles/agriculture-and-climate-change

FAO, 2009. Climate change in Africa: The threat to agriculture. Available from: https://www.uncclearn.org/sites/default/files/inventory/fao34.pdf

Feyssa DH, Gemeda DO (2015). Impacts of Climate Change on Production System in Semi-arid regions of Ethiopia, J. Biol. and Chem. Res. 32(2):755-764.

Huq, S., Reid, H., Konate, M., Rahman, A., Sokona, Y., & Crick, F. (2004). Mainstreaming adaptation to climate change in Least Developed Countries (LDCs). Climate Policy, 4(1), 25–43. https://doi.org/10.1080/14693062.2004.9685508

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Group I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Kim Chang-Gil, Lee Sang-Min, Jeong Hak-Kyun, Jang Jeong-Kyung and Lee Chung-Keun,, 2009. Impacts and Countermeasures of Climate Change in Korean Agriculture. Research Report No. 593. Korea Rural Economic Institute.

Nordhaus, W. D. (2006). Geography and macroeconomics: new data and new findings. Proceedings of the National Academy of Sciences of the United States of America, 103(10), 3510–3517. https://doi.org/10.1073/pnas.0509842103.

Pereira, L. (2017). Climate Change Impacts on Agriculture across Africa. Oxford Encyclopedia of Agriculture and the Environment. https://doi.org/10.1093/acrefore/9780199389414.013.292

Ray, D. K., Gerber, J.S., MacDonald, G.K. and West, P.C., 2015. Climate variation explains a third of global crop yield variability, Nat. Commun., 6, 5989. https://doi.org/10.1038/ncomms6989.

Rose, R. M. (2015). The Impact of Climate Change on Human Security in the Sahel Region of Africa. Donnish Journal of African Studies and Development, 1(2), 9–14.

Singh, A., & Purohit, B. M. (2014). Public Health Impacts of Global Warming and Climate Change. Peace Review, 26(1), 112–120. https://doi.org/10.1080/10402659.2014.876326

UN Environment, 2018. Responding to climate change. Available from: https://www.unenvironment.org/regions/africa/regional-initiatives/responding-climate-change

Rattani, V., 2017. Climate disruption. Available from: https://www.downtoearth.org.in/news/climate-disruption-58580

Chapter 4. Core principles of Conservation Agriculture

ACT, 2018. African Conservation Tillage Network website: Our History. Available from: http://www.act-africa.org/content.php?com=2&com2=14&com3=

Auerbach, R. 2000. Towards a farmer-led Landcare movement in South Africa. Keynote address, National Landcare Workshop, Pretoria, South Africa.

Baker, C.J., Saxton, K.E., Ritchie, W.R. 2002. No-tillage seeding: science and practice, 2nd edn. CAB, Oxford.

Barret, D.W.A., Wiles, T.L., Barker, M.R. 1972. Spray-seed with the bipyridyls in Western Australia. In: Proceedings no-tillage systems symposium, Columbus, 21–22 Feb 1972, pp 83–92.

Baudron, F., Jaleta, M., Okitoi, O., Tegegn, A. 2014. Conservation agriculture in African mixed crop-livestock systems: expanding the niche. Agriculture, Ecosystems & Environment 187, 171–182

Bäumer, K. 1970. First experiences with direct drilling in Germany. Neth J Agric Sci 18:283–292.

Boisgontier, D., Bartholomy, P., Lescar, L. 1994. Feasibility of minimum tillage practices in France. In: Proceedings of the EC-Workshop-I-, Giessen, 27–28 June, 1994, Experience with the applicability of no-tillage crop production in the West-European countries, Wissenschaftlicher Fachverlag, Giessen, pp 81–91

Borges, G. de O. 1993. Resumo histórico do plantio direto no Brasil. In: EMBRAPA, Centro Na- cional de Pesquisa de Trigo (Passo Fundo, RS). Plantio direto no Brasil. EMBRAPA-CNPT/ Fundacep Fecotrigo/Fundação ABC/Aldeia Norte, pp 13–17.

Brown, B., Nuberg, I., Llewellyn, R., 2018. Pathways to intensify the utilization of conservation agriculture by African smallholder farmers. Renewable Agriculture and Food Systems, 1-13.

Cannel, R.Q., Hawes, J.D. 1994. Trends in tillage practices in relation to sustainable crop production with special reference to temperate climates. Soil Till Res 30:245–282.

Choto, C., Saín, G. 1993. Análisis del mercado de rastrojo y sus implicaciones para la adopción de la labranza de conservación en El Salvador. Síntesis de resultados experimentales del PRM 1992. Vol. 4, pp. 212-222

Derpsch, R. 1998. Historical review of no-tillage cultivation of crops. In: Proceedings of the 1st JIRCAS Seminar on Soybean Research on No-tillage Culture & Future Research Needs, pp. 1-18. March 5-6, 1998, Iguassu Falls, Brazil, JIRCAS Working Report No. 13.

Derpsch, R. 2007. Historical review of no- tillage cultivation of crops. Available from: http://www.rolf-derpsch. com/notill.htm#1#1

Derpsch, R. Friedrich, T. 2009a. Global Overview of Conservation Agriculture Adoption. Proceedings, Lead Paper, 4th World Congress on Conservation Agriculture, pp. 429-438. 4-7 February 2009, New Delhi, India.

Derpsch, R. Friedrich, T. 2009b. Development and Current Status of No-till Adoption in the World; Proceedings on CD, 18th Triennial Conference of the International Soil Tillage Research Organization (ISTRO), June 15-19, 2009, Izmir, Turkey.

Dumanski, J., Reicosky, D.C., Peiretti, R.A. 2014. Pioneers in soil conservation and Conservation Agriculture. Special issue, International Soil and Water Conservation Research 2(1), March 2014.

FAO, 2002. Agricultura de Conservación. Estudio de casos en América Latina y África. Boletín de suelos de la FAO. Roma 2002.

FAO, 2008. Proceedings of an International Technical Workshop on Investing in Sustainable Crop Intensification: The case for improving soil health. FAO, Rome, 22- 24 July 2008. Integrated Crop Management, Vol. 6. 2008. FAO, Rome.

FAO, 2009. Conservation Agriculture in Uzbekistan. Crop and Grassland Service Working Paper 2, FAO, Rome. 38 pp.

FAO, 2010. FAO CA website at: www.fao.org/ag/ca

FAO, 2010. How to feed the world in 2050. En: http://fao.org

FAO, 2011. Save and Grow: A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production. FAO, Rome.

FAO, 2012. El estado de los recursos de tierras y aguas del mundo para la alimentación y la agricultura. 342 pp. La gestión de los sistemas en situación de riesgo. ISBN FAO: 978-92-5-306614-8.

FAO, 2018. Conservation Agriculture website. Available from: http://www.fao.org/conservation-agriculture/en/

FAOSTAT, 2014. Available from: http://faostat.fao.org/site/377/default.aspx#ancor

Farooq, M., Flower, K., Jabran, K., Wahid, A., Siddique, K.H.M. 2011a. Crop yield and weed management in rainfed conservation agriculture. Soil Till Res 117:172–183

Farooq, M., Siddique, K.H.M. 2015. Conservation Agriculture: Concepts, Brief History, and impacts on Agriculture. In: Farooq M., Siddique K. (eds) Conservation Agriculture. Springer, Cham

Faulkner, E.H. 1945. Ploughman's Folly. Michael Joseph, London. 142 pp.

Fowler, R. 2000. A hundred years of learning. Introductory remarks, Conservation tillage for sustainable soil management workshop. Global Dialogue, EXPO 2000, Hannover.

Friedrich, T., Kassam, A.H. 2009. Adoption of Conservation Agriculture Technologies: Constraints and Opportunities. Invited paper at the IV World Congress on Conservation Agriculture. 4-7 February 2009, New Delhi, India.

