Holistically Examining the Environmental and Economic Benefits of Conservation Agriculture Adoption in the South African Wheat Production: A Stepwise Life Cycle Analysis Approach

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BACKGROUND

- Conservation agriculture (CA) has been shown to reduce soil erosion and increase soil health and fertility globally (Lal, 2015).
- In the Republic of South Africa (RSA), CA practices has increased amongst commercial wheat producers in an effort to mitigate the increased frequency and intensity of drought and heat stress.
- The Western Cape province accounts for 60% of RSA wheat production and has the country's highest CA adoption rate of 51%.
- CA is endorsed by the African Research Council ARC in rainfed wheat farming in response to increased precipitation variability and soil degradation (Patose and Ncala, 2020).
- CA has the potential to increase wheat yields and profit, reduce soil erosion, and improve water quality and soil health.
- Two CA systems are prevalent in Western Cape:
  - **No-till** which uses a knifepoint opener for seeding and
  - **Zero-till** which uses a disc, also know as low disturbance non-till.
- While economists recognize the environmental benefits of CA we often fail to monetize its value, thus undervaluing its true benefits

OBJECTIVES

- Monetize the environmental benefits from switching from conventional to CA wheat production in Western Cape via a Stepwise Life Cycle Assessment (LCA) on a per hectare basis;
- Estimate the environmental damage total factor productivity (TFP) of commercial wheat production in Langgewens on a per hectare basis between conventional tillage and CA wheat production in Langgewens, Western Cape.

SUMMARY STATISTICS

Table 1. Summary of Production Data for Minimum and Zero Tillage Wheat Production (2002-2020).

Location/Tillage	Wheat yield (ton/ha)		Cost (2020ZAR/ha)		N
Tygerhoek	Mean	SD	Mean	SD	572
• No-till	3.61	1.00	4,511.79	677.24	
• Zero-till	3.37	1.52	4,425.46	568.59	
Langgewens					471
• No-till	3.43	1.02	5,454.89	1,276.34	
• Zero-till	3.30	0.83	5,237.61	2,094.73	

MATERIALS AND METHODS

- A data set was used consisting of 1,043 plot-level wheat observations collected on long-term trials run by the Western Cape Department of Agriculture in Langgewens and Tygerhoek from 2002 to 2020.
- Complete data include detailed input types and amounts as well as yield observations under zero-till and no-till.
- A stepwise LCA was implemented to monetize the cradle-to-farm gate environmental impacts of producing one ha of wheat under conventional tillage, zero-till and no-till wheat production with their respective input usage and yields.
- LCA software SimaPro 9.1.0.8. (PRé Consultants bv) and the Ecoinvent and Agri-footprint databases (Wernet et al., 2016; Durlinger et al., 2017) were used for the stepwise LCA
- Wheat profitability analyzed with @Risk (Palisade, Ithaca, NY)
- The net profit (NP) for wheat production was calculated as

$$NP_{ij} = TR_{ij} - TC_{ij} \quad (1)$$

where NP_{ij}, TR_{ij}, and TC_{ij} are respectively the simulated net profit per hectare, total revenue per hectare, and total cost per hectare in ZAR (South African Rands) of producing wheat under i^{th} practice (zero-till or no-till) in j^{th} site (Langgewens or Tygerhoek). TR_{ij} was obtained from $TR_{ij} = Y_{ij} * Average\ Price$ (2), where Y_{ij} the simulated wheat yield in ton per hectare under i^{th} practice (zero-till or no-till) at j^{th} site (Langgewens or Tygerhoek) was multiplied by the simulated average price of wheat in 2020ZAR per ton from 2002-2020.

