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Comparing the financial benefits of different grain production systems in South Africa's summer rainfall region

There is growing evidence that soil degradation, among other factors, has led to both the decline and constraint of agriculture in southern Africa. Conservation and regenerative agriculture (CA/RA) have been proposed as a grain crop production system that could slow down, halt or even reverse some of these disturbing trends. But the question remains whether it is financially viable. We sought to find an answer to this question by comparing the financial returns of a CA/RA system over a 20-year period to its alternatives, namely conventional tillage (CT) and no-tillage (NT) production systems. The cumulative free cash flow (CFCF) of the average between the realistic and conservative CA/RA scenarios in year 20 is considerably higher than that of the other systems under investigation. The CFCF for CA/RA in year 20 in Mpumalanga is estimated to be ZAR86 million, compared to -ZAR51 million for CT and about ZAR4 million for NT. That is a net difference between ZAR137 million (compared to CT) and ZAR82 million (compared to NT). In the Maluti area, the CFCF for the CA/RA production system is estimated at ZAR26 million, compared to -ZAR66 million for CT and -ZAR19 million for NT. In the North-West production area, the CFCF for the CA/RA production system is estimated at ZAR35 million, compared to -ZAR9 million for CT and about ZAR21 million for NT. The differences between the CFCF of the CA/RA system and the other systems represent the financial opportunity cost of not converting to the CA/RA system.

Significance:

- Soil degradation leads to both the decline and constraint of agriculture in southern Africa.
- Conservation and regenerative agriculture (CA/RA) have been proposed as a grain crop production system that could slow down, halt or even reverse some of these disturbing trends.
- CA/RA are financially more viable in three grain production areas of South Africa.
- The cumulative free cash flow (CFCF) CA/RA in year 20 is considerably higher than that of the other systems.
- The differences between the CFCF of the CA/RA system and the other systems represent the financial opportunity cost of not converting to the CA/RA system.

Introduction

There is growing evidence that factors such as land and soil degradation, water insecurity and changes in climatic conditions have led to both the decline and constraint of agriculture at all levels in southern Africa.[1-3] These factors pose a major risk to the continuity and sustainability of the sector with an adverse impact on national and household food security. Given the widespread poverty and South Africa's precarious socio-economic context, the country is in great need of taking proactive steps to reduce all threats to food production.[4,5] The agriculture sector, be it small-scale, subsistence or commercial, must adapt to the current conditions and mitigate the risk factors in a way that protects the environment and its natural resources and reinforces production and sustainability.[6,7] To achieve this, the sector must embrace resilient, productive and profitable production systems that will restore, protect and sustain the health and productivity of the country's natural resources, notably its soil.

According to the Food and Agriculture Organization of the United Nations[8], about 60% of South Africa's commercial farming sector, on an area basis, employs conventional deep-tillage and monocrop grain crop-livestock production systems. While this system has proven its high productive capacity in the past, it is very disruptive and leads to environmental degradation. This reduces a farm's resilience, sustainability and profitability.[9,10] Unfortunately, a vicious circle emerges. Conventional production systems' focus on maximising yields on increasingly degraded and disturbed soils makes them more dependent on the intensive and increasing use of external inputs to boost productivity, manage diseases and control pests, which, in turn, leads to further degradation, the sterilisation of the soil, and increased land requirements.[11-13] To combat this vicious circle of yield maximisation that requires high external inputs and leads to degradation that requires further external inputs to secure the yields, prudent or virtuous alternatives are required. These sought after virtuous alternatives must enable farmers to both adapt to climate variation and restore the land, while reducing the cost of production and upholding yield (Table 1).[14-19]

Conservation and regenerative agriculture (CA/RA) has been proposed as one such alternative and virtuous production system.[20,21] CA/RA systems have gained much ground, mainly due to their long-term ecological and economic benefits.[22-27] CA/RA is, however, not a recipe, but an approach embedded in five principles and practices: minimum soil disturbance, maximum cropping diversity, permanent organic soil cover, maintenance of a living root for as long as possible, and integration of livestock.[28,29] Although CA/RA has gained momentum, the relative success, feasibility and applicability of the system are still debated.[30-32] Questions have been raised about (1) the

Table 1: Advantages and disadvantages of alternative farming systems in South Africa

	Advantages (benefits)	Disadvantages (costs)
CT	High yields (crop maximising). Ensures sufficient food production. Provides substantial revenue levels year-on-year.	Loss of soil organic carbon, leading to an increase in soil degradation and compromised soil health. Increased soil erosion, soil structure breakdown, acidification, and compaction. Loss of soil nutrients. High dependence on the use of fertilisers and chemicals. Loss of biodiversity, and a decline in water quality and quantity. Overall alteration of on-farm ecosystem functions and services. Reduced farm capacity to respond to environmental challenges, resulting in elevated impacts of environmental challenges. Increased risk of reduced crop productivity. Increased costs of production. Reduced profitability. Increasing rates of debt-repayment defaulting. Extra fuel costs due to additional passes over fields.
NT	Prevention of soil erosion and moisture depletion. Reduction of weed pressure and water loss. Improved soil aggregation, structure, aeration, infiltration, drainage, and nitrogen. Increased crop yields. Less greenhouse gases, time, and labour requirements. Improved energy efficiencies. Increased soil organic carbon. Reduced capital and operating costs.	Lower climate resilience. Limited soil organic carbon and soil restoration. Higher risk of possible crop failure or impaired crop production in adverse weather conditions. Possible reduced income.
CA/RA	Minimum soil erosion, compaction, pollution, and disturbance. Improved infiltration, water holding capacity and drought resilience. Improved soil aggregation, fertility, health, and nutrient cycling. Increased input use efficiency, atmospheric carbon drawdown, and soil organic carbon. Enhanced crop productivity and productive capacity. Long-term sustained yields and soil quality. Reduced capital, maintenance, and replacement costs. Improved farm profitability. Overall reduction in risk. Additional medium- to long-term economic gains. Strengthened financial position and sustainability. Higher levels of climate resilience and adaptation.	A high initial livestock investment is required for soil restoration. Other additional financial expenses when introducing the principles of CA/RA, such as a no-tillage planter and cover crops in a crop rotation. Short-term profitability may decline. The time-lag effect (J-curve) on the benefits during the transition phase. The financial viability of cover crops. Associated trade-offs (lost/forgone cash crop revenue). Possible failure to successfully implement and manage the new system is often due to lack of resources, knowledge, and skills (knowledge- and management-intensive). Perceived risk of impaired crop and financial performance due to farm managerial competencies.

lack of evidence with respect to a detailed financial analysis that quantifies the real costs and benefits of adopting or switching to CA/RA, and (2) the perceived risk and uncertainty associated with the adoption of CA/RA due to its relatively high initial costs and management ambiguities. In light of this, the objectives of this study were the following:

- To evaluate the financial implications (costs and benefits) of adopting the CA/RA systems relative to both conventional tillage (CT) and no-till (NT) systems.
- To assess the short-, medium- and long-term risks associated with both the adoption and non-adoption of CA/RA, and what implications these have on food security and the food system.

