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Is Conservation Agriculture Viable in Namibia? A System Dynamics Model and Environmental Cost-Benefit Analysis

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ABSTRACT

Conservation agriculture (CA) has been touted as a means to increase resilience and conserve the environment. However, adoption of CA in Namibia has been slow. This study, therefore, evaluates the environmental and economic viability of CA using data from Mashare Irrigation Farm. An environmental cost-benefit analysis (ECBA) for maize and wheat production under four scenarios: conventional farming (CF) without (CF1) and with (CF2) environmental costs, and CA production farming systems without (CA1) and with (CA2) environmental benefits. A system dynamics model was developed with net present value (NPV) over 20 years (2023-2042) to assess the viability of the models. The study finds that although CA is financially viable in Namibia, it is only when environmental externalities (benefits and costs to the community) are incorporated that CA becomes preferable to CF. CF1 (conventional farming) produced an NPV of N$11.4 million, CF2 (CF with environmental costs) -$N52 million, while CA produced an NPV of $5 million (CA1) without environmental benefits, and N$51 million with environmental benefits (CA2). These benefits would be difficult to "sell" to farmers considering a switch, and a regulatory solution may be needed to facilitate the adoption of more sustainable farming practices.

Keywords: Conservation Agriculture, Irrigation, Namibia, System Dynamics, Cost-Benefit Analysis, Net Present Value, Wheat, Maize.

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1. INTRODUCTION

Conventional agricultural practices, such as traditional tilling, have long been perceived as unsustainable and environmentally damaging. Sanika (2021) describes conventional irrigated agriculture as an agricultural system that uses artificial chemical fertilisers, pesticides, herbicides, intensive tillage and intensive irrigation. Conventional agriculture requires greater use of chemicals and energy to achieve the highest crop yield. The goal of conventional agriculture is to achieve maximum crop yields through the use of chemicals and highly mechanised practices (Singh, 2017). Unfortunately, the results have been the opposite: conventional farming practices have yielded lower yields than more sustainable practices and have caused catastrophic environmental damage (Shah *et al*., 2021; Teng *et al.*, 2024).

The consequences of climate change and conventional agriculture pose the challenge of ensuring food security amid global population growth while sustainably protecting the natural environment and mitigating global warming. The above concerns sparked interest in alternative agricultural production, and farmers are moving towards conservation agriculture (CA). CA means improved agricultural production combined with ecosystem conservation (FAO, 2022). CA is the agroecological approach to agricultural production that aims to conserve resources through three principles: minimal soil disturbance, permanent land cover and diversified crop rotation (FAO, 2022). However, the definition and principles of CA have been adapted to specific agronomic practices in specific regions of the world and, at times, expanded beyond the three main principles (Andersson & D'Souza, 2014). The understanding behind CA is that agriculture must support natural biological processes that enrich soil fertility and promote water and nutrient cycling, thereby benefiting farmers by increasing crop yields and reversing soil degradation.

Africa has been at the forefront of CA adoption worldwide (Kassam *et al*., 2019). The highest rates of conservation agriculture (CA) adoption in Southern Africa are (in order from highest to lowest): South Africa, Zambia, Mozambique, Malawi and Zimbabwe (Kassam *et al*., 2019). Together, these five countries accounted for more than 99 percent of CA adoption in Southern Africa by 2015/16 (Kassam *et al*., 2019). Other Southern African countries (including Namibia) are relative newcomers to the adoption of conservation agriculture, with relatively small areas under CA by 2015/16 (Kassam *et al*., 2019).

Bottom-up approaches are crucial in Namibia to facilitate the widespread adoption of CA (Jona & Terblance, 2018). Lessons learned from South Africa (e.g., Blignaut et al., 2014; Van

Niekerk et al., 2024) indicate that economic approaches can support agricultural specialists in their extension services, thereby promoting the adoption of new technologies in Namibia.