Friedrich, T., Derpsch, R., Kassam, A.H. 2012. Overview of the global spread of Conservation Agriculture. Field Actions Science Reports, Special Issue 6: 1-7.

Fukuoka, M. 1975. One straw revolution, Rodale, Tokyo, p 138

Giráldez, J.V., González, P. 1994. No-tillage in clay soils under Mediterranean climate: physical aspects. In: proceedings of the EC-Workshop-I-, Giessen, 27–28 June 1994, Experience with the applicability of no-tillage crop production in the West-European countries, Wissenschaftlicher Fachverlag, Giessen, 1994, pp 111–117.

Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, W., Watson, A. and Sombatpanit, S. (eds) 2006. No-Till Farming Systems. Special Publication No. 3. World Association of Soil and Water Association, Bangkok, Thailand

Goddard, T., Zoebisch, M.A., Gan, Y.T., Ellis, W., Watson, A., Sombatpanit, S. (Eds) 2008. No-Till Farming Systems. World Association of Soil and Water Conservation. Special Publication No. 3. Bangkok: WASWC. 540 pp.

Gonzalez-Sanchez, E.J., Veroz-Gonzalez, O., Blanco-Roldan, G.L., Marquez-Garcia, F., Carbonell-Bojollo, R. 2015. A renewed view of conservation agriculture and its evolution over the last decade in Spain. Soil and Tillage Research, 146 (PB), pp. 204-212.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K.D., Dixon, J., Dendooven, L. 2009. Conservation agriculture and soil carbon sequestration; between myth and farmer reality. Crit Rev Plant Sci 28:97–122.

Greenland, D.J. 1975. Bringing the green revolution to the shifting cultivators. Science 190:841–844.

Haggblade, S., Tembo. 2003. Conservation Farming in Zambia. EPTD Discussion Paper 108: Washington, D.C.: International Food Policy Research Institute (IFPRI). Available from: http://www.ifpri.org/

Harrington, L., 2008. A Brief History of Conservation Agriculture in Latin America, South Asia and Sub-Saharan Africa. PACA, 1st Floor, NASC Complex, DPS Marg, Pusa, New Delhi, India.

Hobbs, P.R., Sayre, K., Gupta, R. 2008. The role of conservation agriculture in sustainable agriculture. Philos. Trans. Roy. Soc. B 363, 543–555.

Hobbs, P.R., Gupta, R.K. 2004. Problems and challenges of no-till farming for the rice–wheat systems of the Indo-Gangetic Plains in South Asia. In: Lal R, Hobbs P, Uphoff N, Hansen DO (eds) Sustainable agriculture and the rice–wheat system. Ohio State University/Marcel Dekker, Columbus, pp 101–119.

Jat, R.A., Sahrawat, K.L. and Kassam, A.H. (eds) 2014. Conservation Agriculture: Global Prospects and Challenges. CABI, Wallingford. 393 pp.

Kassam, A.H. 2009. Sustainability of farming in Europe: is there a role for Conservation Agriculture? Journal of Farm Management 10: 717-728.

Kassam, A.H., Friedrich, T., Shaxson, F., Pretty, J. 2009. The spread of conservation agriculture: justification, sustainability and uptake. Int J Agric Sustain 7:1–29.

Kassam, A.H., Basch, G., Friedrich, T., Shaxson, F., Goddard, T., Amado, T., Crabtree., B., Hongwen, L., Mello, I., Pisante, M. and Mkomwa, S.(2013. Sustainable soil management is more than what and how crops are grown. In: R. Lal and Stewart, R.A (Eds) Principles of Soil Management in Agro-ecosystems. Advances in Soil Science. CRC Press.

Kassam, A., Friedrich, T., Derpsch, R., Kienzle, J. 2015. Overview of the Worldwide Spread of Conservation Agriculture. Field Actions Science Reports, Special Issue 8: 1-11.

Kassam, A., Mkomwa, S. 2017. International Conservation Agriculture Advisory Panel for Africa (ICAAP-AFRICA). Available from: http://icaap.act-africa.org/

Kassam, A., Mkomwa, S., Freidrich, T. 2017. Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate. CABI, Walingford.

Kassam, A., Friedrich, T., Derpsch, R. 2018. Global spread of Conservation Agriculture. International Journal of Environmental Studies. https://doi.org/10.1080/00207233.2018.1494927

Lal, R. 1976. No tillage effects on soil properties under different crops in western Nigeria. Soil Sci Soc Am Proc 40:762–768.

Lichtfouse, E., Hamelin, M., Navarrete, M., Debaeke, P., Henri, A. 2010. Emerging agroscience. Agronomy for Sustainable Development. 30, 1-10.

Lindwall, C.W., Sonntag, B. (Eds) 2010. Landscape Transformed: The History of Conservation Tillage and Direct Seeding. Knowledge Impact in Society. Saskatoon: University of Saskatchewan.

Lorentz, P. 1936. The Plow that Broke the Plains. US Resettlement Administration.

Marongwe, L.S., Kwazira, K., Jenrich, M., Thierfelder, C., Kassam, A., Friedrich, T. 2011. An African success: the case of conservation agriculture in Zimbabwe. Int J Agric Sustain 9:153–161.

McKibben, G.E. 1968. No-tillage planting is here - suitable equipment is on market most practices are little different from what good farmers are already doing advantages are many and it works. Crops and Soils Magazine. 20, 19.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. Proc Natl Acad Sci U S A 104:13268–13272.

Ndah, H. T., Schuler, J., Uthes, S., Zander, P., Triomphe, B., Mkomwa, S., Corbeels, M., 2015. Adoption potential for Conservation Agriculture in Africa: a newly developed assessment approach (QAToCA) applied in Kenya and Tanzania. Land Degradation and Development, 26 (2): p. 133-141.

Perszewski, R. 2005. Ideas leading to no-till's second revolution. Available from: http://www.no-tillfarmer.com/ages/Feature-Articles---Ideas-Leading-To-No-Tills-Second-Revolution.php

Putte, A.V., Govers, G., Diels, J., Gillijns, K., Demuzere, M. 2010. Assessing the effect of soil tillage on crop growth: a meta-regression analysis on European crop yields under conservation agriculture. Eur J Agron 33:231–241.

Ryan, G.F. 1970. Resistance of common groundsel to simazine and atrazine. Weed Sci 18:614–616.

Reicosky, D.C. 2008. Carbon sequestration and environmental benefits from no-till systems. In: No-Till Farming Systems, pp. 43-58. Eds T Goddard, M Zoebisch, Y T Gan, W Ellis, A Watson, S Sombatpanit. World Association of Soil and Water Conservation, Special Publication No. 3. Bangkok: WASWAC. 540 pp.

Sartori, L., Peruzzi, P. 1994. The evolution of no-tillage in Italy: a review of the scientific literature. In: Proceedings of the EC-Workshop-I-, Giessen, 27–28 June, 1994, Experience with the applicability of no-tillage crop production in the West-European countries, Wissenschaftlicher Fachverlag, Giessen, 1994, pp 119–129.

Serraj, R., Siddique, K.H.M. 2012. Conservation agriculture in dry areas. Field Crops Res 132:1–6.

West, T.O., Marland, G. 2002. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. Agric Ecosyst Environ 91:217–232.

Chapter 5. Conservation Agriculture: a sustainable intensification of agriculture

Boserup, E. 1965. The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure. London: Allen & Unwin.

Conway, G.R., Barbier, E.B. 1990. After the green revolution. Sustainable agriculture for development. London: Earthscan.

Conway, G. 2012. One Billion Hungry. Can We Feed the World? Cornell University Press. 456 pp.