Given these objectives, an answer to the following question was sought: Is CA/RA the more financially desirable management practice when compared to its alternatives, namely CT and NT? We sought to address this question by employing an Excel-based financial modelling approach using primary data for the three production systems (CA/RA, CT, and NT) from six fully statistical trials from three different summer rainfall grain production regions in South Africa. Herein, we do not argue for or against CA/RA's claims with respect to its environmental benefits or its superior ability to adapt to climate change and other challenges. We seek to provide insights into the short-, medium- and long-term financial performance of the three crop production systems over a 20-year period.

Materials and methods

Site description

Data from six on-farm trials in summer grain crop production areas in South Africa has been used. These areas are the Mpumalanga Highveld area (three trial sites), the Maluti area in the eastern Free State (two trial sites), and the North West Province (data from one study group and one trial) (see Figure 1). The latter data were collected by the Delareyville study group in cooperation with Noord-Wes Koöperasie (NWK), a local farmers' cooperative, as well as an on-farm trial done in collaboration with the Ottosdal No-till Club. All the on-farm trials were implemented through the CA Farmer Innovation Programme (FIP) with funding from The Maize Trust and coordination by ASSET Research.[33]

The three regions lie in the summer grain crop production area of South Africa with average annual rainfall varying between 500 mm (in the west) and 900 mm (in the east). Daily maximum temperatures during the growing season are frequently above 20 °C, especially in the west. Rainfall in these areas typically occurs in the form of thunderstorms with frequent long dry spells in between. The arable soils in these crop production areas vary considerably. However, deep, well-drained sandy soils dominate in the dryer western parts, while shallower sandy-loam soils dominate in the wetter eastern areas. These soils naturally have low soil organic carbon (SOC) content of between around 1% in the west and 2% in the east. The average SOC level in soils under annual cropland in SouthAfrica has been reduced by 46% due to tillage[34], and combined with bare fallow tilled fields, the soils are extremely susceptible to erosion, leading to average long-term soil loss rates from water erosion of 13 tonnes/ha/year under annual grain crops[35]. This is about equivalent to 3 tonnes of soil lost for every tonne of maize produced per year.

On-farm trials as the basis for innovation platforms and modelling

The on-farm trials were conducted for the 2020/2021 and 2021/2022 production seasons during which the three dominant farming systems discussed above, namely CT, NT and CA/RA, were compared. The basic description of the trial design and treatments at the sites, inclusive of the crop rotations followed, are shown in Table 2.

Data collection

Trial data were collected on production income and input costs (expenditure) as per the typical production budget. These data were used to calculate various financial indicators, such as the gross and net margins of cash crops, cover crops and livestock production (see Table 3). Grain yield was determined per farm by the farmer using combined harvesters with digital yield report equipment, dividing the total kg of grain by the distance or area

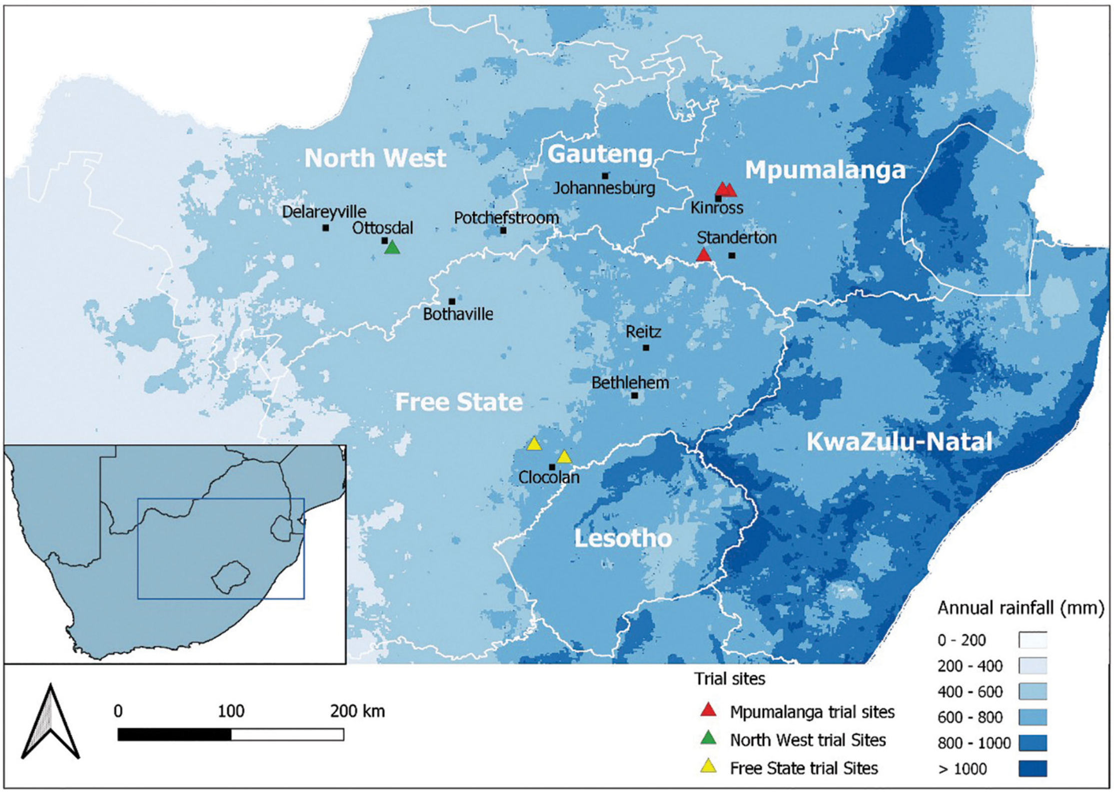

Figure 1: Map of the on-farm trial sites in the study.

