Promoting and advancing the uptake of sustainable, regenerative, conservation agricultural practices in South Africa with a specific focus on dryland maize and extensive beef production

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Protect and restore the soil,

and the soil will take care of the animals and plants on which humans depend for life.

The project team

Key findings and recommendations

- **Required: An acknowledgment of the fact that**
  - farming methods, irrespective of the scale, that have a high environmental demand and are largely dependent on external inputs are leading to the depletion and degradation of natural resources; this is unsustainable and irresponsible,
  - if the health of the natural resources, especially soil, is compromised, the food security of the country is compromised – not only does it jeopardise the productive capacity of the land, but also the financial viability of farming operations,
  - compromising the country's food security is a matter of national security and therefore demands attention at the highest possible level, and
  - the protection and restoration of the country's natural resources is not only a necessity, but a matter of extreme urgency given its link to national security.

- **Response: A nation-wide soil protection and restoration initiative that**
  - stimulates appropriate research and development into the protection and restoration of the country's natural resources, particularly soils,
  - promotes the implementation of sustainable, regenerative conservation agriculture principles and practices country-wide,
  - comprises all role players such as farmers and agricultural organisations, government, private sector, civil society and academia.

- **Result:**
  - Building a resilient country ready to face the challenges brought on by future changes.

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Introduction

Worldwide there is consensus that resource-intensive and negligent farming production systems, still widely practised in South Africa, has unsustainable elements which, with continued promotion and application, endangers global capacities to respond to the food security concerns (FAO 2008). For example, ploughing and removing crop residues after harvesting leave the soil naked and vulnerable to wind and rain, resulting in gradual, often unnoticed erosion. Similar to tire tread wear on your car — unless given the attention and respect it deserves, catastrophe is only a matter of time. Erosion also puts carbon into the air, contributing to climate change.

In South Africa, crop production systems based on intensive and continuous soil tillage have led to excessively high soil degradation rates in grain producing areas. This adds to the growing problems relating to profitability and poverty in some of the rural areas. According to Le Roux *et al.* (2008), the average soil loss under annual grain crops in the country is 13 ton $ha^{-1}yr^{-1}$. This is much higher than the natural soil formation rate and implies, for example, we are losing almost 3 ton $ha^{-1}yr^{-1}$ for every ton of maize produced every year. For farmers to have a better chance of survival and if sustainable and economically viable agriculture and food security are to be achieved, the paradigms of agriculture production and management have to change. The same applies to beef production – a myriad of different land use and cattle management methods are applied, some much more sustainable than others when measured in terms of the demands placed on the environment to support the production of beef. This will be a topic of consideration later in this document.

When considering maize production, there is general agreement among key role players, such as government, research institutions and producers' organisations, that these outcomes will be achieved through the adoption and implementation of conservation agriculture (CA). CA is seen as an alternative system that promotes sustainable and climate-smart agricultural intensification, through which farmers can attain higher levels of productivity and profitability (i.e. 'green prosperity') while improving soil health and the environment. **Box 1** displays a definition of CA and how the sustainability of crop production could be increased and intensified through a transition from conventional, high-input, tillage-based practices (stage 1) to regenerative CA systems (stage 5 and 6), and even low-input organic systems (stage 7). **Box 2** summarises why CA is essential.

Ample evidence from the last three decades now exists of the successes of CA under many diverse agro-ecological conditions to justify a major investment of human and financial resources in catalysing a shift, whenever and wherever conditions permit it, towards CA (Gassen & Gassen 1996, Calegari *et al.* 1998, FAO 2001, Derpsch 2003, Pretty *et al.* 2003, Smith *et al*. 2008, Thierfelder & Wall 2010, Nangia *et al.* 2010, Smith *et al.* 2010, Modiselle *et al.* 2015).

Box 1 Defining conservation agriculture (CA)

CA (see also Annexure 1) is 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 three linked principles (FAO 2004, 2013), namely:

- continuous minimum mechanical soil disturbance,
- permanent organic soil cover, and
- diversification of crop species grown in sequences and/or associations.

CA principles are universally applicable to all agricultural landscapes and land uses with locally adapted practices. CA enhances biodiversity and natural biological processes above and below the ground surface. Soil interventions, for example mechanical soil disturbance, are reduced to an absolute minimum or avoided. External inputs, for example agrochemicals and plant nutrients of mineral or organic origin, are applied optimally and in ways and quantities that do not interfere with, or disrupt, the biological processes. CA facilitates good agronomy, such as timely operations, and improves overall land husbandry for rain-fed and irrigated production. Complemented by other known good practices, such as the use of quality seeds, and integrated pest, nutrient, weed and water management, CA is a base for sustainable agricultural production intensification. It opens increased options for integration of production sectors, such as crop-livestock integration and the integration of trees and pastures into agricultural landscapes. CA approaches are furthermore underpinned by the full participation of farmers and rural people in all processes of problem analysis and technology development, adaptation and extension. This is with the objective to promote more equitable access to productive resources and opportunities, and progress towards more socially and environmentally-just forms of agriculture.

CA, with ongoing planting of cover crops, results in increased agricultural productivity and soil quality. This is measured by an increase in soil organic matter (SOM) which is linked to soil organic carbon (SOC) (Ruehlmann & Körschens 2009). An increase in the latter leads to improved water-use efficiency and available water capacity resulting in higher yields.

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

Source: Adapted from Blignaut *et al.* (2014).

This will lead to large and demonstrable savings in machinery and energy use and in carbon emissions, a rise in soil organic matter content and biotic activity. It will also reduce carbon emissions, ensure less erosion, increase crop water availability and thus resilience to drought, improve recharge of aquifers and reduce the impact of the apparent increased volatility in weather associated with climate change. It will reduce production costs, lead to more reliable harvests and reduce risks especially for smallholders. The latter point has been the basis of the low external input conservation agriculture (CA_{LEI}) concept (see CA stage 6 in **Box 1**). While obviously beneficial to the large-scale commercial farmer, CA_{LEI} is especially attractive if not essential for the household food security of the approximately 3 million smallholder families in South Africa. It simply means that the adoption and application of CA_{LEI} could sustain yields (and household food supply) on acceptable high levels with a minimum amount of external inputs, that is only those external inputs which are accessible (available and affordable) to smallholders.