FAO. 2009. World Summit on Food Security. Available from: http://www.fao.org/wsfs/world-summit/en/?no_cache=1

FAO. 2011. Save and Grow: A New Paradigm of Agriculture – A Policymaker's Guide to the Sustainable Intensification of Smallholder Crop Production. Available from: http://www.fao.org/ag/save-and-grow/en/index.html

FAO. 2013. The state of food and agriculture. Available from: http://www.fao.org/publications/sofa/the-state-of-food-and-agriculture/en/

FAO. 2015. Sustainable Development Goals. Available from: http://www.fao.org/sustainable-development-goals/en/

FAO. 2018. Sustainable Intensification of Agriculture. Available from: http://www.fao.org/policy-support/policy-themes/sustainable-intensification-agriculture/en/

Foresight. 2011. The future of global food and farming. Final Project Report. London: Government Office for Science London.

Garnett, T., Godfray, C.H. 2012. Sustainable intensification in agriculture: navigating a course through competing food system priorities. Food Climate Research Network and the Oxford Martin Programme on the Future of Food, University of Oxford, UK.

Gonzalez-Sanchez, E.J., Veroz-Gonzalez, O., Blanco-Roldan, G.L, Marquez-Garcia, F., Carbonell-Bojollo, R. 2015. A renewed view of conservation agriculture and its evolution over the last decade in Spain. Soil Till Res 146: 204-212.

Gómez, M.I., Barrett, C.B., Raney, T. 2013. Post-green revolution food systems and the triple burden of malnutrition. Food Policy 42: 129 – 138.

IAASTD. 2009. Agriculture at a crossroads. International Assessment of Agricultural Knowledge, Science and Technology for Development. Washington DC: Island Press.

INSPIA. 2018. Initiative for Sustainable and Productive Agriculture. Available from: http://www.inspia-europe.eu/

Jat, M.L., Dagar, J.C., Sapkota, T.B., Yadvinder-Singh, Govaerts, B., Ridaura, S.L., Saharawat, Y.S., Sharma, R.K., Tetarwal, J.P., Jat, R.K., Hobbs, H., Stirling, C., 2016. Climate change and agriculture: adaptation strategies and mitigation opportunities for food security in South Asia and Latin America. Adv. Agron., 137:127–236.

Kassam, A.H., Friedrich, T., Shaxson, T.F., Pretty, J. 2009. The spread of Conservation Agriculture: Justification, sustainability and uptake. In: International Journal of Agriculture Sustainability 7/4, pp. 292–320.

Kassam, A.H., Basch, G., Friedrich, T., Shaxson, F., Goddard, T., Amado, T., Crabtree, B., Hongwen, L., Mello, I., Pisante, M., Mkomwa, S. 2013. Sustainable soil management is more than what and how crops are grown. In: R. Lal and Stewart, R.A (Eds) Principles of Soil Management in Agro-ecosystems.

Marongwe, L. S., Kwazira, K., Jenrich, M., Kassam, A., Friedrich, T. 2011. An African success: the case of conservation agriculture in Zimbabwe's International Journal of Agricultural Sustainability 9(1), 153-161.

McDermott, J.J., Staal, S.J., Freeman, H.A., Herrero, M., Van de Steeg, J.A., 2010. Sustaining intensification of smallholder livestock systems in the tropics, Livestock Science 130 (2010) 95–109.

Mutua, J., Muriuki, J., Gachie, P., Bourne, M., Capis, J. 2014. Conservation Agriculture with Trees: Principles and Practice. ICRAF, Nairobi, Kenya.

NRC. 2010. Towards sustainable agricultural systems in the 21st century. Committee on Twenty-First Century Systems Agriculture. Washington, DC: National Academies Press.

Poffenberger, M., Zurbuchen, M.S. 1980. The economics of village Bali: three perspectives. New Delhi: The Ford Foundation.

Pretty, J. 1997. The sustainable intensification of agriculture, Natural Resources Forum, Blackwell Publishing Ltd.

Pretty, J. Bharucha, Z.P. 2014. Sustainable intensification in agricultural systems. Annals of Botany, 114: 1571 – 1596.

Pretty, J.N., Toulmin, C., Williams, S. 2011. Sustainable intensification in African agriculture. In: International Journal of Agricultural Sustainability 9/1, pp. 5–24.

Raintree, J.B., Warner, K. 1986. Agroforestry pathways for the intensification of shifting cultivation. Agroforestry Systems 4: 39 – 54.

Owenya, M. Z., Mariki, W. L., Kienzle, J., Friedrich, T., Kassam, A. 2011. 'Conservation agriculture (CA) in Tanzania: the case of Mwangaza B CA farmer field school (FFS), Rhotia Village, Karatu District, Arusha', International Journal of Agricultural Sustainability 9(1), 145 – 152.

Royal Society. 2009. Reaping the benefits: science and the sustainable intensification of global agriculture. London: The Royal Society.

Shapouri, S., Rosen, S., Peters, M., Baquedano, F., Allen, S. 2010. Food security assessment 2010–20. USDA Economic Research Service Report Summary.

Silici, L., Ndabe, P., Friedrich, T., Kassam, A., 2011, 'Harnessing sustainability, resilience and productivity through conservation agriculture: the case of Likoti in Lesotho', International Journal of Agricultural Sustainability 9(1), 137 – 144

Smith, P. 2013. Delivering food security without increasing pressure on land. Global Food Security 2: 18 – 23.

Swaminathan, M.S. 1989. Agricultural production and food security in Africa. In: d'Orville H, ed. The challenges of agricultural production and food security in Africa. A report of the proceedings of an international conference organized by the Africa Leadership Forum 27 – 30 July, 1989. Ota, Nigeria. Available from: http://www.africaleadership.org/rc/the%20challenges%20of% 20agricultural.pdf#page=23 .

Tilman, D., Balzer, C., Hill, J., Befort, B.L. 2011. Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences, USA 108: 20260 – 20264.

Wiggins, S., Slater, R. 2010. Food Security and Nutrition: Current and Likely Future Issues, SR27, Foresight Global Food and Farming Project, London.

World Bank. 2008. Agriculture for Development: World Development Report 2008, Washington, DC

Chapter 6. Mitigation of and adaptation to climate change through Conservation Agriculture

Akinnagbe, O.M., Irohibe, I.J. 2015. Agricultural adaptation strategies to climate change impacts in Africa: a review. Bangladesh Journal of Agricultural Research, 39(3): 407-418.

Balesdent, J., Mariotti, A., Boisgontier, D. 1990. Effects on tillage on soil organic carbon mineralization estimated from 13C abundance in maize fields. J. Soil Sci. 41: 584-596.

Bouma, J., Mcbratney, A. 2013. Framing soils as an actor when dealing with wicked environmental problems. Geoderma, 200, 130–139.

Brown, L., Donaldson, G.V., Jordan, V.W.L., Thornes, J.B. 1996. Effects and interactions of rotation, cultivation and agrochemical input levels on soil erosion and nutrient emissions. Aspect of Applied Biology 47, Rotations and Cropping Systems, 409-412.

Carbonell-Bojollo, R., González-Sánchez, E.J., Veróz-González, O., Ordóñez-Fernández, R. 2011. Soil management systems and short term CO_2 emissions in a clayey soil in southern Spain. Science of the Total Environment. 409: 2929–2935.

FAO. 2016. Mid-term evaluation of the Conservation Agriculture Scaling-up (CASU) project. Available from: http://www.fao.org/3/a-bq888e.pdf

FAO. 2018a. Conservation Agriculture website. Available from: http://www.fao.org/conservation-agriculture/en/

FAO. 2018b. FAOSTAT website. Available from: http://www.fao.org/faostat/en/#home

Fapojuwo, O.E., Olawoye, J.E., and Fabusoro, E. 2012. Soil Conservation Techniques for Climate Change Adaptation among Arable Crop Farmers in Southwest Nigeria. In: Producing and reproducing farming systems. New modes of organisation for sustainable food systems of tomorrow. 10th European IFSA Symposium, Aarhus, Denmark, 1-4 July 2012 2012 pp.unpaginated ref.30

Fryear, D.W. 1985. Soil Cover and Wind Erosion. Transactions of the ASAE. 28 (3): 0781-0784.