Table 2: Farming systems definitions and region-specific crop rotation systems used in trials

System	Definition	Type	Crop rotation system	
			Mpumalanga Highveld and Maluti Eastern Free State	North West
Conventional tillage (CT)	Employed various primary and secondary tillage practices before planting with simple crop rotations and livestock grazing on the grazing lands (veld) only.	Mixed system with livestock not integrated.	Maize and soya	Maize and sunflower
	Increased use of pre- and post-emergence herbicides for weed control and the planting of a clean seedbed.			
	High rates of fertiliser use.			
No tillage (NT)	Employed no-tillage planters with simple rotations, and livestock grazing on the grazing lands (veld) only.	Mixed system with livestock not integrated.	Maize and soya	Maize and sunflower
	Chemical weed, pest, and fungus control.			
	High rates of fertiliser inputs.			
Regenerative conservation agriculture (CA/RA)	Employed no-tillage practices with a more complex crop rotation system (integrating cash crops with cover crops), while livestock is used intensively in both the grazing area and croplands.	A fully integrated crop-livestock system with seasonal rotations.	1. Maize + WCC intercropping	1. Maize + WCC intercropping
	Decreasing chemical control of weeds, pests and fungi and increasing use of bio-stimulants and bio-foliar.		2. SCC + WCC (double cover crop)	2. SCC + WCC (double cover crop)
	Decreasing use of fertilisers.		3. Soya + WCC intercropping	3. Sunflower + WCC intercropping
			4. SCC + WCC (double cover crop)	4. SCC + WCC (double cover crop)

Note: SCC is a summer multi-species cover crop mixture; WCC is a winter cover crop mixture or grains.

Table 3: An outline of the income and expenditure data collected from the trials

Data collected		Sources of information
Income	Cash crops: sale of crops	Grain SA, Trial and Delareyville study group data
	Livestock related: grazing crop residue and grazing cover crop income	Trial data
Operating expenditure	Cash crops: fertiliser, lime, foliar application, seed, inoculant, fuel, herbicide, insecticides/fungicide, marketing costs, repair and maintenance, interest on production credit	Grain SA, Trial and Delareyville study group data
	Cover crops: fertiliser, seed, fuel, herbicides, repair and maintenance, interest on production credit	Trial and Delareyville study group data
	Livestock: veterinarian costs, licks, and other expenses	Trial data
Capital expenditure	Tractors, planters and harvesters	VKB and trial data
	Trailers, tillage implements, sprayers and lime distributors	VKB and trial data
	Livestock: buying cattle for higher grazing intensities on cover crops and pasture	Trial data
	Other	VKB

Sources: The South African grain producer's organisation, Grain SA[36] | CA Farmer Innovation Programme trials | The local farmers' cooperatives VKB (Vrystaat Koöperasie Beperk) and NWK (Noord-Wes Koöperasie) | The Delareyville study group. Income and operating expenditure data for CT, NT and CA/RA were obtained for two seasons, 2020/2021 and 2021/2022, for the Mpumalanga and Maluti regions, and only one season 2020/2021 for the North West region. Capital expenditure data was for the 2020/2021 financial period and varied per type and number of implements required by each farm (on which a trial was implemented) for all three farming systems and regions.

covered. All modelled yields were verified against the farm's long-term averages. Grain income per ton was derived from SAFEX rates at the time of harvest minus a standardised fee for grain handling and storage. Additional income from livestock through grazing of crop residues and cover crops was derived from farm-collected production data, that is, dry matter (DM) yield of the cover crop, feed use efficiency and feed conversion ratios to determine kg of meat produced per ha multiplied by meat prices for the type of animal (i.e. beef, sheep) used. All farm expenditure was discussed and verified with the trial farmers based on their commercial enterprise experience. Actual costs were used for fertiliser, herbicide and pesticide rates applied, multiplied per unit cost as per that season's farm expenditure sheets. Diesel prices would fluctuate during the season; therefore, one annual rate was used, based on the farmer's price per litre of diesel. All commercial farmers are granted a lower diesel price than consumer pump prices due to bulk purchases. All farm equipment (mechanisation) passes are described per system. The diesel use per pass is based on the actual cost per farm, based on farmer experience. The diesel used per farm per pass can therefore differ per trial (and mechanisation tables) depending on the type of equipment and farm conditions. Farm expenditure included all variable input costs. Overhead costs were obtained per farm and verified per farming system (CA/RA, NT, and CT). Overhead costs differed per farm and comprised administration, land purchase and labour costs.

Model assumptions

Uniform assumptions

The Microsoft Excel-based financial cost-benefit model used the above trial design and data to calculate and compare a range of financial indicators for all the production systems at the six trial sites, most notably the cumulative free cash flows (CFCFs) (after taking into consideration loan settlements and the value of livestock at the end of the modeling period) and the average free cash flow/ha in real terms (AFCs). CFCF is defined as cash flow that is available to shareholders (the owners) of a company and is free of any claims from other stakeholders. The macro assumptions (see Table 4) have been kept uniform for all three production systems.

In addition to these macro assumptions (Table 4), we kept the production per production area and crop uniform (Figure 2). These are based on the averages obtainable in each production region. For cover crops, additional tonnes of biomass from both intercropping and double cover cropping were included. Unlike cash crops, covered crop biomass (yield) was included only under the CA/RA production system.

Production system-specific assumptions

Three sets of production system-specific assumptions were necessary. These relate to the cover crop utilisation, the efficiency of the major production inputs (fertiliser, herbicides, and pest control), and the capital replacement period of each. In addition, to allow for system-wide variation under the CA/RA system, optimistic and conservative scenarios were considered. These assumptions are as follows:

1. Intercrop utilisation
    - Zero for CT and NT
    - CA/RA
        - *Optimistic scenario:* based on regional average biomass (Figure 2).
        - *Conservative scenario:* reduced to accommodate internal and external conditions that might affect the planting, growth cycle and yield of cover crops. In the Mpumalanga region, maize intercrop and soya intercrop yields were reduced from 2 tons each to 1.2 and 1.5, respectively; in the Maluti region, these were reduced to 0.7 and 1, respectively, while for the North West these were reduced to 1 and 1.5 tons, respectively. Utilisation rates were not changed but kept the same as in the optimistic scenario (DCC = 50%, SCC = 50%, WCC = 70% and IC = 70%).
2. Cover crop utilisation:
    - Zero for CT and NT
    - CA/RA:
        - *Optimistic scenario:* based on regional average biomass (Figure 2).
        - *Conservative scenario:* reduced to accommodate internal and external conditions that might affect the planting, growth cycle and yield of cover crops. In the Mpumalanga and Maluti regions, SCC and WCC yields were reduced to 6 and 1.5 tons, respectively, while in the North West, these were reduced to 10 and 1.5, respectively. Utilisation rates were not changed but kept the same as in the optimistic scenario (DCC = 50%, SCC = 50%, WCC = 70% and IC = 70%).