Box 2 Why CA? A motivation

1. The increasing cost-pressure and declining gross margins of farming enterprises using conventional tillage, as seen in model outcomes below (CV - stage 1).
2. The decline and collapse of soil quality and soil ecosystem services. At this stage competitive yields are not feasible without the use of inorganic fertilizer, but declining yield trends in some areas show that the effect of this practice is reaching its limit and that soil ecosystem services should be restored to regain soil productivity, reduce risk and increase profitability. Soils can be rebuilt or recuperated with CA through quality application of all its principles.
3. The impact of climate change on weather patterns, water regimes, biodiversity and ecosystems services will put pressure on farmers to adapt their farming systems and management styles to increase their resilience and sustainability.
4. A growing awareness, knowledge and self-organisation among farmers (as stewards of the land and natural resources), scientists and agribusiness to use and promote sustainable agricultural practices. The networking of these key actors creates so-called innovation platforms, which are ideal structures to promote and scale out CA.
5. A need to improve the resource use efficiency and competitiveness of farming practices relies on healthy soils, healthy biodiversity and innovative farmers.
6. The need to rebuild the status and image of farming, which has been severely damaged by a negative environmental footprint and poor socio-economic conditions. CA innovation platforms have the ability to generate or contribute to considerable social capital in rural societies, which could have several positive socio-economic spin-offs to the benefit of the society as a whole.

Because of the multiple benefits that both CA systems (stages 5 and 6) generate in terms of yield, sustainability of land use, income, timeliness of cropping practices, ease of farming and eco-system services, the area under CA systems has been growing exponentially in many countries, largely as a result of the initiative of farmers and their organisations (Derpsch 2008, Derpsch *et al.* 2010). In South Africa, the total area under CA is still small relative to areas farmed using tillage (stage 1). There is, however, an upswing in the number of innovative farmers (commercial and smallholder) practising CA successfully, which has been greatly influenced by key research and development initiatives having had significant success in promoting it among farmers. Key examples of these initiatives are described by Smith *et al.* (2008), Smith *et al.* (2010), and Smith & Visser (2014). **Figure 1** depicts the spread of CA adoption among grain producers in South Africa, and the Western Cape and KwaZulu-Natal are clearly regions of high adoption. It should be noted that many farmers are converting to various stages of reduced to no tillage (stages 2–4), mostly because of economic/financial considerations (Knot 2014). This could be seen as a first step in a phased approach towards CA_{HEI}.

For an evidence-based assessment of CA, please see Annexure 2.

Sustainable maize production

Conservation agriculture (CA) as a farming practice is characterised by minimum soil disturbance, permanent soil cover and crop rotation (Hobbs 2007, Kassam *et al*. 2009) with either high or low use of external production inputs (see **Box 1**). Conventional agriculture (CV), on the other hand, tills the soil, removes soil cover (Amelia *et al.* 2009) and is highly dependent on external production inputs (see **Box 1**). A list of a number of indicators that can be used, either individually or in combination, to measure, monitor and compare CA success and adoption is provided in **Box 3**.

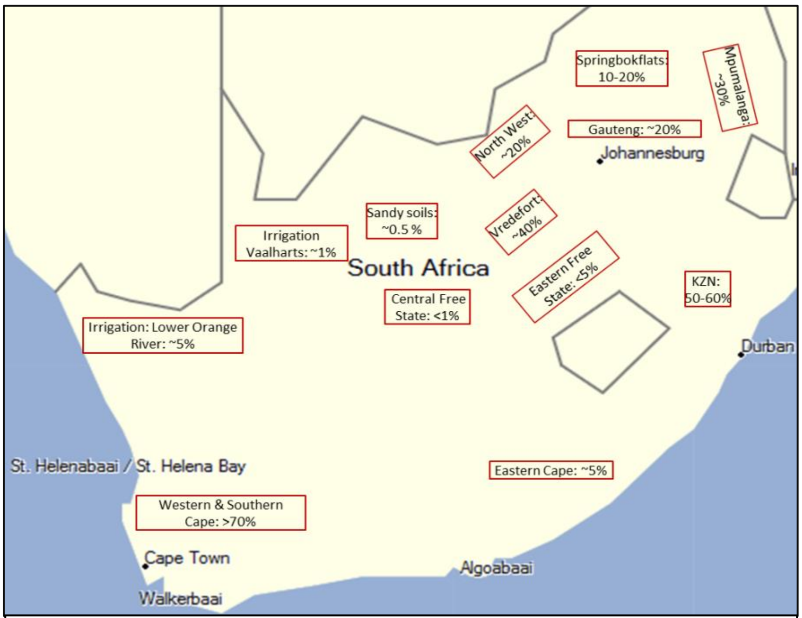

Figure 1 Distribution of CA adoption among grain producers (*circa* 2014/5)
Source: Personal communication: Sybrand Engelbrecht, Maize Trust (2015)

Box 3 Measuring conservation agriculture

The following is a list of indicators that can be used either individually or in combination to measure CA success and adoption:

1. return on investment with regard to yield (t/ha)
2. levels of (reduced) external production inputs: measured in R/ha and/or kg/ha/yr for fertilisers, herbicides, pesticides and lit/ha/yr for fuel use
3. soil health measurements – chemical
   a. balanced ratio of certain micro and macro nutrients, pH, acidity level, etc. (see also Soil Health Tool below)
4. soil health measurements – biological
   a. Soil Health Tool (SHT Index), and/or
   b. microbial genetic diversity (DNA Sequencing), microbial functional diversity (BIOLOG assay), carbon cycling (Solvita CO_2 respiration, soil enzymes), nitrogen cycling (part of SHT), soil biomass (microbial biomass, earthworm populations) and key species (Mycorrhiza, pathogens)
5. soil health measurements – physical
   a. soil organic matter (SOM) and soil organic carbon (SOC) build-up with regard to an appropriate baseline (consider different Soil C fractions, e.g. active or labile fractions)
   b. aggregate stability
6. water use efficiency (WUE) measured in terms of kg/mm rainfall or evapo-transpiration
7. reduced riskiness (combination of yields, WUE and return on investment linked to knowledge and management levels)
8. soil loss (ton/ha/yr) through soil loss modelling and field observations
9. number of CA farmer groups, such as study groups, clubs, etc. (measured by impact survey)
10. number of CA awareness events, such as farmers' days, conferences and cross visits
11. number of farmers adopting CA per region (adoption rate)
12. number of no-till planters sold per region per year
13. number of infestations by pests or other forms of invasive alien organisms per season per region