González-Sánchez, E.J, Moreno-García, M., Kassam, A., Holgado-Cabrera, A., Triviño-Tarradas, P., Pisante, M., Veroz-González, O., Basch, G. 2017. Conservation Agriculture: Making Climate Change Mitigation and Adaptation Real in Europe. European Conservation Agriculture Federation (ECAF). ISBN: 978-84-697-4303-4.

González-Sánchez E.J., Ordóñez-Fernández R., Carbonell-Bojollo R., Veroz-González O., Gil-Ribes J.A. 2012. Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture. Soil Till Res, 122, pp. 52-60.

Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agriculture, Ecosystems and Environment. 103: 1-25.

International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). 2013. Agriculture at A Crossroads: Synthesis Report. Available from: http://www.unep.org/dewa/agassessment/reports/iaastd/en/agriculture%20at%20a%20crossroads_synthesis%20report%20(English).pdf

IPCC. 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Jat, R.A., Sahrawat, K.L., Kassam, A.H. 2014. Conservation Agriculture: Global Prospects and Challenges. CABI, Wallingford.

Kassam, A., Mkomwa, S., Friedrich, T. 2017. Conservation Agriculture for Africa: building resilient farming systems in a changing climate. CABI. Wallingford, UK, xxviii + 289 pp. ISBN 9781780645681.

Kassam, A., Friedrich, T., Derpsch, R. 2018. Global spread of Conservation Agriculture. International Journal of Environmental Studies. Available from: https://doi.org/10.1080/00207233.2018.1494927

Kertész, A., Madarász, B., Csepinszky, B., Bádonyi, K. 2010. Conservation agriculture as a tool against soil erosion and for improving biodiversity. In Proceedings of the European Congress on Conservation Agriculture. ISBN: 978-84-491-1038-2. Ministerio de Medio Ambiente y Medio Rural y Marino. Asociación Española Agricultura de Conservación / Suelos Vivos: 501-506.

Kinsella, J. 1995. The effects of various tillage systems on soil compaction. In: Farming for a Better Environment: A White Paper. Soil and Water Conservation Society, Ankeny, IA: 15–17.

Lal, R. 2008. Carbon sequestration. Philosophical Transactions of the Royal Society B 363, 815-830.

Lema, M.A., Majule, A.E. 2009. Impacts of climate change, variability and adaptation strategies on agriculture in semi-arid areas of Tanzania: The case of Manyoni District in Singida Region, Tanzania. African Journal of Environmental Science and Technology. 3 (8), Pp. 206-218.

López-Garrido, S., Madejón, E., Murillo, J. M., Moreno, F. 2010. Soil quality alteration by mouldboard ploughing in a commercial farm devoted to no-tillage under Mediterranean conditions. Agriculture, Ecosystems and Environment. 140: 182-190.

Moreno, F., Pelegrin, F., Fernandez, J.E., Murillo, J.M. 1997. Soil physical properties, water depletion and crop development under traditional and conservation tillage in southerm Spain. Soil and Tillage Research. 41(1-2): 25-42.

Moret, D., Arrúe, J.L., López, M.V., Gracia, R. 2006. Influence of fallowing practices on soil water and precipitation storage efficiency in semiarid Aragon (NE SPAIN). Agric. Water Manage. 82: 161-176.

Muñoz, A., López-Piñeiro, A., Ramírez, M. 2007. Soil quality attributes of conservation management regimes in a semi-arid region of south western Spain. Soil & Tillage Research. 95: 255–265.

Muriel, J.L., Vanderlinden, K., Perea, F., Jiménez, J.A., García-Tejero, I., Pérez, J.J. 2005. Régimen hídrico en suelos arcillosos de campiña sometidos a distintos sistemas de manejo. En: Actas Congreso Internacional sobre Agricultura de Conservación: 537-542. Ed AEAC.SV. Córdoba.

Murillo, J. M., Moreni, F., Pelegrín, F., Fernández, J. E. 1998. Responses of sunflower to traditional and conservation tillage underrainfed conditions in souther Spain. Soil & Tillage Research. 49(3): 233-241.

Ngaira, J.K.W. 2007. Impact of climate change on agriculture in Africa by 2030. Scientific Research and Essays. 2(7): 238-243.

Nyong, A., F. Adesina and O. Elasha 2007. The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. Mitig. Adapt. Strat. Glob. Change. 12, Pp. 787 -797.

Olson, K.R., Lang, J.M., Ebelhar, S.A. 2005. Soil organic carbon changes after 12 years of no tillage and tillage of Grantsburg soils in sotuthern Illinois. Soil & Tillage Research. 81: 217-225.

Reicosky, D.C. 1995. Impact of tillage on soil as a carbon sink p. 50-53. In: Farming for a Better Environment, A White Paper, Soil and Water Conservation Society, Ankeny, Iowa, USA, pp.67.

Reicosky, D.C. 1997. Tillage-induced methods CO_2 emissions from soil. Nutrient Cycl. Agoresyst. 49: 273-285.

Reicosky, D.C. 2011. Conservation agriculture: Global environmental benefits of soil carbon management. In ‘Fifth World Congress on Conservation Agriculture’. Vol. 1. pp. 3–12. (ACIAR: Canberra, ACT).

Reicosky, D.C., Archer, D.W. 2007. Moldboard plow tillage depth and short-term carbon dioxide release. Soil and Tillage Research. 94: 109-121.

Reicosky, D.C., Lindstrom, M.J. 1993. Fall tillage methods: Effect on short-term carbon dioxide flux from soil. Agronomy Journal. 85(6): 1.237-1.243.

Six, J., Ogle, S.M., Breidt, F.J., Conant, R.T., Mosiers, A.R., Paustian, K. 2004. The potential to mitigate global warming with no-tillage management is only realized when practiced in the long term. Global Change Biology. 10: 155-160.

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

Thierfelder, C., Nyagumbo, I. 2011. Conservation Agriculture (CA) in Southern Africa: Longer term trends in soil quality and crop productivity. Presentation to 5WCCA. Brisbane, Australia.

Thierfelder, C., Rusinamhodzi, L., Ngwira, A.R., Mupangwa, W., Nyagumbo, I., Kassie, G.T., Cairns, J.E. 2014. Conservation agriculture in Southern Africa: Advances in knowledge. Renewable Agriculture and Food Systems, 30(4): 328-348.

Towery, D. 1998. No-till´s impact on water quality. In: 6º Congreso Nacional Argentino sobre Siembra Directa (AAPRESID): 17-26, Mar de Plata, Argentina.

Wilkes, A., Tennigkeit, T., Solymosi, K. 2013. National integrated mitigation planning in agriculture: a review paper. FAO, Rome.

Wortmann, C.S., Klein, R.N., Wilhelm, W.W., Shapiro, C. 2008. Harvesting crop residues. NebGuide G1846. Lincoln, Neb.: University of Nebraska-Lincoln Extension.

UNFCCC. 2018. United Nations Framework Convention on Climate Change: South Africa's Intended Nationally Determined Contribution (INDC). Available from: http://www4.unfccc.int/ndcregistry/PublishedDocuments/South%20Africa%20First/South%20Africa.pdf

Papers reviewed for obtaining the carbon sequestration rates

Abaker, W.E., Berninger F., Saiz G., Braojos V., Starr M. 2016. Contribution of Acacia senegal to biomass and soil carbon in plantations of varying age in Sudan. For. Ecol. Manage. 368, 71–80.

Aguilera, E., Lassaletta, L., Gattinger, A., Gimeno, B.S. 2013. Managing soil carbon for climate change mitigation and adaptation in Mediterranean cropping systems: A meta-analysis. Agric. Ecosyst. Environ. 168, 25–36.