Table 4: The macro assumptions used in the model kept uniform for all the production systems

Categories		2020/2021	2021/2022	Source
Selling prices of crops (ZAR/t, after 10% marketing commission)	Maize	ZAR2 731.56	ZAR3 369.20	SAFEX[37]
	Soya	ZAR7 423.86	ZAR6 678.48	
	Sunflower	ZAR7 168.41	-	
Selling prices of cattle (ZAR/kg)	200 kg class weaners	ZAR47.98	ZAR53.94	Red Meat Producers' Organization prices[38]
	C class cows or bulls	ZAR41.85	ZAR47.98	
Unit price of cattle	Cow	ZAR15 000 and ZAR50 000	ZAR15 000 and ZAR50 000	Assumption
	Bull			
Inflation	Cost	6%	6%	Statistics South Africa CPI History[39]
	Revenue	5%	5%	
Discount rate		7%		Assumption
Biomass production from veld and permanent pasture in tonnes of dry matter per hectare (tDM/ha)	CT and NT	3 t DM/ha at 40% utilisation rates throughout		Assumption
	CA/RA	3 t DM/ha at a 65% utilisation rate in year 4, which was incrementally phased in from 40% in year 1 (per CT and NT)		Assumption
DM required as a percentage of body weight		2.70%		Assumption
t/DM/year/livestock unit (LSU) (LSU = 450 kg)		4.4 t		Assumption
Fertility rate (calves weaned per cow in the herd)		75%		Assumption
Mortality rate		2%		Assumption

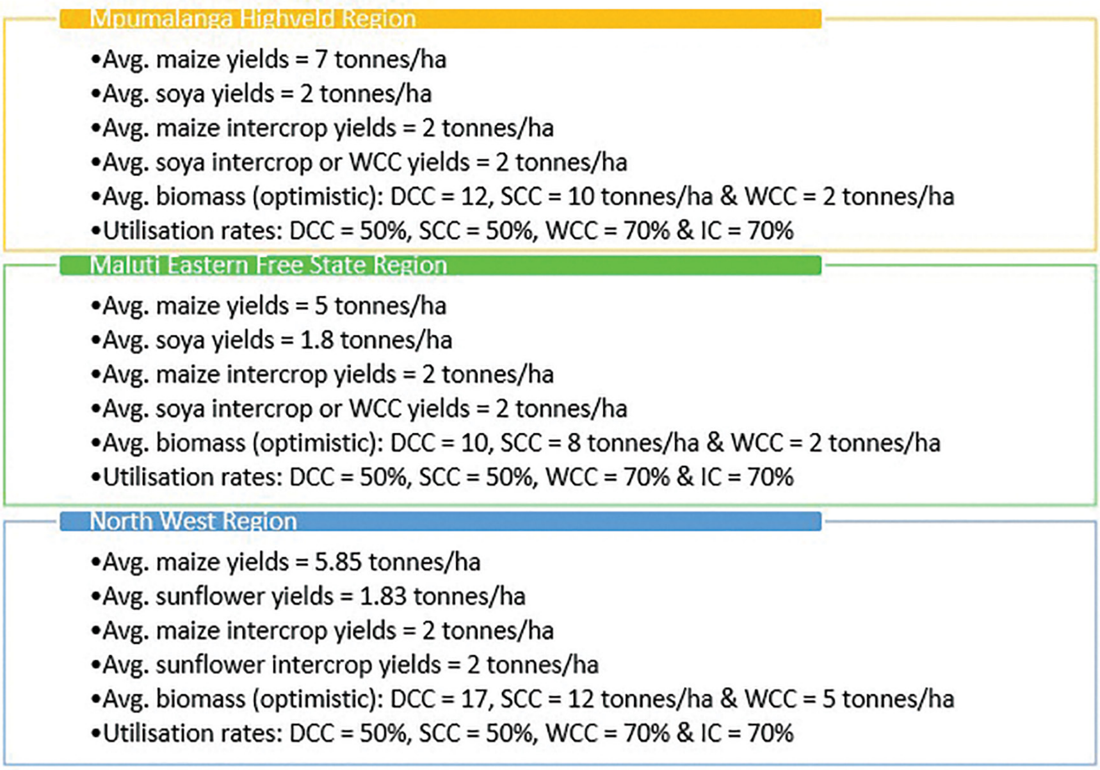

Figure 2: Cash, intercrop and cover crop production and utilisation assumptions; kept uniform for all production systems.

3. Input efficiency (fertiliser, herbicides and pest control):
   - CT: 0.5% increase in input volume required per annum, adding up to an overall 110% input requirement by year 20.
     - This assumption is because tillage will continue degrading the soil's fertility, which will require increasing amounts of synthetic fertilisers.[40,41]
   - NT: kept constant at 100% of the initial input volume requirement.
     - This assumption is because, while no-till systems do not lead to physical soil degradation, they also do not lead to an adequate restoration of soil health and fertility, lacking crop diversity, biomass, and livestock integration.[42-44]
   - CA/RA:
     - *Optimistic scenario:* Kept constant at 100% of the initial volume required during the first 4 years for Mpumalanga and Maluti (5 years for the North West), followed by a 10% annual decrease in volume for the next five years, and stabilised at 50% of the initial requirement thereafter.
     - *Conservative scenario:* Kept constant at 100% of initial volume required during the first 4 years for Mpumalanga and Maluti (5 years for North West); followed by a 5% annual decrease in volume required for the next 10 years; stabilising at 50% of the initial requirement thereafter.

       This assumption is based on sufficient evidence that fully integrated crop-livestock CA/RA systems lead to the restoration of soil health, increased natural fertility and, hence, the reduction of required synthetic fertiliser quantities.[45–47]
4. Capital replacement period:
   - Every 5 years for CT and every 8 years for NT
   - CA/RA:
     - *Optimistic scenario:* every 8 years
     - *Conservative scenario:* every 7 years

       This assumption was based on data from VKB, farmer co-workers, and justified by the reduced number of passes and implements (units) in the NT and CA/RA systems.[45] The conservative scenario is to accommodate the additional planting and harvesting of cover crops that is not applicable in the NT systems.