This paper reports on an economic study for Mashare Irrigation Farm (MIF) in Kavango East Region, situated in North-Eastern Namibia. A cost-benefit analysis is conducted, incorporating an economic valuation of environmental impacts, comparing conventional farming practices with CA options. The study utilises the system dynamics modelling technique to conduct the cost-benefit analysis and the environmental cost-benefit analysis.

2. MATERIALS AND METHODS

2.1. Background to the Study Area

The study was conducted in Mashare Constituency, Kavango East Region, where the case study farm, Mashare Irrigation Farm (MIF), is located (Figure 1). MIF is a conventional farming system (CF) in which conservation agriculture practices are being considered. In addition to the smallholder irrigated farms along the Kavango River, there are five commercial irrigated farms in the Kavango East Region, 4,500 ha (Iita, 2012). The region still has great potential for future irrigation development. The region is of interest because it has five commercial conventional irrigation farms, suggesting potential pollution and environmental degradation from irrigation activities. The Kavango East Region was therefore a prime area to investigate whether the use of CA in irrigated agriculture makes environmental and economic sense for addressing environmental degradation and improving human well-being. The decision to limit the study to the Mashare constituency is because the direct negative impacts of MIF activities primarily affect its residents (Ankama, 2024). MIF was selected because the farm has consistent production and is well managed, which means it could provide better data than other farms in the region; hence, the results of the MIF case study can provide an important understanding of the adoption of CA in irrigated agriculture in Namibia.

The specific features of the MIF case study site are given in Table 1. Although data from MIF are utilised in the study, the cost-benefit analysis (CBA) is reworked so that the MIF data represent a “typical” conventional farming system in the area, which farms maize and wheat. What this means in practice is that, although MIF data are used throughout the study, MIF is not treated as a going concern; rather, the MIF case study data are reworked to include startup costs for both CF and CA farming systems. For example, if MIF were treated as a going concern, there may be no or reduced capital startup costs, as all the equipment would already be in MIF's possession (at least this is the case for CF). However, treating MIF as a new venture allows the complete costs of CF and CA to be estimated. This is important since CBA requires that the total costs and total benefits of a project be estimated (IMD, 2025). This makes the results more generic than just for MIF.