Araya, T. Corneli, W.M., Nyssen, J., Govaerts, B., Getnet, F., Bauer, H., Amare, K., Raes, D., Haile, M., Deckers, J. 2012. Medium-term effects of conservation agriculture based cropping systems for sustainable soil and water management and crop productivity in the Ethiopian highlands. Field Crops Res. 132, 53-62.

Barthès, B., Azontonde, A., Blanchart, E., Girardin, C., Villenave, C., Lesaint, S., Oliver, R., Feller, C. 2004. Effect of a legume cover crop (Mucuna pruriens var. utilis) on soil carbon in an Ultisol under maize cultivation in southern Benin. Soil Use Manag. 20, 231-239.

Baumert, S., Khamzina, A., Vlek, P.L.G. 2016. Soil organic carbon sequestration in Jatropha curcas Systems in Burkina Faso. Land Degrad. Dev. 27, 1813–1819.

Bright, M.B.H., Diedhiou, I., Bayala, R., Assigbetse, K., Chapuis-Lardy, L., Ndour, Y., Dick, R.P. 2017. Long-term Piliostigma reticulatum Intercropping in the sahel: crop productivity, carbon sequestration, nutrient cycling, and soil quality. Agric. Ecosyst. Environ. 242, 9–22.

Cheesman, S., Thierfelder, C., Eash, N.S., Kassie, G.T., Frossard, E. 2016. Soil carbon stocks in conservation agriculture systems of Southern Africa. Soil Tillage Res. 156, 99-109.

Corbeel, M., Cardinael, R., Naudin, K., Guibert, H., Torquebiau, E. 2018. The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-Saharan Africa. Soil and Tillage Research. In press. https://doi.org/10.1016/j.still.2018.02.015

Diels, J., Vanlauwe, B., Van der Meersch, M.K., Sanginga, N., Merckx, R. 2004. Long-term soil organic carbon dynamics in a subhumid tropical climate: 13C data in mixed C3/C4 cropping and modeling with RothC. Soil Biol. Biochem. 36, 1739–1750.

Gelaw, A.M., Singh, B.R., Lal, R. 2014. Soil organic carbon and total nitrogen stocks under different land uses in a semi-arid watershed in Tigray, Northern Ethiopia. Agric. Ecosyst. Environ. 188, 256–263.

Gwenzi, W., Gotosa, J., Chakanetsa, S., Mutema, Z. 2009. Effects of tillage systems on soil organic carbon dynamics, structural stability and crop yields in irrigated wheat (Triticum aestivum L.)-cotton (Gossypium hirsutum L.) rotation in semi-arid Zimbabwe. Nutrient Cycling Agroecosyst. 83, 211-221.

Kaonga, M.L., Coleman, K. 2008. Modelling soil organic carbon turnover in improved fallows in easter Zambia using RothC-26.3 model. Forest Ecol. Manag. 256, 1160-1166.

Kimaro, A., Isaac, M., Chamshama, S. 2011. Carbon pools in tree biomass and soils under rotational woodlot systems in eastern Tanzania. In: Kumar, B., Nair, P. (Eds.), Carbon

Sequestration Potential of Agroforestry Systems. Springer, pp. 142–156.

Lahmar, R., Bationo, B.A., Lamso, N.D., Guero, Y., Tittonell, P. 2012. Tailoring conservation agriculture technologies to West Africa semi-arid zones: Building on traditional local practices for soil restoration. Field Crops Res. 132, 158–167.

Makumba, W., Akinnifesi, F.K., Janssen, B., Oenema, O. 2007. Long-term impact of a gliricidia-maize intercropping system on carbon sequestration in southern Malawi. Agric. Ecosyst. Environ. 118, 237–243.

Materechera, S., Mkhabela, T.S. 2001. Influence of land-use on properties of a ferralitic soil under low external input farming in southeastern Swaziland. Soil Tillage Res. 62, 15-25.

Mujuru, L., Mureva, A., Velthorst, E.J., Hoosbeek, M.R. 2013. Land use and management effects on soil organic matter fractions in Rhodic Ferralsols and Haplic Arenosols in Bindura and Shamva districts of Zimbabwe. Geoderma 209–210, 262–272.

Ngwira, A., Sleutel, S., De Neve, S. 2012. Soil carbon dynamics as influenced by tillage and crop residue management in loamy sand and sandy loam soils under smallholder farmers' conditions in Malawi. Nutrient Cycling Agroecosyst. 92, 315–328.

Njaimwe, A.N., Mnkeni, P.N.S., Chiduza, C., Muchaonyerwa, P., Wakindiki, I.I.C. 2016. Tillage and crop rotation effects on carbon sequestration and aggregate stability in two contrasting soils at the Zanyokwe Irrigation Scheme, Eastern Cape province, South Africa. South African J. Plant Soil 33, 317-324.

Nyamadzawo, G., Chikowo, R., Nyamugafata, P., Nyamangara, J., Giller, K.E. 2008. Soil organic carbon dynamics of improved fallow-maize rotation systems under conventional and no-tillage in Central Zimbabwe. Nutr. Cycl. Agroecosyst. 81, 85–93.

Okeyo, J.M., Norton, J., Koala, S., Waswa, B., Kihara, J., Bationo, A. 2016. Impact of reduced tillage and crop residue management on soil properties and crop yields in a long-term trial in western Kenya. Soil Res. 54, 719-729.

Paul, B.K., Vanlauwe, B., Ayuke, F., Gassner, A., Hoogmoed, M., Hurisso, T.T., Koala, S., Lelei, D., Ndabamenye, T., Six, J., Pulleman, M.M. 2013. Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. Agric. Ecosyst. Environ. 164, 14-22.

Paul, B.K., Vanlauwe, B., Hoogmoed, M., Hurisso, T.T., Ndabamenye, T., Terano, Y., Six, J., Ayuke, F.O., Pulleman, M.M. 2015. Exclusion of soil macrofauna did not affect soil quality but increased crop yields in a sub-humid tropical maize-based system. Agric. Ecosyst. Environ. 208, 75–85.

Rimhanen, K., Ketoja, E., Yli-Halla, M., Kahiluoto, H. 2016. Ethiopian agriculture has greater potential for carbon sequestration than previously estimated. Global Change Biol. 22, 3739–3749.

Thierfelder, C., Cheesman, S., Rusinamhodzi, L. 2012. A comparative analysis of conservation agriculture systems: Benefits and challenges of rotations and intercropping in Zimbabwe. Field Crop Res. 137, 237-250.

Thierfelder, C., Wall, P.C. 2012. Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. Soil Use Manag. 28, 209-220.

Thierfelder, C., Mombeyarara, T., Mango, N., Rusinamhodzi, L. 2013a. Integration of conservation agriculture in smallholder farming systems of southern Africa: identification of key entry points. International J. Agric. Sustainability 11, 317–330.

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

Thierfelder, C., Chisui, J.L., Gama, M., Cheesman, S., Jere, Z.D., Bunderson, W.T., Eash N.S., Rusinamhodzi L. 2013c. Maize-based conservation agriculture systems in Malawi: long-term trends in productivity. Field Crop Res. 142, 47-57.

Verchot, L.V., Dutaur, L., Shepherd K.D., Albrecht A. 2011. Organic matter stabilization in soil aggregates: understanding the biogeochemical mechanisms that determine the fate of carbon inputs in soils. Geoderma 161, 182–193.

Vicente-Vicente, J.L., García-Ruiz, R., Francaviglia, R., Aguilera E., Smith, P. 2016. Soil carbon sequestration rates under Mediterranean woody crops using recommended management practices: A meta-analysis. Agric. Ecosyst. Environ. 235, 204-214.

Chapter 7. Other benefits of Conservation Agriculture

Andrade, D. S., Colozzi-Filho, A., Balota, E. L., Hungria, M. 2001. Long-term effects of agricultural practices on microbial community. Conservation Agriculture, a worldwide challenge. First World Congress on Conservation Agriculture. 1: 275-280.