The modelling exercise, which ran over a period of 20 years, started with all the production systems on the same level, implying that they all had to incur the necessary costs (operating and capital) unique to each right at the start.

Results

We analysed the above-stated question of whether CA/RA is the more profitable practice compared to CT and NT in two ways. First, by observing the financial performance of each system by means of a year-on-year system-specific analysis of the average discounted free cash flow in real terms (AFC) (R/ha) and overall net benefit or cost (loss) achievable in each system. Figure 3 illustrates the region-specific AFCs/ha over 5-, 10-, 15- and 20-year periods to provide a regional overview of how each system performs on average. It should be noted that all cost values are inflated by 6% and all revenue values by 5%, as defined in Table 4. This implies a marginal reduction in nominal cash flows only offset by possible production changes, as highlighted above. To compare the results, we calculated real cash flows using a discount rate of 7%. Aside from any productivity gains, a declining trend in all the AFCs is thus to be expected. Second, we compared the relative financial performance of the three different systems over the long term (20 years) by means of cumulative free cash flows (CFCFs). Finally, the results were broken into a financial analysis of the cost of major production inputs, total costs of production, revenue from crop and cattle production, and debt uptake.

A comparative analysis of the average discounted free cash flow in real terms of various summer grain production systems

The AFC/ha under the CT system in Mpumalanga declined significantly from about ZAR1 960/ha in year 5 to -ZAR900 in year 20 in real terms (Figure 3). The AFCs/ha under the NT system is relatively constant for the first 10 years at approximately ZAR2 200/ha, but then declines to about ZAR560/ha in real terms by year 20 due to cost-push effects. Both the optimistic and conservative scenarios of the CA/RA systems behave differently, following an inverse trend. The AFC at year 5 ranges between ZAR900/ha and ZAR2 760/ha, peaking at almost ZAR3 600/ha in year 10, and settles between ZAR1 130/ha and ZAR3 100/ha in real terms in year 20. There are, therefore, no negative cash flows over time in real terms despite the cost-push effects. The results in both Maluti and the North West (Figure 3) mirror those in Mpumalanga, albeit at a marginally lower level in Maluti. In the North West region, CT indicates longer periods of positive returns for the CT system than Maluti and Mpumalanga.

A comparative analysis of the CFCFs of various summer grain production systems

The CFCFs of the various production systems in the three areas are shown in Figure 4. There is a consistent trend across the three regions of high initial free cash flow accumulation under the CT production system that, over time, becomes an accumulated negative cash flow. The CFCF of the NT and conservative CA/RA scenarios track each other in most cases, with the CA/RA scenario slightly higher than the NT in Mpumalanga but lower in the North West and virtually the same for the Maluti region. The CFCFs of the optimistic scenario are at a much higher level in all cases. Despite this, the pattern of the CFCF follows what is known as the investment curve, also known as the J-curve. This curve indicates an initial decline in free cash flow for a period, whereafter it takes an upward turn, cumulating net positive cash flow. The results are summarised in Table 5. The average of the two CA/RA systems in year 20 is considerably higher than that of all the other systems for all three production areas. For example, the CFCF in year 20 for Mpumalanga is estimated to be ZAR86 million, compared to -ZAR51 million for CT and about ZAR4 million for NT. That is a net difference of between ZAR137 million when compared to CT and ZAR82 million compared to NT. The smallest difference is compared to the NT system in the North West of ZAR14 million. These differences represent the financial opportunity cost of not converting to CA/RA systems. No additional economic benefit with respect to any possible environmental benefit has been included.

A comparative breakdown of the cost, revenue and debt uptake of various summer grain production systems

Considering the total direct allocated variable cost (TDAVC) (ZAR/ha), Table 6 shows that, over the 20-year period, CT had the highest % growth rate followed by NT, while CA/RA have the lowest growth rate. The total cost of the four major production inputs also shows the same trend as the TDAVC/ha with fertiliser and herbicides as key drivers.

CT generated the highest total revenue from crop production throughout the 20-year period, followed by NT, while CA/RA generated the lowest crop revenue. However, the opposite is observed for total revenue from cattle production, where both CT and NT generate the lowest revenue relative to CA/RA, which has the highest revenue at an exponential rate. Figure 5 shows the total net accumulated cattle and crop revenue. Of the three systems, CA/RA requires the most initial cattle investment (J-curve) throughout the period.

In terms of debt (loan repayments and finance costs), CT incurred the highest uptake over the period (shown by a steep upward trendline), followed by NT, while CA/RA incurred the lowest uptake. The same was observed for wear and tear (see Figure 6).