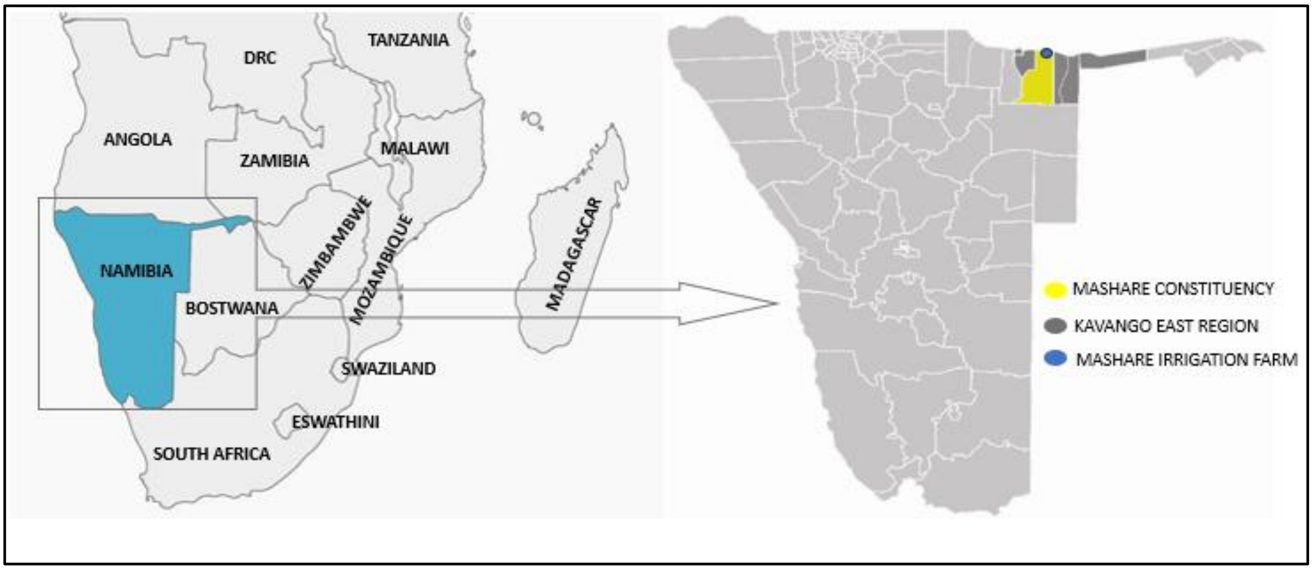

FIGURE 1: Map Location of Mashare Irrigation Farm and Mashare Constituency

TABLE 1: Agronomic and Infrastructure Features of MIF

INFRASTRUCTURES	**PARAMETERS**
Farm Total Area	527ha
Cropped Area	380ha
Irrigation System	Centre Pivots
Project Lifespan	20 Years (2023-2042)
Water Source	Kavango River
Distance from Water Source	200m-5km
Energy Source	Grid-Tied Electricity and Diesel
AGRONOMIC ACTIVITIES	PARAMETERS
Crop Produced	Maize and Wheat
Production Season	Summer (Dec-April) and Winter (June-Oct)
Cropping System	Monoculture
Soil Type	Sandy

Characteristics of Soil Quality	Poor Soil
Tillage Practice	Conventional Tillage
Fertilisers Application	Mechanised synthetic fertiliser application
Pest Control Management	Mechanised synthetic chemicals application

2.2. Study Approach

2.2.1. Environmental Cost-Benefit Analysis (ECBA)

Cost-benefit analysis (CBA) is an economic evaluation tool used to compare the costs of a project or programme with its benefits. CBA is used by decision-makers to determine whether to undertake a particular project or programme, or to compare different options (Holland *et al*., 2012). CBA theories define benefits as "increases in human well-being (utility) and costs as decreases" (Pearce *et al*., 2006, p. 42). For a project to be viable from a cost-benefit analysis perspective, its net benefits must surpass its net costs. According to De Graaff and Kessler (2009a), the goal of CBA is to compare the present value of net benefits (positive impacts) to the present value of all investment and ongoing costs (negative impacts). In a standard CBA, the costs of production are evaluated against the total monetary benefits the investment is estimated to produce (Boardman *et al*., 2017). Environmental Cost-Benefit Analysis (ECBA) is an extension of conventional CBA that incorporates environmental costs and/or benefits (Atkinson & Mourato, 2008). While a number of these environmental benefits and costs may not have quantifiable monetary values (marketed economic values), techniques such as the contingent valuation method (CVM) are used to place economic values on these non-market values.

2.2.2. Contingent Valuation Survey (CVM)

The study engaged constituency residents as participants in a contingent valuation method (CVM) survey to quantify the external environmental costs and benefits associated with current production and adoption of CA. The random cluster sampling method was used to select a representative sample of heads of households in the Mashare constituency for the CVM survey (Jamil, 2018). The survey aimed to quantify the non-market environmental costs and benefits for current production and, upon introduction of CA at MIF, for CA production. The formula to estimate the total sample size, based on Yamane (2012) and Israel (2015), is given as:

$$n = \frac{N}{N.(d)^2 + 1}$$

Where n is the sample size, N is the total population, and d is the degree of precision or trust. The total population of Mashare constituency was estimated to be 19,008 in 2023. Assuming a 10 per cent precision, a total of 95 households were targeted for the survey.