For the purpose of this study an attempt was made to assess commercial dry-land maize production and its accompanying environmental demand and costs under CV and CA systems. A system dynamics approach was used to model the transition from CV to CA systems in four maize producing regions in South Africa, namely Western Free State (WFS), Eastern Free State (EFS),

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KwaZulu-Natal (KZN) and North West (NW) over a 20-year period. Four region-framed production and environmental sub-models were therefore constructed that make provision for the unique farming characteristics of both CV and CA systems in the studied regions. **Table 1** displays some of the production data that informed the modelling. The data was obtained from a number of sources (e.g. farmer interviews, Department of Agriculture, Forestry and Fisheries, OVK, Grain SA, Novon, Pannar and Profert) and was verified by experts through Grain SA channels.

In modelling the transition from CV to CA systems, the relationships between soil organic matter (SOM), soil organic carbon (SOC) and water holding capacity (see **Table 2**) were used to inform changes in yield. In addition, the data from **Table 1** was used to (i) model CA systems' gradual yield increases (due to improved soil health) over a 20-year period (see **Table 3**), whereby (ii) cost reductions are phased in over a 10-year period.

Table 1 Profile of maize production systems (2013/2014)

Region: production system	Plant population	Growing season rainfall	Fertilizer	Pesticide	Herbicide	Diesel	Yield	Variable cost	Overhead cost	Total cost	Income	Net income
	'000/ha	mm	kg/ha	l/ha	l/ha	l/ha	t/ha	R/ha	R/ha	R/ha	R/ha	R/ha
NW: CV	19.0	550	367	0.3	4.7	79.3	3.65	5 921.20	1 776.36	7 697.57	5 521.10	-2 176.47
NW: CA	24.7	550	162	0.0	2.93	49.7	8.30	5 656.93	1 551.36	7 208.29	12 554.83	5 346.54
WFS: CV	18.5	492	418	0.1	7.5	89.2	5.4	6 807.29	2 064.66	8 871.95	8 168.20	-703.74
WFS: CA	24.0	492	165	0.0	5.25	44.4	7.3	5 812.81	1 767.44	7 580.25	11 042.20	3 461.94
EFS: CV	27.7	700	436	1.7	3.7	67.0	4.2	7 087.12	2 142.63	9 229.75	6 353.05	-2 876.70
EFS: CA	36.0	700	173	0.0	3.25	41.9	10.5	6 141.00	1 859.86	8 000.86	15 882.62	7 881.76
KZN: CV	42.0	800	400	0.7	3.0	68.7	8.4	8 178.00	1 652.60	9 830.59	12 736.34	2 905.75
KZN: CA	54.6	800	150	0.0	3.35	47.0	12.0	7 057.56	1 537.45	8 595.01	18 151.56	9 556.55

Table 2 SOM, SOC, AWHC and yield relationships

Change in soil organic matter	Change in soil organic carbon	Change in available water holding capacity	Change in yield
	Ruehlmann & Körschens (2009)	Reicosky (2005), Hudson (1994)	Lal (2010)
1.0%	0.58%	3.7%	2.76%
1.5%	0.87%	5.6%	4.14%
2.0%	1.16%	7.4%	5.52%
2.5%	1.45%	9.3%	6.91%
3.0%	1.74%	11.1%	8.29%
3.5%	2.04%	13.0%	9.67%
4.0%	2.33%	14.8%	11.05%
4.5%	2.62%	16.7%	12.43%
5.0%	2.91%	18.5%	13.81%

Table 3 Target yield after 20 years for CA systems

Regions	CV avg. yield (actual)	CA yield (potential)	Target yield after 20 yrs	Production % change p.a.	Yield growth
	t/ha	t/ha	t/ha & (% of CA pot.)	%	%
NW	3.65	8.30	4.15 (50%)	0.26%	13.7%
WFS	5.40	7.30	5.48 (75%)	0.03%	1.5%
EFS	4.20	10.50	7.88 (75%)	1.67%	87.6%
KZN	8.42	12.00	9.60 (80%)	0.26%	14.0%

The environmental component, which quantifies and monetises the GHG emissions associated with the use of fertilisers, herbicides, pesticides and diesel in CV and CA systems in the various regions was informed by the emissions data contained in **Table 4**. For the CA systems the probable soil carbon sequestration in the various regions was also estimated.

Table 4 Emission factors for various production inputs

	Units	CO_2e emission factors and price	Data source
Direct Diesel	$KgCO_2e/l$	2.6769	Defra (2012)
Indirect Diesel	$KgCO_2e/l$	0.5644	
Indirect fertilizer	$KgCO_2e/Kg$	2.25	
Indirect pesticide	$KgCO_2e/l$	0.97	
Indirect herbicide	$KgCO_2e/l$	0.76	
Damage cost of CO_2	R/tCO_2e	120	National Treasury (2013:15)

Based on the assumptions provided above, **Figures 2 and 3** show the net present values (NPVs), which express a future string, or time series, of financial values in today's terms, of both the CV and CA systems in the four maize producing regions. All the figures depict a very large monetary benefit of adopting CA systems, with or without the incorporation of positive externalities. In **Figures 2 and 3** it can be seen that the viability of maize production improves in all regions with the adoption of CA systems but the potential is more so in the Eastern and Western Free State[1]. This is as a result of cost reduction owing to lower input use, increases in yields, less emissions into the environment and carbon sequestration. While **Figure 4** show improvements in the financial viability of CA systems versus CV, North West CA systems remain negative (see value at the end of the simulation period) indicating that the investment is not economical without even more adaptation and diversification. (It is, however, worth mentioning that the NPV for CA systems is by far better than that of not adopting CA; i.e. CV NPV = -R16 billion while that of CA-friendly systems is about -R3 billion.) The NPVs of CA maize production in all other regions are positive indicating CA-friendly systems to be good investments. Maize production is most economical in KwaZulu-Natal, followed by Eastern Free State and then Western Free State.

