CONSERVATION AGRICULTURAL PRACTICES IN SOUTH AFRICA:

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

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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-1yr-1. This is much higher than the natural soil formation rate and implies, for example, we are losing almost 3 ton ha-1yr- 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, highinput, 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.

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 (CALEI) concept (see CA stage 6 in Box 1). While obviously beneficial to the large-scale commercial farmer, CALEI 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 CALEI 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.

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

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.

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 CAHEI.

Sustainable maize production

Conservation agriculture (CA) as a far-ming practice is characterised by mini-mum 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 combina-tion, to measure, monitor and compare CA success and adoption is provided in Box 3.

For the purpose of this study an at-tempt was made to assess commer-cial 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 sy-stems in four maize producing regions in South Africa, namely Western Free State (WFS), Eastern Free State (EFS), KwaZulu-Natal (KZN) and North West (NW) over a 20-year period.

Four region-framed production and environmental sub-models were the-refore constructed that make provi-sion for the unique farming characteri-stics 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 capa-city (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.

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 com-bination 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. 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 CO2 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 eva-po-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

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$_2$e emission factors and price	Data source
Direct Diesel	KgCO$_2$e/l	2.6769	Defra (2012)
Indirect Diesel	KgCO$_2$e/l	0.5644	
Indirect fertilizer	KgCO$_2$e/Kg	2.25	
Indirect pesticide	KgCO$_2$e/l	0.97	
Indirect herbicide	KgCO$_2$e/l	0.76	
Damage cost of CO$_2$	R/tCO$_2$e	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 State1.

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.

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).
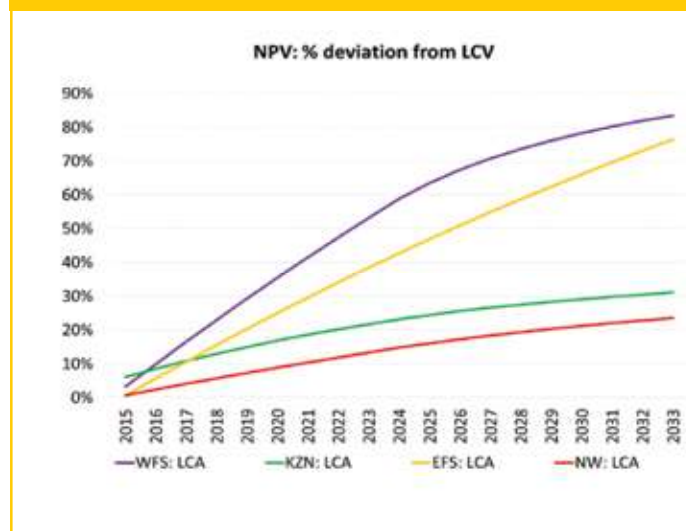
FIGURE 2 NPVS WITHOUT EXTERNALITIES