In CVM, people are directly asked in a survey how much they would be willing to pay (WTP) or to accept (WTA) for environmental services to derive non-market values of the environment (Sajise *et al.*, 2021). The data analysis from the CVM survey was conducted using regression analysis in Microsoft Excel and RStudio. The analysis helped to derive the WTP and WTA for the external environmental costs and benefits of MIF with and without the adoption of GTs. These non-market values were used in the environmental cost-benefit analysis (ECBA) models. The WTA survey estimates the maximum amount residents would be willing to accept as compensation for unsustainable conventional farming practices and the associated environmental damage. This resulted in a cost to conventional farming when environmental impacts were considered (sc2). The WTP survey estimated how much residents were willing to pay for a switch to conservation agriculture, and resulted in improved environmental services associated with CA. These resulted in a benefit to CA when environmental benefits were considered (sc4).

2.2.3. Definitions and Formulae in the ECBA

The ECBA estimates the Net Present Value, the Internal Rate of Return, and the Benefit-Cost Ratio for both conventional agriculture and CA. The definitions of these concepts and formulae used in the study are described here.

DISCOUNT RATE (r): The study's discount rate is based on Namibia's social rate of time preference (SRTP). The SRTP refers to the general observation that people prefer to consume now rather than later and the fact that banks pay interest on deposits to encourage people to forgo current spending. The SRTP is taken as the average of the Namibian Government Development Bonds issued for the period from 2023 to 2043 2043; so, the discounting of future costs and benefits to their present values (2023) was done using an 8% discount rate.

NET PRESENT VALUE (NPV): The NPV of an intervention or alternative is the "difference between the PV of its incremental benefits and the PV of its incremental social costs",

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discounted to the present value (Boardman *et al*., 2017; Cortes & Mayrhofer, 2019). Cortes and Mayrhofer (2019) provide the following formula for determining the NPV, where *n* is the year, *r* is the discount rate, *t* is the intervention or project period, and benefits and costs are the incremental benefits and incremental costs over the time frame, respectively.

$$\boldsymbol{NET\ PRESENT\ VALUE(NPV)} = \sum_{t=0}^{n} \frac{\boldsymbol{Benefits - Costs}}{\boldsymbol{(1+r)^{n}}}$$

Boardman *et al*. (2017) state that the project or intervention should have a positive NPV. According to this NPV decision rule, if the present value of benefits exceeds the present value of costs, the project can be recommended for proceeding. When there are multiple alternatives or the status quo is being analysed, the project with the highest NPV should be selected.

ENVIRONMENTAL NPV: There is an environmental cost associated with conventional farming (CF) in one of the alternative scenarios, and an environmental benefit associated with conservation agriculture (CA) (i.e. a premium market price for safe and environmentally friendly methods of growing maize and wheat grains) in another alternative scenario. By considering the environmental impacts, the Environmental Net Present Value (NPV) is given by the equation below, where **NPV'** is the ordinary Net Present Value without environmental impacts and **EC** denotes the discounted Net Present Value of environmental impacts (which may be either net environmental cost or benefit, denoted by positive and negative, respectively):

$$\boldsymbol{NPV = NPV' - EC}$$

BENEFIT-COST RATIO (B/C): The benefit-cost ratio is one of the economic appraisal outcomes of ECBA that determines the viability of an intervention (Boardman *et al*., 2017). Neupane *et al*. (2020b, p. 386) describe it as “the ratio between the present value of benefits and the present value of costs for a given period”. This decision-making tool is important because it allows for a direct comparison of benefits and costs at the beginning of the intervention (i.e., at time zero). The formula for determining the B/C ratio, as provided by Cortes and Mayrhofer (2019), is shown below:

$$\boldsymbol{Benefit - Cost\ Ratio} = \frac{\boldsymbol{PV\ of\ Benefits}}{\boldsymbol{PV\ of\ Costs}}$$

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Neupane *et al*. (2020b, p. 386) state that "an intervention with a B/C value of less than one indicates an inefficient investment, while a B/C ratio greater than one indicates a cost-effective intervention". A ratio below 1.0 indicates that investment costs outweigh benefits (Cortes & Mayrhofer, 2019). The decision rule is that the higher the B/C ratio, the better.