Bado, B. V., Bationo, A., Cescas, M. P., 2006. Assessment of cowpea and groundnut contributions to soil fertility and succeeding sorghum yields in the Guinean savannah zone of Burkina Faso (West Africa). Biology and Fertility of Soils 43: 171-176.

Bationo, A., Ntare, B. R., 2000. Rotation and nitrogen fertilizer effects on pearl millet, cowpea and groundnut yield and soil chemical properties in a sandy soil in the semi-arid tropics, West Africa. Journal of Agricultural Science 134: 277-284.

Ben Moussa-Machraoui, S., Errouissi, F., Ben-Hammouda, M., Nouira, S., 2010. Comparative effects of conventional and no-tillage management on some soil properties under Mediterranean semi-arid conditions in northwestern Tunisia. Soil and Tillage Research 106: 247-253.

Brito, I., De Carvalho, M., Goss, M.J., Chatagnier, O., Van Tuinen, D., 2010. Impact of no-till vs. conventional tillage on arbuscularmycorrhiza fungal community in the soil under Mediterranean conditions. European Congress on Conservation Agriculture. MARM and AEAC.SV. 271-275.

Brussaard, L., 2012. Ecosystem services provided by the soil biota. In: Wall, D.H., Bardgett, R.D., Behan-Pelletier, V., Herrick, J.E., Hefin Jones, T., Ritz, K., Six, J., Strong, D.R., van der Putten, W.H. (Eds.), Soil and ecology and ecosystems services. Oxford University Press, Oxford, UK, pp 45-58.

Buerkert, A., Bationo, A., Dossa, K., 2000. Mechanisms of residue mulch-induced cereal growth increases in West Africa. Soil Science Society of America Journal 64: 346-358.

Chivenge, P. P., Murwira, H. K., Giller, K. E., Mapfumo, P., Six, J., 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for Conservation Agriculture on contrasting soils. Soil and Tillage Research 94: 328-337

Claessens, L., Knapen, A., Kitutu, M.G., Poesen, J., Deckers, J.A., 2007. Modelling landslide hazard, soil redistribution and sediment yield of landslides on the Ugandan footslopes of Mount Elgon. Geomorphology 90: 23–35. DOI: 10.1016/j.geomorph.2007.01.007

Cohen, M.J., Shepherd, K.D., Walsh, M.G., 2005. Empirical reformulation of the universal soil loss equation for erosion risk assessment in a tropical watershed. Geoderma 124: 235–252.

Crabtree, W. L., 2010. Search for Sustainability with no-till Bill in Dryland Agriculture. Crabtree Agricultural Consulting, 204 pp.

CTIC, 2018. Top 10 Conservation Tillage Benefits. Available from: http://www.ctic.purdue.edu/resourcedisplay/293/

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

Derpsch, R., Duiker, S., Franzluebbers, A., Gall, C., Köller, K., and Reicosky, D. C., 2012. About the necessity of standardizing No-tillage research. Proceedings of the 19th ISTRO Conference, IV SUCS Meeting. Striving for Sustainable High Productivity, 24-28 September, Montevideo, Uruguay.

Diekow, J., Mielniczuk, J., Knicher, H., Bayer, C., Dick, D.P., Kogel-Knaber, I., 2005. Soil C and N stocks as affected by cropping systems and nitrogen fertilization in a southern Brazil Acrisol managed under no-tillage for 17 years. Soil and Tillage Research 81: 87-95. DOI: 10.1016/j.still.2004.05.003

Du Preez, C. C., Steyn, J. T., Kotze, E., 2001. Long-term effects of wheat residue management on some fertility indicators of a semi-arid plinthosol. Soil and Tillage Research 63: 25-33.

Dubreil, N., 2011. Targeting Conservation Agriculture (CA) innovations to combat soil degradation and food insecurity in semi-arid Africa – a literature review. MSc Thesis. Master of Science in International Land and Water Management, Wageningen University, Netherlands.

Ellis-Jones, J., Mudhara, M., 1997. Conservation tillage for resource poor farmers: the critical importance of farm power. In: Agro-ecological and economical aspects of soil tillage.

Proceedings of the 14th ISTRO Conference, 27 July – 1 August, 1997, Pulaway, Poland.

FAO, 2000. Global assessment of Soil Degradation (GLASSOD).

Fereres, E., Orgaz, F., Gonzalez-Dugo, V., Testi, L., Villalobos, F.J., 2014. Balancing crop yield and water productivity tradeoffs in herbaceous and woody crops. Funct. Plant Biol., 41: 1009–1018.

Fey, M.V., 2010. Soils of South Africa. Cape Town: Cambridge University Press.

Findlay, J.B.R., Hutchinson, N.C., 1999. Development of conservation tillage in African countries: A partnership approach. In: Breth, S.A. (Ed.), Partnerships for rural development in sub-Saharan Africa. Centre for Applied Studies in International Negotiations, Geneva, pp. 52-63.

Formowitz, B., Joergensen, R. G., Buerkert, A., 2009. Impact of legume versus cereal root residues on biological properties of West African soils. Plant and Soil 325: 145-156.

Friedrich, T., Kassam A. H., Shaxson, F. T., 2009. Conservation Agriculture. In: Agriculture for Developing Countries. Science and Technology Options Assessment (STOA) Project. European Technology Assessment Group, Karlsruhe, Germany.

Gicheru, P., Gachene, C., Mbuvi, J., Mare, E., 2004. Effects of soil management practices and tillage systems on surface soil water conservation and crust formation on a sandy loam in semi-arid Kenya. Soil and Tillage Research 75: 173-184.

González-Sánchez E.J., Ordóñez-Fernández R., Carbonell-Bojollo R., Veroz-González O., Gil-Ribes J.A. 2012. Meta-analysis on atmospheric carbon capture in Spain through the use of conservation agriculture. Soil Till Res, 122, pp. 52-60.

González-Sánchez, E.J, Moreno-García, M., Kassam, A., Holgado-Cabrera, A., Triviño-Tarradas, P., Pisante, M., Veroz-González, O., Basch, G. 2017. Conservation Agriculture: Making Climate Change Mitigation and Adaptation Real in Europe. European Conservation Agriculture Federation (ECAF). ISBN: 978-84-697-4303-4.

Govaerts, B., Fuentes, M., Mezzalama, M., Nicol, J. M., Deckers, J., Etchevers, J. D., Figueroa-Sandoval, B., Sayre, K. D., 2007. Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation management. Soil Tillage and Research 94: 209-219.

Green, T. R., Ahujaa, L. R., Benjaminb, J. G., 2003. Advances and challenges in predicting agricultural management effects on soil hydraulic properties. Geoderma 116: 3-27.

Gwenzi, W., Gotosa, J., Chakanetsa, S., Mutema, Z., 2009. Effects of tillage systems on soil organic carbon dynamics, structural stability and crop yields in irrigated wheat (Triticum aestivum L.)-cotton (Gossypium hirsutum L.) rotation in semi-arid Zimbabwe. Nutrient Cycling in Agroecosystems 83: 211-221.

Hobbs, P. R., Govaerts, B., 2010. How conservation agriculture can contribute to buffering climate change. In M. P. Reynolds (Ed.), Climate Change and Crop Production (pp. 177-199). CAB International 2010.

Jarecki, M. K., Lal, R., 2003. Crop management for soil carbon sequestration. Crit. Rev. Plant Sci. 22, 471-502

Jeranyama, P., Waddington, S. R., Hesterman, O. B., Harwood, R. R., 2007. Nitrogen effects on maize yield following groundnut in rotation on smallholder farms in sub-humid Zimbabwe. African Journal of Biotechnology 6: 1503-1508.