[1] A theoretic conclusion justifies large scale experience-based research in this matter.

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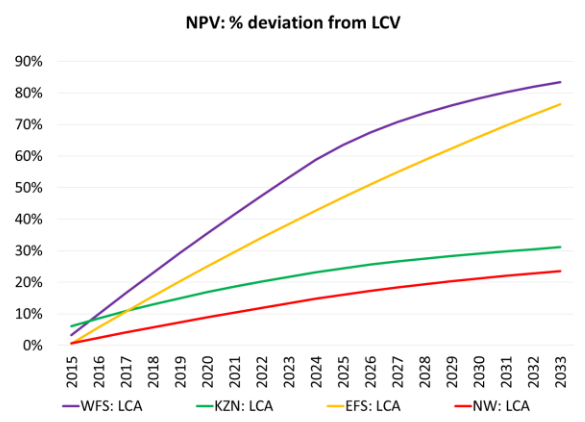
The outcomes of this study demonstrate that the transition from CV to CA systems has the potential of not only reducing costs, increasing yields, increasing net farm income, but also ecological benefits too. This is through lower GHG emissions, lower input use and carbon sequestration. Maize farmers should therefore be encouraged to adopt CA systems to improve the profitability of their farms (more so in Eastern Free State, Western Free State and North West – see **Table 1** and **Figure 4**) and also to reduce the environmental load of maize production (see **Table 5**).



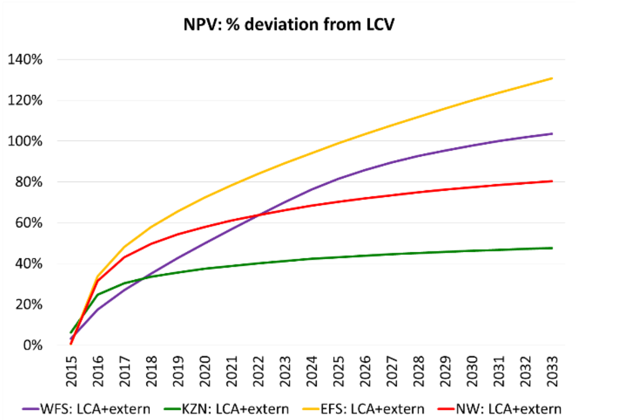


Figure 2 **NPVs without externalities** **Figure 3** **NPVs with externalities**

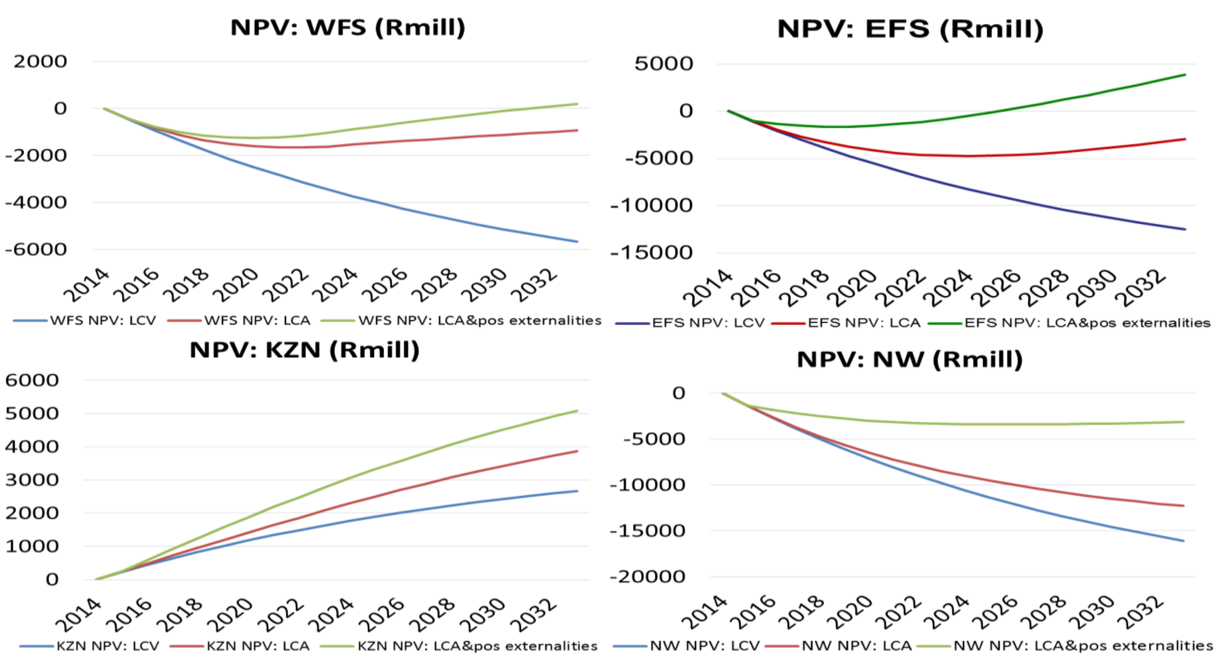


Figure 4 **NPVs of CV and CA-friendly systems**

Table 5 CO_2e emissions of CV and CV to CA-friendly systems

Region	CV total CO_2e emissions	Total net CO_2e emissions saved through adopting CA*
	ton/ha/yr	ton/ha/yr
NW	1.087	10.705
WFS	1.235	1.326
EFS	1.204	13.613
KZN	1.126	11.532

* Total net CO_2e emissions saved through adopting CA = CV CO_2e emissions - CA CO_2e emissions + CO_2 sequestrated. It is an averaged value over the modelling period (20 years) due to the fact that the CA emission values are time varying (i.e. CA emission values gradually reduce as a CV farmer transition to CA-friendly systems owing to gradual reduction in fertiliser, diesel, herbicide and pesticide use).