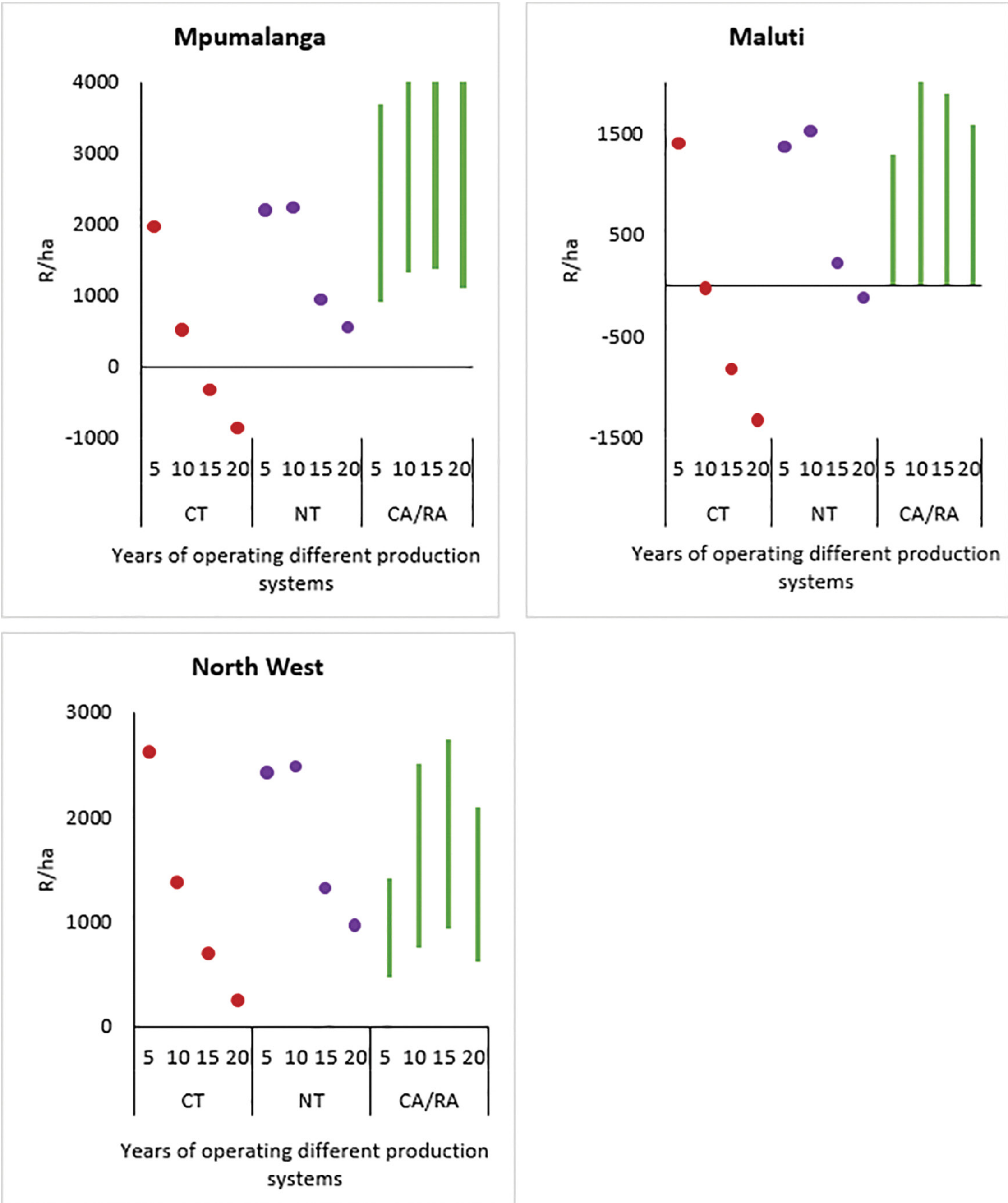

Figure 3: Mpumalanga Highveld, Maluti Eastern Free State, and North West – average free cash flow per ha in real terms (AFC/ha) over four different periods; the most plausible range for CA/RA has been indicated as a bar with the lower end reflecting the conservative value and the upper end reflecting the optimistic value.

Discussion

The results indicate that, in the short term (5 years), CT had the highest average free cash flow in real terms on a per-hectare basis, followed by NT with CA/RA producing the lowest returns on investment. In the long term (10–20 years), the opposite is observed, wherein CT produced the highest losses, followed by NT, while CA/RA produced the best return on investment. These results are consistent across the three regions, with minor variations.

Short-term financial implications of CT, NT and CA/RA production systems

The high initial gains under the CT system might be due to: the continued high cash flow generated from crop production (Figure 5); the absence of additional investments required for extra cattle (Table 7); and relatively lower finance costs for the farm (Figure 6) and loan repayments toward additional cattle and infrastructure investments at the start of the period (Figure 6). Similar reasons apply for the high initial gains under NT farming. These positive returns, however, accrue for a relatively longer period than CT due to: relatively lower operational costs incurred through the years, resulting in prevailing cost savings; delayed capital replacement costs; and additional ecological benefits that translate into significant economic value to NT farmers and their operations (Tables 1 and 6).[10,43,45,48] Contrariwise, the initial negative return (financial dip) observed under the CA/RA system is consistent with the general understanding in literature that farmers often experience an additional financial expense when introducing the principles of fully integrated CA/RA systems.[49,50] The results of this study confirm that the main factor contributing to the initial dip relates to the additional livestock investment required as a

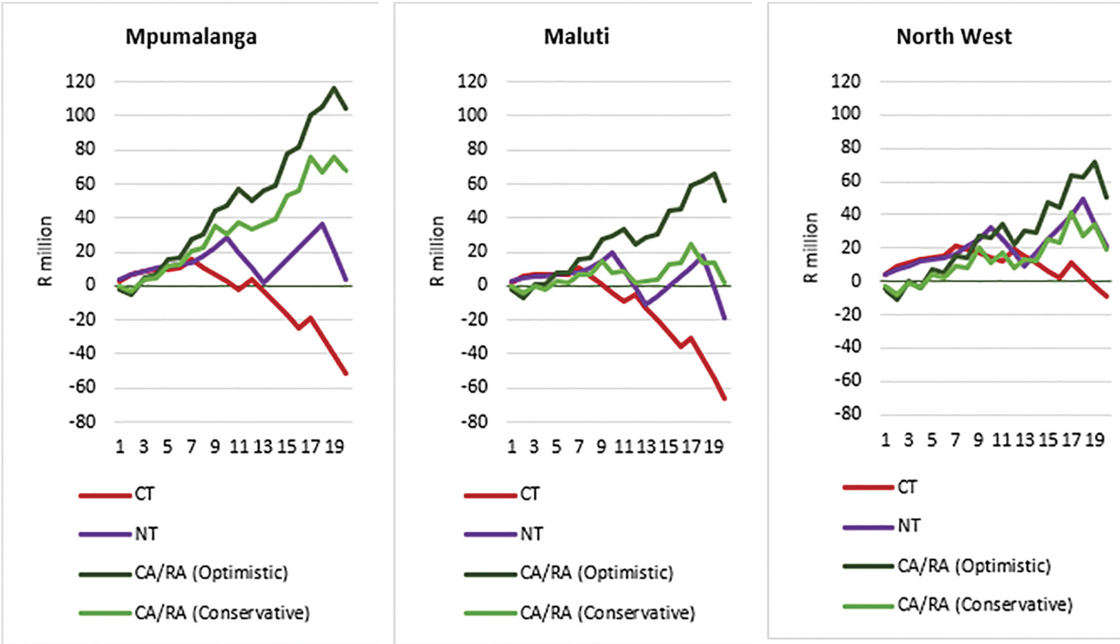

Figure 4: Cumulative free cash flows of the three regions over a 20-year period under CT, NT and CA/RA.