Kassam, A., Friedrich, T., Shaxson, F., Pretty, J., 2009. The spread of Conservation Agriculture: justification, sustainability and uptake. International Journal of Agricultural Sustainability 7: 292-320. DOI: 10.3763/ijas.2009.0477.

Kassam, A., Friedrich, T., Derpschs, R., Lanmar, R., Mrabet, R., Basch, G., González-Sánchez, E.J., Serraj, R., 2012. Conservation agriculture in the dry Mediterranean climate. Field Crops Research 132: 7–17.

Kassam, A., Basch, G., Friedrich, T., Shaxson, T. F., Goddard, T., Amado, T., Crabtree, B., Hongwen, L., Mello, I., Pisante, M., and Mkomwa, S., 2013. Sustainable soil management is more than what and how crops are grown. In R. Lal and Stewart, R. A. (Eds.), Principles of Soil Management in Agro-ecosystems. 2012. Advances in Soil Science. CRC Press.

Kassam, A., Mkomwa, S., Friedrich, T. 2017. Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate. CABI, Wallingford.

Kertész, A., Madarász, B., Csepinszky, B., Bádonyi, K., 2010. Conservation agriculture as a tool against soil erosion and for improving biodiversity. In Proceedings of the European Congress on Conservation Agriculture. ISBN: 978-84-491-1038-2. Ministerio de Medio Ambiente y Medio Rural y Marino. Asociación Española Agricultura de Conservación / Suelos Vivos: 501-506.

Kertész, A., Madarász, B., 2014. Conservation Agriculture in Europe. Int. Soil Water Conserv. Res., 2, 91–96.

Kirui, O.K., Mirzabaev, A., 2014. Economics of Land Degradation in Eastern Africa, s.l.: Department of Political and Cultural Change Center for Development Research, University of Bonn, Germany.

Kolawole, G. O., Tijani-Eniola, H., Tian, G., 2004. Phosphorus fractions in fallow systems of West Africa: Effect of residue management. Plant and Soil 263: 113-120.

Kosgei, J. R., Jewitt, G. P. W., Kongo, V. M., Lorentz, S. A., 2007. The influence of tillage on field scale water fluxes and maize yields in semi-arid environments: A case study of potshini catchment, South Africa. Physics and Chemistry of the Earth, 32: 1117-1126.

Kouyaté, Z., Franzluebbers, K., Juo, A. S. R., Hossner, L. R., 2000. Tillage, crop residue, legume rotation, and green manure effects on sorghum and millet yields in the semiarid tropics of Mali. Plant and Soil 225: 141-151.

Labrière, N., Locatelli, B., Laumonier, Y., Freycon, V., Bernoux, M., 2015. Soil erosion in the humid tropics: A systematic quantitative review. Agriculture, Ecosystems and Environment 203: 127-139. DOI: 10.1016/j.agee.2015.01027

Lafond, G.P., Walley, H., Schoenau, J., May, W.E., Holzafel, C.B., McKell, J., Halford, J., 2008. Long-term vs. short-term conservation tillage. In: Proceedings of the 20th Annual Meeting and Conference of the Saaskatchewan Soil Conservation Association, 12–13 February, Regina, Saaskatchewan, pp. 28–43.

Lal, R, 1995. Erosion-Crop Productivity Relationships for Soils of Africa. Soil Science Society of America Journal, 59: 661–667. DOI: 10.2136/sssaj1995.03615995005900030004.

Lal, R., Follett, F., Stewart, B. A., Kimble, J. M., 2007. Soil carbon sequestration to mitigate climate change and advance food security. Soil Sci. 172, 943-956.

Larbi, A., Smith, J. W., Adekunle, I. O., Agyare, W. A., Gbaraneh, L. D., Tanko, R. J., et al., 2002. Crop residues for mulch and feed in crop-livestock systems: Impact on maize grain yield and soil properties in the West African humid forest and savanna zones. Experimental Agriculture 38: 253-264

Le Roux, J.J., Morgenthal, T.L., Malherbe, J., Pretorious, D.J., Sumner, P.D., 1998. Water erosion prediction at a national scale for South Africa. Water SA 34: 305-314.

Lindwall, C.W., Sonntag, B., (Eds.) 2010. Landscape Transformed: The History of Conservation Tillage and Direct Seeding. Knowledge Impact in Society. University of Saskatchewan, Sakskatoon.

López-Garrido, S., Madejón, E., Murillo, J. M., Moreno, F., 2010. Soil quality alteration by mouldboard ploughing in a commercial farm devoted to no-tillage under Mediterranean conditions. Agriculture, Ecosystem and Environment, 140: 182-190.

López-Piñeiro, A., Muñoz, A., Ramírez, M., 2005. Short and Long-term effect of direct seeding on soil microbial diversity. Congreso Internacional sobre Agricultura de Conservación. AEAC.SV, ECAF and Diputación de Córdoba. 453-457.

Machado, P. L. O. A., Silva, C. A., 2001. Soil management under no-tillage systems in the tropics with special reference to Brazil. Nutr. Cycl. Agroecosyst. 61, 119-130.

Mariki, W. L., Owenya, M. Z., 2007. Weed management in conservation agriculture for sustainable crop production. In B. I. Stewart, A. F. Asfary, A. Belloum, K. Steiner, and T. Friedrich (Eds.), Proc. international workshop "Conservation Agriculture for Sustainable Land Management to Improve the Livelihood of People in Dry Areas" (pp. 49-56). http://www.fao.org/ag/ca/doc/CA%20Workshop%20procedding%2008-08-08.pdf

Márquez-Garcia, F., González-Sánchez, E.J., Castro-García, S., Ordóñez-Fernández, R., 2013. Improvement of soil carbon sink by cover crops in olive orchards under semiarid conditions. Influence of the type of soil and weed. Spanish Journal of Agricultural Research. 11: 335-346.

Montgomery, D.R., 2007. Soil erosion and agricultural sustainability. Proceedings of the National Academy of

Sciences of the United States of America 104: 13268–72. DOI: 10.1073/pnas.0611508104.

Mousques, C., Friedrich, T., 2007. Conservation Agriculture in China and the Democratic People's Republic of Korea. FAO crop and grassland service working paper. Rome: Food and Agriculture Organization of the United Nations.

Mrabet, R., 2002. Stratification of soil aggregation and organic matter under conservation tillage systems in Africa. Soil and Tillage Research 66: 119-128.

Muhr, L., Tarawali, S. A., Peters, M., Schultze-Kraft, R., 2002. Soil mineral N dynamics and maize grain yields following centrosema macrocarpum and stylosanthes guianensis: Effects of different rotations and varying levels of N fertiliser. Field Crops Research 78: 197-209.

Munodawafa, A., Zhou, N., 2008. Improving water utilization in maize production through conservation tillage systems in semi-arid Zimbabwe. Physics and Chemistry of the Earth 33: 757-761.

Mupangwa, W., Twomlow, S., Walker, S., Hove, L., 2007. Effect of minimum tillage and mulching on maize (Zea mays L.) yield and water content of clayey and sandy soils. Physics and Chemistry of the Earth 32: 1127-1134.

Myaka, F. M., Sakala, W. D., Adu-Gyamfi, J. J., Kamalongo, D., Ngwira, A., Odgaard, R., et al., 2006. Yields and accumulations of N and P in farmer-managed intercrops of maize-pigeonpea in semi-arid Africa. Plant and Soil 285: 207-220.

Naudin, K., Gozé, E., Balarabe, O., Giller, K. E., Scopel, E., 2010. Impact of no tillage and mulching practices on cotton production in north Cameroon: A multi-locational on-farm assessment. Soil and Tillage Research 108: 68-76.

Ncube, B., Twomlow, S. J., Van Wijk, M. T., Dimes, J. P., Giller, K. E., 2007. Productivity and residual benefits of grain legumes to sorghum under semi-arid conditions in southwestern Zimbabwe. Plant and Soil 299: 1-15.