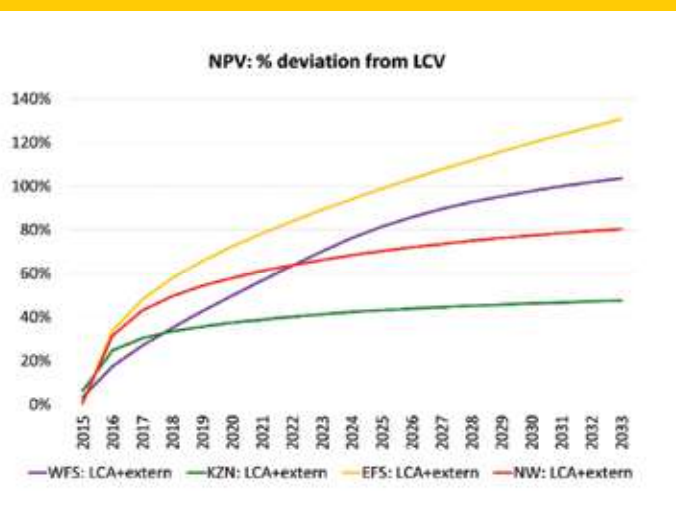

FIGURE 3 NPVS WITH EXTERNALITIES
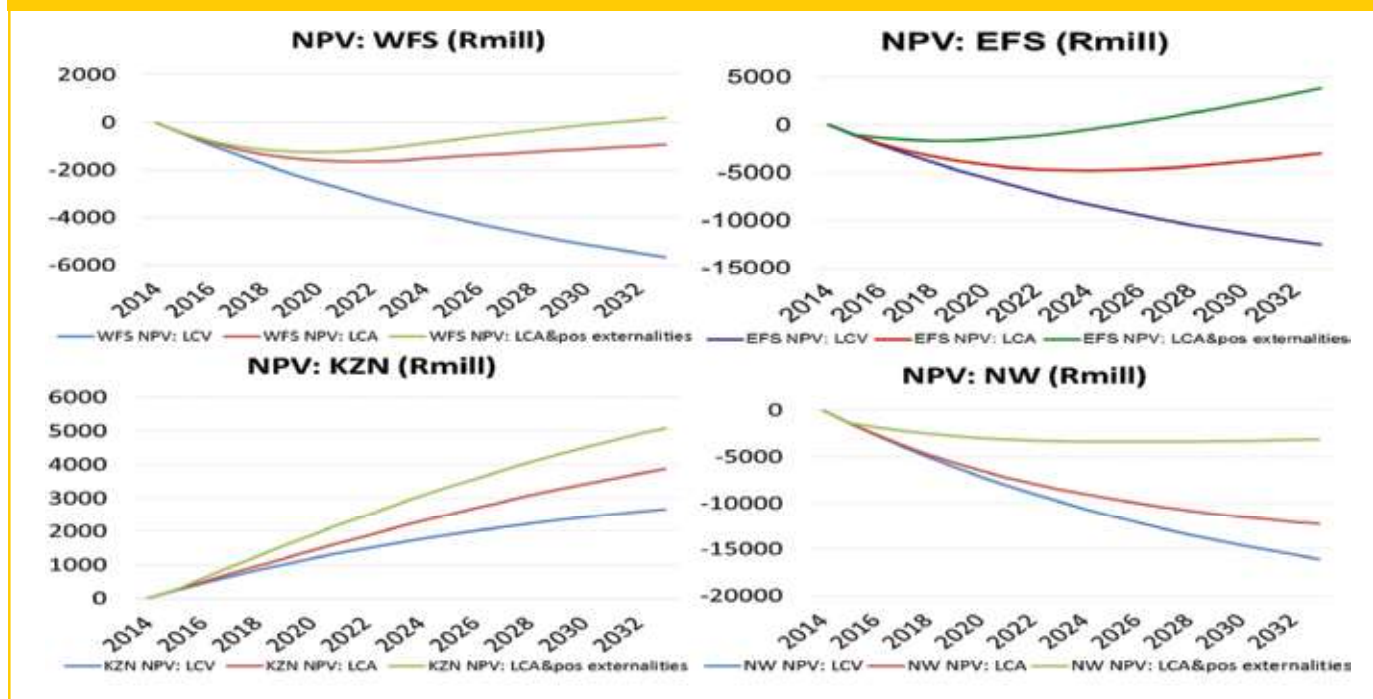
FIGURE 4 NPVS OF CV AND CA-FRIENDLY SYSTEMS

TABLE 2 SOM, SOC, AWHC AND YIELD RELATIONSHIPS

Region	CV total CO₂e emissions	Total net CO₂e 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 CO2E EMISSIONS SAVED THROUGH ADOPTING CA = CV CO2E EMISSIONS - CA CO2E EMISSIONS + CO2 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 FERTI-LISER, 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 can- not be considered and evaluated from a sustainability perspective. Here we consider 12 different typical farm-le- vel extensive beef production systems (see Table 6). Farms 1–3 represent typical average, good and bad commer- cial operations, Farms 4–6 represent typical average, good and bad emer- ging farmers' operations, Farms 7–9 represent typical average, good and bad communal farmers' operations and Farms 10–12 represent typical avera- ge, good and bad nationalyear period. level operations. While the data has been derived from actual data and ve- rified by industry experts, they repre- sent 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' OPERA- TIONS 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/m3 – 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. Lim- popo (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.
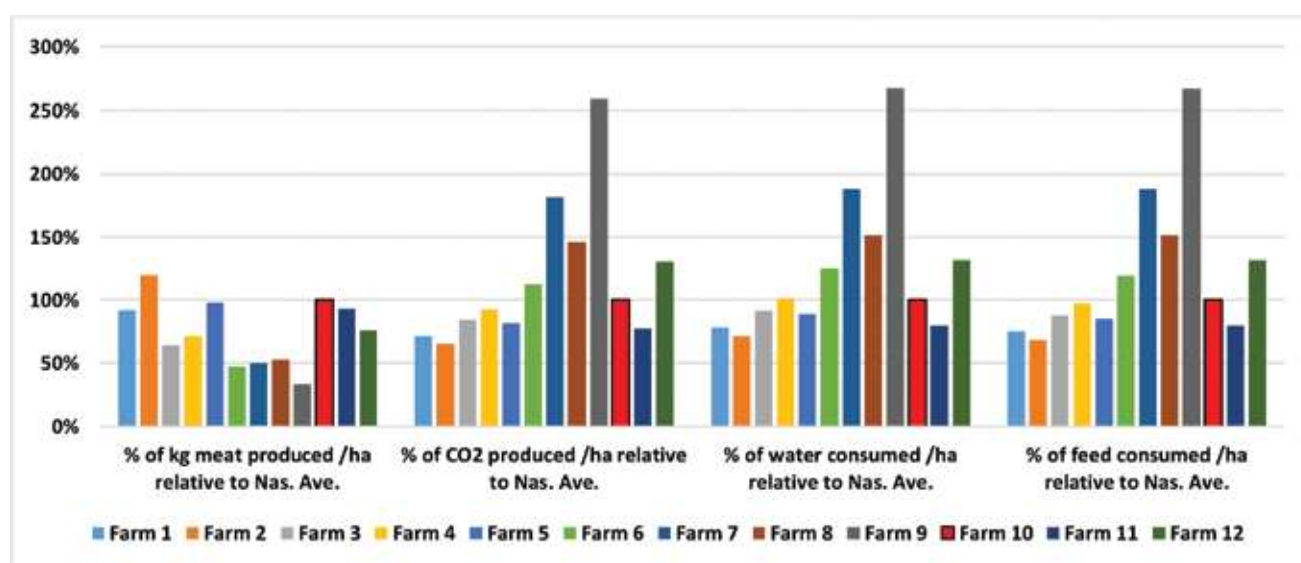
TABLE 7 ESTIMATED TOTAL FARM-LEVEL LIFE-CYCLE ENVIRONMENTAL DEMAND PER FARMING SYSTEM*

	Total CO$_2$equiv.	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.