Table 5: Cumulative free cash flow (CFCF) in year 20 for three production systems in three regions

	CFCF (ZAR millions) in year 20			Difference (ZAR millions) between CA/RA and CT or NT	
	CT	NT	Average CA/RA	CT	NT
Mpumalanga	–51.11	4.17	86.29	137.40	82.12
Maluti	–65.61	–18.74	25.60	91.20	44.33
North West	–9.26	20.84	35.27	44.53	14.43

Table 6: Total direct allocated variable cost (ZAR/ha) and total of four major inputs % difference over the 20-year period for three production systems in three regions

		Mpumalanga		Maluti		North West	
		Maize (year 1 vs year 19)	Soya (year 2 vs year 20)	Maize (year 1 vs year 19)	Soya (year 2 vs year 20)	Maize (year 1 vs year 19)	Sunflower (year 2 vs year 20)
Total direct allocated variable cost (ZAR/ha)	CT	240%	195%	221%	193%	192%	193%
	NT	237%	185%	212%	185%	185%	185%
	CA/RA OPT	119%	151%	135%	143%	131%	130%
	CA/RA CSV	119%	151%	135%	143%	130%	128%
Total of four major inputs (fertiliser, fuel, herbicide and pest control)	CT	261%	201%	249%	200%	200%	199%
	NT	249%	185%	233%	185%	185%	185%
	CA/RA OPT	42%	98%	117%	88%	62%	69%
	CA/RA CSV	42%	98%	117%	88%	62%	69%

tool for soil restoration at the start of the period (Table 7). During the initial transition period, the incorporation of double-cover crops in the crop rotation system resulted in forgone cash crop revenue (Figure 5), while the average free cash flow of crops was still high.[51] This situation changes after the transition period because the integration process has an associated time-lag effect wherein (1) the financial benefits (i.e. the reduction in inputs) of the additional financial investment and spending (on cattle) are not immediate but are dependent on the restoration process[46]; and (2) the average free cash flow of cropping under CT drops due to increasing volumes and costs of total direct allocated variable and capital costs.[52]

Medium- to long-term financial implications of CT, NT and CA/RA production systems

Looking at the CT results, the main contributing factors to this medium- to long-term decline in both AFCs/ha and CFCFs include the (1) year-on-year increase in the volume and cost of **major production inputs** (fertiliser,

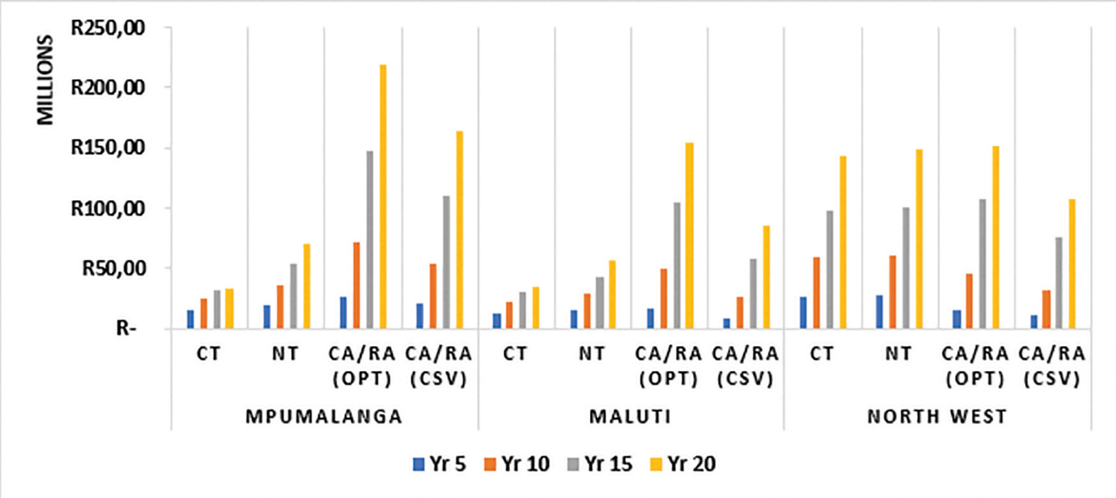

Figure 5: Cumulative net cattle and crop production revenue over a 20-year period under CT, NT and CA/RA.

Table 7: Cumulative cattle investment (purchase cost) over a 20-year period under CT, NT and CA/RA over the 20-year period for three production systems in three regions

		Year 5	Year 10	Year 15	Year 20
Mpumalanga	CT	ZAR399 575	ZAR853 734	ZAR1 261 540	ZAR1 980 974
	NT	ZAR399 575	ZAR853 734	ZAR1 261 540	ZAR1 980 974
	CA/RA (opt)	ZAR13 977 813	ZAR30 028 958	ZAR43 500 557	ZAR70 235 739
	CA/RA (csv)	ZAR9 304 375	ZAR20 064 482	ZAR29 013 629	ZAR46 808 561
Maluti	CT	ZAR399 575	ZAR853 734	ZAR1 261 540	ZAR1 980 974
	NT	ZAR399 575	ZAR853 734	ZAR1 261 540	ZAR1 980 974
	CA/RA (opt)	ZAR12 024 313	ZAR25 651 184	ZAR37 066 885	ZAR59 805 635
	CA/RA (csv)	ZAR6 095 313	ZAR13 530 224	ZAR19 743 294	ZAR32 039 486
North West	CT	ZAR420 031	ZAR920 742	ZAR1 370 347	ZAR2 163 524
	NT	ZAR420 031	ZAR920 742	ZAR1 370 347	ZAR2 163 524
	CA/RA (opt)	ZAR19 723 785	ZAR44 274 753	ZAR64 760 792	ZAR105 316 725
	CA/RA (csv)	ZAR13 835 342	ZAR31 192 527	ZAR45 648 786	ZAR74 148 590

herbicides, pest control and fuel/diesel) required due to declining soil health (Table 6); (2) an overall excessive rise in the farmer's cost/ha before marketing costs (Table 6a); (3) expensive capital replacement costs (every 5 years); (4) high wear and tear expenditure (Figure 6), (5) the recurrent debt uptake for mechanisation through high loan repayments and finance costs (Figure 6) – all lead to the decline in AFCs/ha. The magnitude of this decline, however, is also largely influenced by the negative impacts associated with CT practices (Table 1).[51,53-55] Apart from the positive start in NT results, the results also indicate a downward trendline in the longer term that varies in magnitude of losses across the three regions. This finding supports the existing argument that the success and performance of NT is to some extent in contexts, regions and climate-specific and can be limited (Table 1). The potential additional cattle revenue forgone under both CT and NT systems also adds to the gap in the performance of the two systems relative to CA/RA (Figure 5).