To up-scale CA, several barriers have to be overcome. These include a change in mindset based on tradition and prejudice, the lack of knowledge on how to do it, the availability of adequate and appropriate machines, the availability of adequate and appropriate herbicides, and adequate and appropriate policies to promote adoption. Derpsch and Friedrich (2009:14), states it as follows:

> *These barriers must be overcome by politicians, public administrators, farmers, researchers, extension officials, agriculturalists and university professors. With adequate policies to promote Conservation Agriculture/No-till, it is possible to obtain what is called the triple bottom line, economic, social and environmental sustainability, while at the same time improving soil health and increasing production. The wide recognition as a truly sustainable farming system should ensure the growth of this technology to areas where adoption is still small as soon as the barriers for its adoption have been overcome. The widespread adoption also shows that No-tillage cannot any more be considered a temporary fashion, instead the system has established itself as a technology that can no longer be ignored by politicians, scientists, universities, extension workers, farmers as well as machine manufacturers and other agriculture related industries.*

Sustainable beef production: a static farm-level perspective

Extensive beef production is often not considered within the context of conservation agriculture since it does not comprise a tillage component, at least not directly. That does not imply that various beef production systems cannot be considered and evaluated from a sustainability perspective. Here we consider 12 different typical farm-level extensive beef production systems (see **Table 6**). Farms 1–3 represent typical average, good and bad commercial operations, Farms 4–6 represent typical average, good and bad emerging farmers' operations, Farms 7–9 represent typical average, good and bad communal farmers' operations and Farms 10–12 represent typical average, good and bad national

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level operations. While the data has been derived from actual data and verified by industry experts, they represent typical farms and not actual farm data.

Table 6 Diagnostic specification of different extensive beef production systems*

	Calf mortality	Unproductive animals	Calf birth weight	Calf age at marketing	Market weight	Income	Fodder consumption	Average daily gain	Avg. feed conversion ratio (calves)
	%	%	kg	Days	kg	(R/calf)	% of weight	(kg/day)	(kg feed for kg meat)
Farm 1	10%	73%	40.0	244.0	220	4 400	2.8%	0.74	4.95
Farm 2	5%	62%	45.0	213.5	220	4 400	2.8%	0.82	4.56
Farm 3	15%	86%	35.0	305.0	220	4 400	2.8%	0.61	5.90
Farm 4	10%	80%	35.0	305.0	190	3 230	3.0%	0.51	6.66
Farm 5	5%	70%	35.0	305.0	200	3 400	3.0%	0.54	6.53
Farm 6	15%	94%	30.0	305.0	180	3 060	3.0%	0.49	6.42
Farm 7	20%	134%	25.0	549.0	190	3 230	3.2%	0.30	11.46
Farm 8	15%	126%	30.0	457.5	200	3 400	3.2%	0.37	9.94
Farm 9	30%	146%	25.0	732.0	180	3 060	3.2%	0.21	15.51
Farm 10	15%	103%	30.0	335.5	190	3 230	3.0%	0.48	6.95
Farm 11	10%	95%	35.0	244.0	220	3 740	3.0%	0.76	5.06
Farm 12	20%	117%	27.5	366.0	180	3 060	3.0%	0.42	7.49

* Farms 1–3 represent typical average, good and bad commercial operations, Farms 4–6 represent typical average, good and bad emerging farmers' operations, Farms 7–9 represent typical average, good and bad communal farmers' operations and Farms 10–12 represent typical average, good and bad national level operations.

The environmental demand of the farm-level life-cycle of producing a market-ready calf for the different farm production systems have been estimated based on the following assumptions:

- GHG emissions per year: Based on Du Toit *et al*. 2013 (valued @R120/t (National Treasury 2013:15))

	Bulls	Cows	Heifers	Oxen	Young oxen	Calves
Commercial	2.83	2.32	1.90	2.24	1.29	1.29
Communal	2.10	1.83	1.57	1.82	1.04	1.02

- Water use: 3 litre per kg dry fodder use (RPO & NERPO 2014) (valued @R2/m^3 – own calculation based on Blignaut *et al.* 2008)
- Fodder (grazing): 2,8–3,2% per day of body weight (valued @ R871/ton – own calculation based on Dept. of Agric. Limpopo (2010) – adjusted for inflation)
- Price of calf (live-weight):
    - Class A: R20/kg
    - Class B: R17/kg

Based on these assumptions, the environmental demand per farming system can be estimated and the results are displayed in **Table 7**.

Table 7 Estimated total farm-level life-cycle environmental demand per farming system*

	Total CO_2equiv.	Total water consumption	Total feed consumption	Total environmental demand	Income hectare	Net income	kg meat @ market age /ha	kg CO_2 / kg meat @ market age	lit water / kg meat @ market age	kg feed / kg meat @ market age
	ton/ha/yr	l/ha/yr	kg/ha/yr	R/ha/yr	R/ha/yr	R/ha/yr	kg meat/ha	ratio	ratio	ratio
Farm 1	0.394	2 869.1	797.7	747.8	351.9	-395.95	17.6	22.4	163.1	45.3
Farm 2	0.465	3 402.4	945.8	886.3	457.4	-428.92	22.9	20.3	148.8	41.4
Farm 3	0.323	2 341.5	651.3	610.8	246.3	-364.45	12.3	26.2	190.1	52.9
Farm 4	0.394	2 879.4	800.8	750.5	232.5	-518.06	13.7	28.8	210.6	58.6
Farm 5	0.477	3 457.8	963.7	903.5	318.1	-585.35	18.7	25.5	184.8	51.5
Farm 6	0.319	2 353.4	652.4	611.1	154.2	-456.98	9.1	35.1	259.5	71.9
Farm 7	0.544	3 756.9	1 087.0	1 019.6	162.8	-856.82	9.6	56.8	392.4	113.5
Farm 8	0.460	3 197.6	925.8	867.9	171.3	-696.61	10.1	45.7	317.3	91.9
Farm 9	0.514	3 543.6	1 024.6	961.2	107.9	-853.29	6.3	81.0	558.1	161.4
Farm 10	0.599	3 993.4	1 157.0	1 087.6	325.7	-761.90	19.2	31.2	208.5	60.4
Farm 11	0.428	2 952.1	854.2	801.3	301.7	-499.64	17.7	24.1	166.4	48.1
Farm 12	0.590	3 968.2	1 146.9	1 077.7	246.8	-830.91	14.5	40.6	273.3	79.0

* Farms 1–3 represent typical average, good and bad commercial operations, Farms 4–6 represent typical average, good and bad emerging farmers' operations, Farms 7–9 represent typical average, good and bad communal farmers' operations and Farms 10–12 represent typical average, good and bad national level operations.