- The total benefits (*TB*) in ZAR per hectare of switching from conventional wheat production to either zero-till or no-till production in Langgewens was calculated as

$$TB_{Langgewens} = \Delta NP_{Langgewens} + EB_{Langgewens} \quad (3)$$

where the difference in net profit (ΔNP) between conventional and zero-till or no-till is summed with the environmental benefits ($EB_{Langgewens}$) of switching from conventional to zero-till or no-till wheat production. The $EB_{Langgewens}$ is the difference in environmental externalities costs (LCA single score in ZAR per hectare) between conventional and zero-till or no-till wheat production.

- The change in ecosystem damage efficiency, described as the percentage change of monetized environmental damage to produce one hectare of wheat, was calculated as

$$Env.Efficiency = \frac{Env.D_{Conv} - Env.D_{CA}}{Env.D_{CA}} * 100 \quad (4)$$

where $Env.D_{conv}$ and $Env.D_{CA}$ are respectively, the environmental externalities costs (LCA) single score (2020ZAR per kg of wheat) resulting from conventional (*conv*) and zero-till or no-till (CA) wheat production.

- The conversion rate of USD to ZAR is 1 USD = 16.39 ZAR as of May 10, 2022.

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RESULTS

Table 2. Results of stepwise LCA with the resulting single score (2020ZAR/kg) by wheat production method.

	Langgewens				
	No-Till	Zero-Till	Conv*		
			Poor	*Average*	*Good*
Total environmental cost[a]	**0.887**	**0.646**	**2.919**	**1.796**	**1.374**
Respiratory inorganics	0.289	0.210	0.920	0.566	0.433
Global warming, fossil	0.524	0.383	1.769	1.088	0.832

* Conv = Conventional wheat production based on LCA inputs sourced from Knott (2015). Knott (2015) established three wheat yields scenarios based on rainfall seasonal variations: poor, average and good year with respectively 1.6, 2.6, and 3.4 ton/ha for conventional tillage wheat production in the Western Cape.

[a] While accounted in the single score, the other impacts categories represent less than 3.5% of the total damage.

- LCA single score results indicate that for every kg of wheat produced there was 0.89, 0.65 and 1.8 ZAR in ecosystems damage for No, Zero and Conventional tillage wheat, respectively.
- When switching from conventional wheat production to zero-till and no-till in Langgewens with a "good" conventional yield assumption, the environmental damage per kg of wheat produced is 53% and 35% more efficient, respectively (eq.(4)/Table 2). That is, CA is more efficient in producing a kg of wheat per unit (ZAR) of environmental damage than conventional tillage.

Table 3. Ecosystem benefits of complete adoption of zero and no-till wheat production in the Western Cape from conventional tillage practice

	Conventional Tillage	Zero-Till	No-Till
LCA single score[a]	1.37	0.65	0.89
Yield[b]	3.40	3.30	3.43
Total hectares needed for 2019 wheat crop[c]	261,882	269,785	259,751
Environmental cost for entire wheat crop (ZAR)[d]	1,223,147,398	575,429,247	789,986,076
Difference relative to conventional tillage (ZAR)	-	-647,718,151	-433,161,321

[a]From Table 2. [b]From Table 1. [c]Total output of 2018/2019 wheat crop in Western Cape was 890,400 MT. Thus, hectares needed is estimated by dividing total output by the mean yield of each respective tillage practice. [d]The product of the LCA single score, yield per hectare, and number of hectares needed for total WC crop.

- Assuming all of Western Cape's 2019 wheat production switched from conventional to CA, there would be a reduction of 647.7 and 433.2 million ZAR in environmental damage for zero and no-till production, respectively (Table 3).

CONCLUSIONS

- CA was found to be both more profitable and less damaging to the ecosystem than conventional tillage wheat production in the Western Cape.
- Based on the identified environmental cost of switching to CA, the government of Western Cape could invest in promoting CA and supporting commercial farmers to disseminate CA as it is more sustainable than conventional tillage.
- While producers will likely not receive payments for any of the ecosystem benefits they provide by switching from conventional to CA, the South African government could attempt to provide incentives for CA adoption in an effort to promote a sustainable wheat industry moving forward.