Likewise, as the ecological functions and services are restored and the benefits associated with the CA/RA system accrue (Table 1), farmers start to accumulate positive financial returns on their investment (indicated by the turning point of the J-curve). These positive returns are mainly driven by the gradual reduction in the volume cost of major inputs required and the overall cost of production (Table 6). Prevailing benefits such as sustained crop productivity and long-term yields also contribute to positive returns through a year-on-year increase in crop revenue, while the benefit of additional biomass contributes to a year-on-year increase in livestock revenue (Figure 5). Significantly low loan repayments, finance costs and wear and tear (Figure 6); altogether, farm profitability increases, which strengthens the financial position and sustainability of CA/RA farmers and their farming operations.[10,41] These positive returns are sustained through the medium- to long-term period and can be observed by the upward/positive trendline after the transition period. Although the long-term upward trendline in the CA/RA system is not smooth but fluctuating (yet positive), this can be attributed to the machinery replacement cycle and the recurring double cover crop with livestock rotation included in the model configuration. When replacement takes place, free cash flow is severely compromised; and when cover crops are in rotation, the revenue from cover crop and livestock on certain fields is lower than on fields with cash crops.[2,56] It is from this premise that the debate around the financial viability of cover crops and associated trade-offs occurs.[57,58] In this case, farmers need to consider the long-term ecological benefits of cover crops and the economic value they add to the whole farming operation.

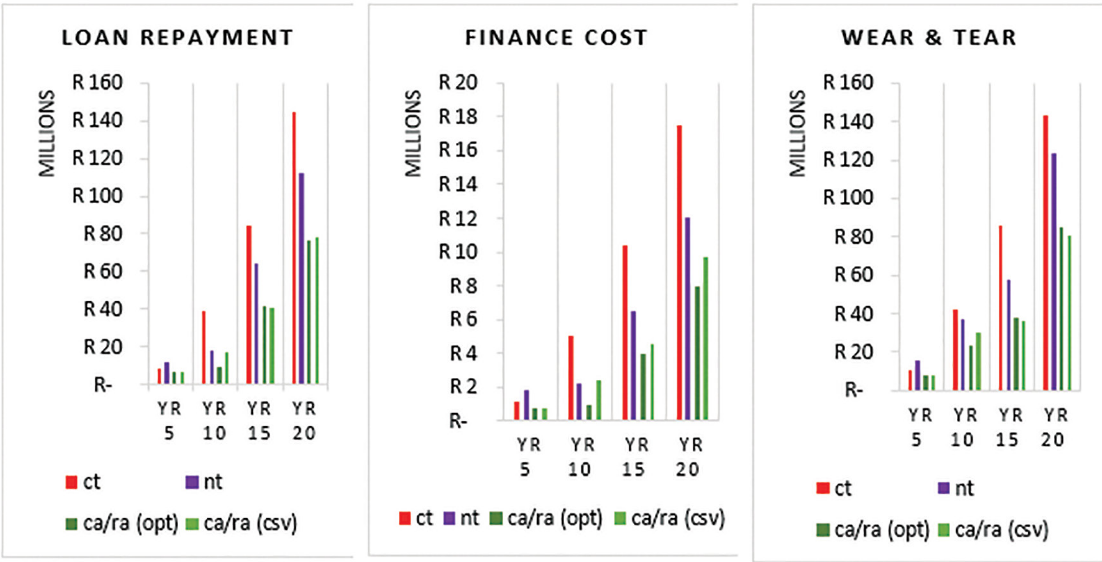

Figure 6: Cumulative debt uptake and wear and tear over a 20-year period under CT, NT and CA/RA.

Conclusion

The agricultural sector is in dire need of transformation and regeneration. The challenge of feeding a growing population will continue to increase with negative environmental impacts, variable climate conditions, rising external production costs and limited land.[59,60] This, in addition to rising costs of production and farm debt uptake, a growing area under production but reduced productivity and declining number of farmers in South Africa. Farmers must start to incorporate sustainable principles geared toward climate change mitigation and adaptation, and if the adoption process is not accelerated, those lacking proper adaptation will quickly reach even higher levels of risk and unprofitable farming operations. Those who have adopted a NT farming system have already started to improve both the physical and biological characteristics of soils. However, this study emphasised the need to transcend the limitations of pure NT systems to a better alternative that will make more significant and lasting changes to soil properties, enhance yield sustainability and safeguard farm profitability. It further showed that CA/RA can relieve farmers of enormous financial risk that has the potential to grow exponentially over the medium to long term by prioritising the restoration of soil and ecosystem goods and services. Various studies have proven that CA/RA can reduce a farm's heavy reliance on expensive inputs, offer significant cost savings and loss-avoidance, and provide supplementary profit-generating opportunities through additional livestock and feed revenue. The results of this study also corroborate existing studies by providing evidence-based support that indicates that, relative to CT and NT, CA/RA offers the best/maximum return on investment in absolute terms, and even more so on a risk-adjusted basis.

As such, this study supported the message that (1) there are sound strategies to successfully navigate through the transition period when adopting and adapting to CA/RA; (2) active farmer networks and support by sharing past knowledge and experiences of success stories can contribute significantly to the inspiration and guidance of farmers starting this new journey; and (3) often NT and CA/RA practices have less total risks than CT if applied correctly (sometimes even in the short term but especially in the long term when taking into consideration the impact of future possible drought conditions among other expected climate variations and extremes). Granting that different conclusions can be drawn from the relevant information available, the reality remains that short-term needs must be balanced with long-term environmental, food and financial sustainability. The existing body of work implores policymakers to consider this reality because the ultimate decision to encourage the adoption of or conversion to CA/RA is centred on their perception of how such a move will alter their overall business risk.

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Data availability

Data pertaining to this study are available on request and can be found at https://assetresearch.org.za/conservation-agriculture/.

Declaration of AI use

We declare that we have not used AI tools in the preparation of this manuscript.

Authors' contributions

M.M.: Conceptualisation, methodology, data collection, data analysis, validation, data curation, writing – the initial draft, writing – revisions, project leadership, project management. N.v.S. Conceptualisation, methodology, data analysis, validation, data curation, writing – revisions. A.d.B.: Conceptualisation, writing – revisions. H.S.: Conceptualisation, methodology, data analysis, validation, data curation, writing – the initial draft, writing – revisions, project leadership, project management. J.B.: Conceptualisation, methodology, data analysis, validation, data curation, writing – the initial draft, writing – revisions, project leadership, project management. J.K.: Conceptualisation, data collection, data analysis, writing – revisions. G.T.: Conceptualisation, data collection, writing – revisions. L.E.: Conceptualisation, data collection, writing – revisions.

Competing interests

We have no competing interests to declare.

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