The relative difference in the productive efficiency and environmental demand among the 12 farming systems, derived from **Table 7** and expressed relative to Farm 10 (the national average production system), is shown in **Figure 5**.

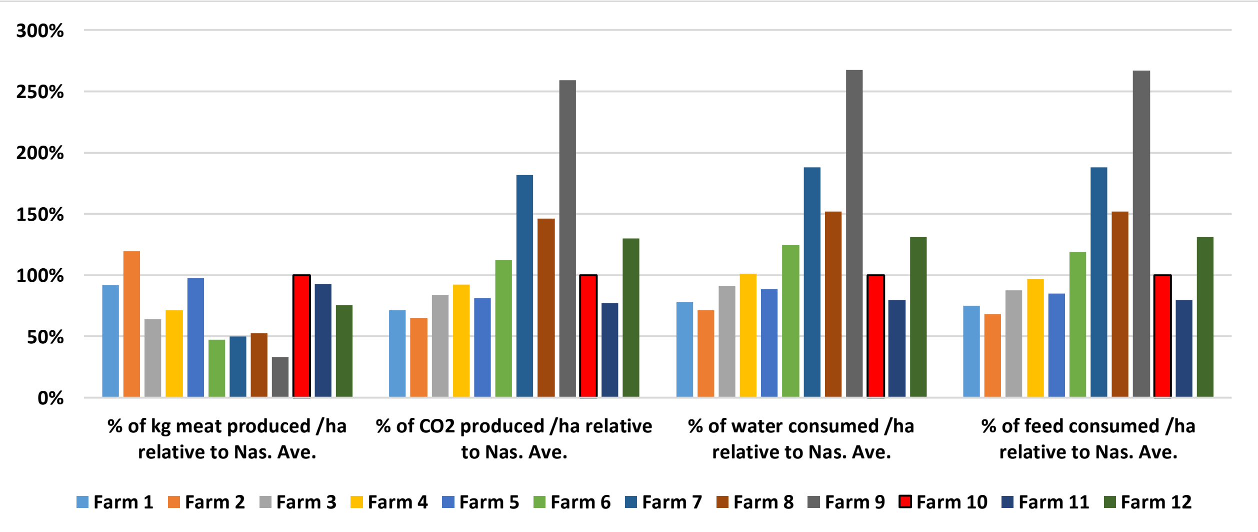

Figure 5 Comparison of the productive efficiency and environmental demand among 12 different farming systems, with Farm 10 (national average) = 100

The above analysis is based on a static farm-level assessment of the environmental demand of different production systems. Next we consider a dynamic country-level assessment.

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Sustainable beef production: a dynamic country-level perspective

Using a systems dynamic model based on historic data (based on DAFF 2015), a country-wide production and environmental demand model was constructed making provision for the different characteristics of both the national commercial and communal herds. Using a social discount rate of 4%, which is relatively-speaking low but reflects a strong adoption rate sensitivity among the different management systems, five scenarios for both the commercial and communal production systems (each subdivided into average, good and bad systems as defined in the previous section) were estimated. These scenarios are as follows:

- Baseline scenario
  - No change to either production or imports over time – composition and size of both commercial and communal herds kept constant and no adoption of sustainable farming practises. No change in production characteristics.
- Realistic scenario
  - Production growth at 4% and import substitution at 1.6% in both commercial and communal herds. Herd composition follows historical trends. Calf sale values and input costs increase in accordance with historical data. Change in production structure over 20 years, thereafter constant.
- Optimistic scenario
  - Production growth at 11% and import substitution at 4% in both commercial and communal herds. Calf sale values increase in accordance with historical data. Increases in fodder price decrease by 50% from 9.7% to 4.85% as better management of the land results in efficiency gains. No change in production characteristics.
- Pessimistic scenario
  - Production growth at 4% and import substitution at 1.6% in both commercial and communal herds. Herd composition follows historical trends. Calf sale values and input costs increase in accordance with historical data. No change in production characteristics.
- National
  - Production growth at 11% and import substitution at 4% in both commercial and communal herds. Calf live weight values increase in accordance with historical trends. Increases in fodder price decrease by 50% from 9.7% to 4.85% as better management of the land results in efficiency gains. Change in production structure over 20 years, thereafter constant.

From **Figure 6** it can be seen that there are very large disparities among the marginal values of producing a kg of meat for each of the five scenarios among the six production systems as represented by differences in the net present values thereof. The net present value represent the discounted net difference (over 30 years) between the value of the calf sales and the value of the environmental demand. As indicated in **Table 7**, all the net values were negative, indicating that the environmental demand exceeds the value of the calf sales. Under the dynamic analysis it is clear that under certain conditions the values can become positive (under the optimistic and national scenarios). The risk, however, lies in the bad communal management practices where the marginal net present value of producing a kg of meat can be as low as -R11 000. It has, however, the potential to be -R335, as depicted under the national scenario.

Both the commercial and communal herd managers therefore have to change their prevailing management practices to reduce the current net environmental loss, but the risk among communal farming practices are far greater.