Nhamo, N., 2007. The contribution of different fauna communities to improved soil health: A case of Zimbabwean soils under conservation agriculture. PhD Thesis. Rheinischen Friedrich-Wilhelms-Universitat, Bonn, Germany, p. 128.

Nkonya, E.; Gerber, N.; Baumgartner, P.; von Braun, J.; de Pinto, A.; Graw, V.; Kato, E.; Kloos, J.; Walter, T., 2011. The Economics of Land Degradation: Towards an Integrated Global Assessment. Development Economics and Policy. Band 66; Peter Lang: Berlin, Germany, p. 262.

Nurbekov, A., 2008. Manual on Conservation Agriculture Practices in Uzbekistan. Tashkent, Uzbekistan, p. 40.

Nyamadzawo, G., Chikowo, R., Nyamugafata, P., Giller, K. E., 2007. Improved legume tree fallows and tillage effects on structural stability and infiltration rates of a kaolinitic sandy soil from central Zimbabwe. Soil and Tillage Research 96: 182-194.

Nyamadzawo, G., Chikowo, R., Nyamugafata, P., Nyamangara, J., Giller, K. E., 2008. Soil organic carbon dynamics of improved fallow-maize rotation systems under conventional and no-tillage in central Zimbabwe. Nutrient Cycling in Agroecosystems 81: 85-93.

Osunbitan, J. A., Oyedele, D. J., Adekalu, K. O., 2005. Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. Soil and Tillage Research 82: 57-64

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., Grace, P., 2014. Conservation agriculture and ecosystem services: An overview. Agriculture, Ecosystems and Environment 187: 87–105. DOI: 10.1016/j.agee.2013.10.010

Paterson, D.G., Smith, H.J., van Greunen, A., 2013. Evaluation of soil conservation measures on a highly erodible soil in the Free State province, South Africa. South African journal of Plant and Soil 30: 213-217. DOI: 10.1080/02571862.2013.861029

Piron, D., Peres, G., Cluzeau, D., 2010. The evaluation and improvement of biodiversity in conservation agriculture systems. European Congress on Conservation Agriculture. MARM and AEAC.SV. 155-162.

Rebafka, F., Ndunguru, B. J., Marschner, H., 1993. Crop residue application increases nitrogen fixation and dry matter production in groundnut (Arachis hypogaea L.) grown on an acid sandy soil in Niger, West Africa. Plant and Soil 150: 213-222.

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A. W., Temesgen, M., Mawenya, L., et al., 2009. Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil and Tillage Research 103: 23-32.

Sangar, S., Abrol, I. P., and Gupta, R. K., 2004. Conference Report- Conservation Agriculture: Conserving Resources-Enhancing Productivity. Pusa Campus, New Delhi 110 012: Centre for Advancement of Sustainable Agriculture, National Agriculture Science Centre (NASC) Complex DPS Marg.

Sileshi, G., Akinnifesi, F. K., Ajayi, O. C., Place, F., 2008. Meta-analysis of maize yield response to woody and herbaceous legumes in sub-saharan Africa. Plant and Soil 307: 1-19.

Sileshi, G., Akinnifesi, F. K., Debusho, L. K., Beedy, T., Ajayi, O. C., Mong'omba, S., 2010. Variation in maize yield gaps with plant nutrient inputs, soil type and climate across sub-saharan Africa. Field Crops Research 116: 1-13.

Sinaj, S., Buerkert, A., El-Hajj, G., Bationo, A., Traoré, H., Frossard, E., 2001. Effects of fertility management strategies on phosphorus bioavailability in four West African soils. Plant and Soil 233: 71-83.

Sommer, R., Bossio, D., Desta, L., Dimes, J., Kihara, J., Koala, Mango, N., Rodriguez, D., Thierfelder, C., Thierfelder, C., Winowiecki, L., 2013. Profitable and sustainable nutrient management systems for East and Southern African smallholder farming systems: challenges and opportunities: a synthesis of the Eastern and Southern Africa situation in terms of past experiences, present and future opportunities in promoting nutrients use in Africa. CIAT; The University of Queensland; QAAFI; CIMMYT. 91 pp. https://repository.cimmyt.org/handle/10883/4035

Stahl, L., Nyberg, G., Hogberg, P., Buresh, R. J., 2002. Effects of planted tree fallows on soil nitrogen dynamics, above-ground and root biomass, N2-fixation and subsequent maize crop productivity in Kenya. Plant and Soil 243: 103-117.

Tamane, L., Le, Q.B., 2015. Estimating soil erosion in sub-Saharan Africa based on landscape similarity mapping and using the revised universal soil loss equation (RUSLE). Nutrient cycling in Agroecosystems 102: 17-31.

Thierfelder, C., Chisui, J. L., Gama, M., Cheeseman, S., Jere, Z. D., Bunderson, W. T., Eash, N. S., Rusinamhodzi, L, 2013. Mai-based Conservation Agriculture systems in Malawi: Long-term trends in productivity. Field Crops Research, 142: 47-57.

Thierfelder, C., Nyagumbo, I., 2011. Conservation Agriculture (CA) in Southern Africa: Longer term trends in soil quality and crop productivity. Presentation to 5WCCA. Brisbane, Australia.

Thierfelder, C., Wall, P. C., 2010. Investigating Conservation Agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. Journal of Crop Improvement 24: 113-121.

Towery, D., 1998. No-till´s impact on water quality. En: 6º Congreso Nacional Argentino sobre Siembra Directa (AAPRESID): 17-26, Mar de Plata, Argentina.

Twomlow, S., Riches, C., O'Neill, D., Brookes, P., Ellis-Jones, J., 1999. Sustainable dryland smallholder farming in sub-Saharan Africa. Annals of Arid Zone.

Vanlauwe, B., Wendt, J., Giller, K.E., Corbeels, M., Gerard, B., Nolte, C., 2014. A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. Field Crops Research 155: 10-13. DOI: 10.1016/j.fcr.2013.10.002

Verhulst, N., Govaerts, B., Verachtert, E., Castellanos-Navarrete, A., Mezzalama, M., Wall, P. C., Chocobar, A., Deckers, J., Sayre, K. D., 2010. Conservation agriculture, improving soil quality for sustainable production systems? In R. Lal, and B. A. Stewart (Eds.), Food security and Soil quality (pp. 137e208) Boca Raton, Florida: CRC Press.

Vesterager, J. M., Nielsen, N. E., Høgh-Jensen, H., 2008. Effects of cropping history and phosphorus source on yield and nitrogen fixation in sole and intercropped cowpea-maize systems. Nutrient Cycling in Agroecosystems 80: 61-73.

Vlek, P., Le, Q.B., Tamene, L., 2010. Assessment of land degradation, its possible causes and threat to food security in Sub-Saharan Africa. In: Lal, R., Stewart, B.A. (Eds.), Food Security and Soil Quality. CRC Press, Boca Raton, Florida, pp. 57 - 86.

Wander, M. 2015. Soil Fertility in Organic Farming Systems: Much More than Plant Nutrition. http://articles.extension.org/pages/18636/soil-fertility-in-organic-farming-systems:-much-more-than-plant-nutrition

Wijewardene, R., 1979. Systems and energy in tropical small holder farming. In Proc.Appropriate Tillage Workshop (pp. 73e86). Zaria, Nigeria: IAR.

Zeleke, T. B., Grevers, M. C. J., Si, B. C., Mermut, A. R., Beyene, S., 2004. Effect of residue incorporation on physical properties of the surface soil in the south central rift valley of Ethiopia. Soil and Tillage Research 77: 35-46.

ACT

ECAF
European Conservation Agriculture Federation

IFAPA
Instituto de Investigación y Formación Agraria y Pesquera

Imperial College London

UNIVERSIDAD DE CÓRDOBA

Life