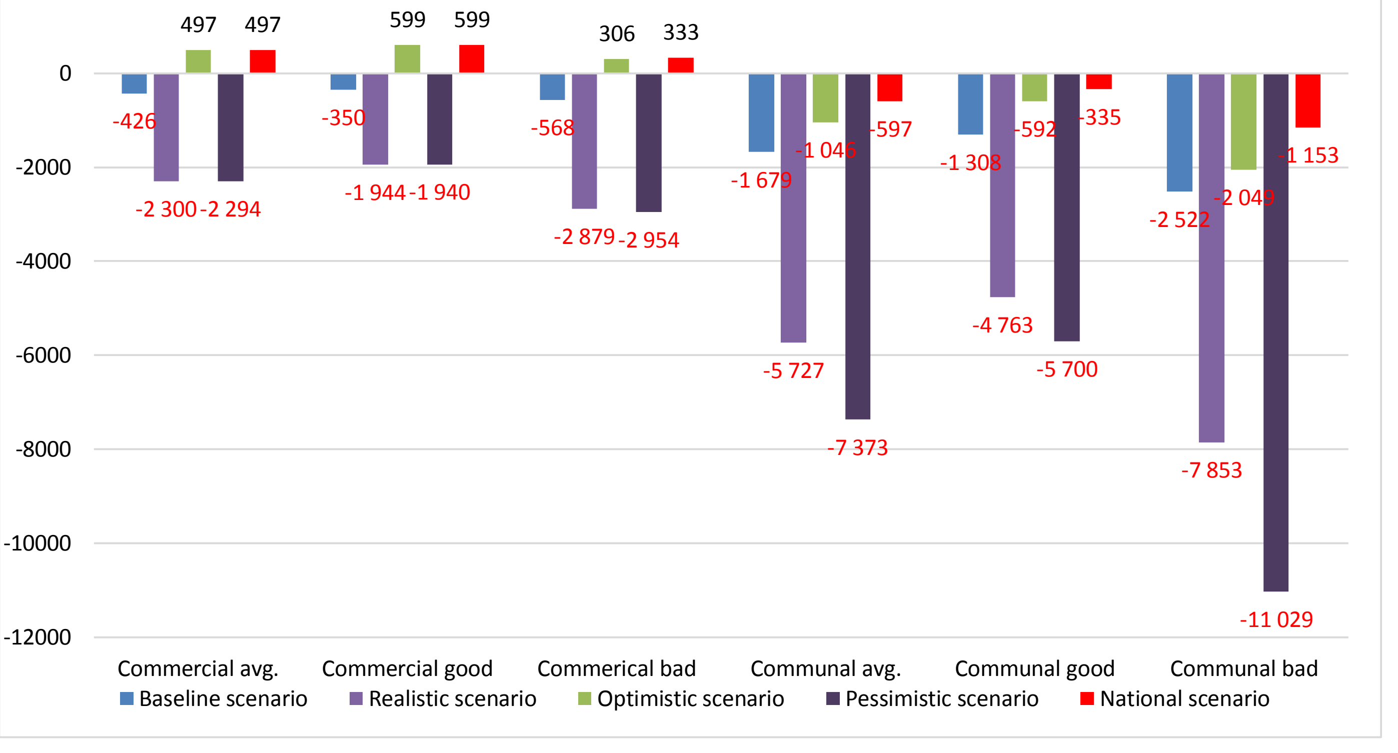

Figure 6 Comparison of net present value (R/kg meat produced over 30 yrs) among six production systems under five scenarios

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Annexure 1: What is conservation and sustainable agriculture?

Regenerative and sustainable agriculture has now become the most important concept in agricultural development (Harwood 1990, WCED 1987, Pretty 1996, Rigby *et al.* 2000, Stoneham *et al.* 2003, Röling & Wagemakers 1998). This is after we learned the hard lesson that intensive, high-external-input agriculture does show increased production of some major food crops under certain conditions but also results in serious degeneration and pollution of the environment in both potential and marginal areas. Contrary to that, Pretty et al. (2003) found that sustainable agricultural practices have led to a 93% increase in per hectare food production, averaged across 208 initiatives (projects) they surveyed worldwide. Röling and Wagemakers (1998) recommended "five interlocking dimensions of the transformation to sustainable farming", which are:

- agricultural practices
- learning those practices
- facilitating that learning
- institutional frameworks that support such facilitation
- conducive policy frameworks

Sustainable agriculture is, therefore, not a simple model or package to be imposed. It is more a *process for learning* (Pretty 1996, Röling & Wagemakers 1998). This type of 'learning process' contrasts with the 'transfer of technology' paradigm for agricultural extension, whereas transfer of technology served the promotion of standardised, prescribed, single-component technologies and aimed at straightforward adoption of these technologies, extension for sustainable agriculture should serve to facilitate holistic change processes at the farm, farmer, group, ecosystem and institutional levels (Van de Fliert 2000). Mostly this 'innovation process' is driven by farmers within and from their social structures or 'innovation platforms' (Smith 2006).

Sustainable agriculture is not a clearly defined production model, but rather a set of complementary approaches that seeks to minimise negative environmental impacts from agriculture, by increasing efficiency of input use and by making greater use of biological and ecological factors in production processes (Bruinsma 2003). Pretty (1996) and Pretty *et al.* (2003) described sustainable agriculture as any system of food or fibre production that systematically pursues the following farming objectives:

- A thorough incorporation of natural processes such as nutrient cycling, nitrogen fixation and pest-predator relationships into agricultural production processes, so ensuring profitable and efficient food production.
- A minimisation in the use of those external and non-renewable inputs with the greatest potential to damage the environment or harm the health of farmers and consumers, and a more targeted use of inputs with a view to minimising costs.
- The full participation of farmers and rural people in all processes of problem analysis and technology development, adaptation and extension.
- A more equitable access to productive resources and opportunities, and progress towards more socially-just forms of agriculture.
- A greater productive use of local knowledge and practices, including innovative approaches not yet fully understood by scientists or widely adopted by farmers.
- An increase in self-reliance among farmers and rural people.
- An improvement in the match between cropping patterns and the productive potential and environmental constraints of climate and landscape to ensure long-term sustainability of current production levels.

Sustainable Crop-Livestock Systems

In recent decades, the integration of **livestock** with CA systems was perhaps among the most significant innovations in these mixed production systems to ensure economic and ecological sustainability and resilience while providing ecosystem services, such as increased biological diversity, nutrient cycling and improved soil health. It also enhances forest preservation and contributes to adaptation and mitigation of climate change. Within the economic and production dimension, sustainable IC-LS enhance livelihood diversification and potentially efficiency through optimisation of production inputs including labour, offer resilience to economic stresses, and reduce risks. From a socio-cultural perspective, these systems are meant to assist farmers to diversify and meet their livelihood aspirations, ensure equitable social dynamics, particularly for elders, women and youth, and increase nutrition security and food safety while meeting consumer choice and demand.

So, some might ask, what is new about this in South Africa and if there is merit in raising awareness, and indeed in promoting integrated and sustainable production of crops and livestock. The reality is that South Africa is in urgent need for more sustainable and productive agricultural systems that could also better adapt to and mitigate the effects of climate change. Currently, most traditional agricultural practices (under both small- and large-scale) lead to severe land degradation and are climate change negative, such as intensive tillage and communal grazing, which often results in greater losses of soil organic matter, poor soil structure and available soil moisture, and increased runoff and soil erosion.

CA, however, has proven in most cases to sequester additional carbon into the soil and frequently result in better soil health, productivity and profitability. Livestock on improved pastures derived from CA-based crop-pasture rotations not only produce more meat per unit of pasture, they produce more per unit of greenhouse gas emission. Based on these positive research results and experiences from farmers and other practitioners in the world (including sub-Sahara Africa region) during the last three decades, a new kind of sustainable intensified agriculture based on CA is emerging.

Annexure 2: The successful implementation of CA in South African wheat

Wheat is South Africa's biggest winter cereal crop. Production systems in the Western Cape (WC) have been based on it since the 1700s and for the Swartland is the main crop for the last century. Up to 1994 the South African Wheat Board protected wheat prices resulting in that farmers planted most of their land to wheat. With the end of the Wheat Board, prices were governed by the free-market and marginal lands became unprofitable, resulting in farmers reducing the area under production by more than half. Today farmers have nearly doubled their output with CA systems (Strauss, n.d.).

Although the local wheat production is of highest quality globally (Dr Strauss, scientist Western Cape DAFF), the country's production is not sufficient for local consumption and subsequently SA imports wheat to meet demand.

The question
Why have 70% of the wheat farmers in the Western Cape adopted CA (HEI) effectively in the last 2 decades?
What can we learn from them and their rate of adoption?

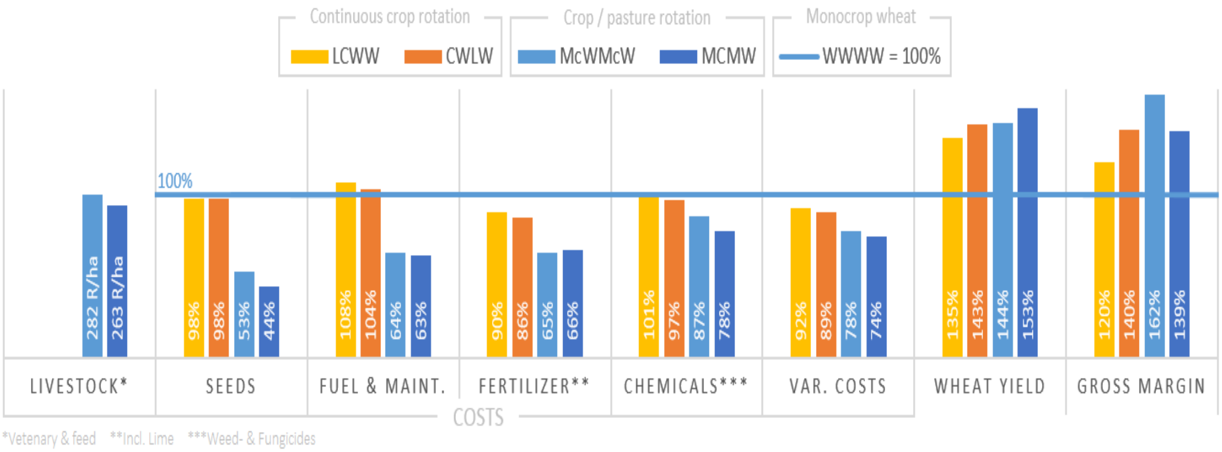
Today's farmers' response:
87% claim total income increases
70% claim labour decreases
60% claim weed sprays increase
63% claim equipment costs increase
80% claim disease control decreases
77% claim soil compaction decreases
65% claim water quality increases
95% claim soil-moisture, microbes, and crop quality increases
Modiselle *et al*. (2015)

An historic account of an early adopter farmer
In the 1970s, a south cape farmer recalls: "We used to have seeders that would only work with well-prepared fine seedbeds and we had to plough. The ploughing also helped with weed control, as we had no weed sprayers those days. We subsequently evaporated a lot of soil borne water and the wheat would have to rely on the little in season rain of 100-200mm, often not giving us more than 2t.

After every rain you would see your soil washing away and the government spent a lot of money to install Keyline systems. That was the first time I understood my dad's scepticism toward grain farming and his preference for livestock and pastures. Then in 1981 we had the worst rains and floods I can recall, washing away thousands of tons of our topsoil. In an effort to find a solution to erosion I visited Australia and the farmers there were amazed that we still ploughed. When I came back I immediately sold my ploughs and we started with no-till and the first principles of CA" (from an interview).

A farmer survey
Targeting 51 CA wheat farmers in the WC, the ARC and the Western Cape DAFF found that almost 40% of respondents had heard about CA from other producers and 81% of them considered the application of CA as relatively easy (Modiselle *et al*. 2015). Almost all interviewed believed that the uptake of this technology was growing. While half of all farmers used either one or two of the three CA principles (min till, soil cover & crop rotation) the other half used all three elements as farming practice (Modiselle *et al*. 2015).

Economic evaluation of long-term crop and pasture rotations in wheat
From a long-term randomised study by Hardy *et al.* (2011), initiated 1996, with eight replicas, we selected the most productive and unproductive rotations for each continuous crop and crop/pasture rotation. **Figure 7** shows a nine-year ('02-'10) average for costs, wheat yield, and gross margins per crop/pasture.



(W=wheat, C=canola, L=lupin, M=medic, Mc=medic/clover)

Figure 7 Nine-year ('02-'10) average for costs, wheat yield, and gross margins per crop/pasture
Source: Hardy *et al.* (2011)