2.2.4. Scenarios in CBA and ECBA Analyses

A total of four scenarios were undertaken (Table 2). There are two scenarios, one for each of CF and CA, and each scenario is further split into a CBA (that doesn't consider environmental impacts) and an ECBA (that does consider environmental impacts).

TABLE 2: Scenarios in the Study and Description

Scenario	Description
CF1: CF no env impact	Conventional production (CF) without environmental impacts (CBA)
CF2: CF - env cost	Conventional production (CF) has less environmental cost (ECBA)
CA1: CA no env impact	Conservation agriculture (CA) without environmental impacts (CBA)
CA2: CA + env benefit	Conservation agriculture (CA) plus environmental benefits (ECBA)

Notes: CF= conventional farming; CA= conservation agriculture

2.2.5. System Dynamics Model

The CBA and ECBA were developed as a system dynamics model in the software Vensim. These models have a strong precedent in the agricultural economics literature in Southern Africa, including the modelling of the transition to conservation agriculture (De Wit & Crookes, 2013; von Loeper *et al*., 2016; Crookes *et al*., 2017). A stock-flow diagram was constructed for each of the four model scenarios (Figures 2-5). The model estimates the change in NPV over time (also called "dynamic NPV") and the benefit-cost ratio (B/C) for each scenario.

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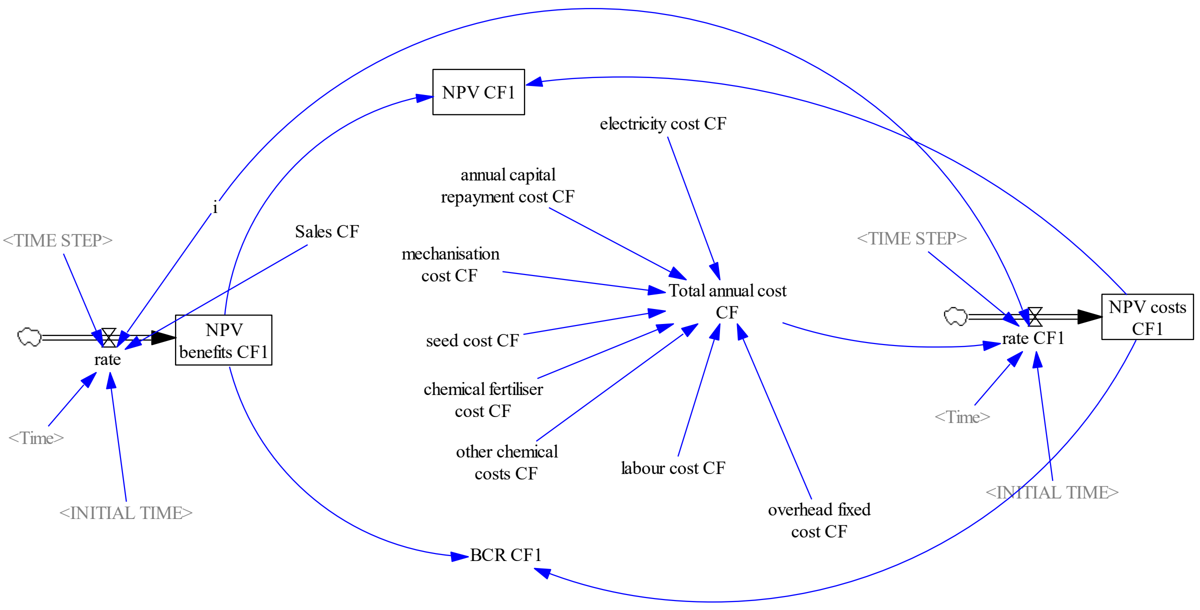

FIGURE 2: Stock Flow Diagram for CF1 Scenario

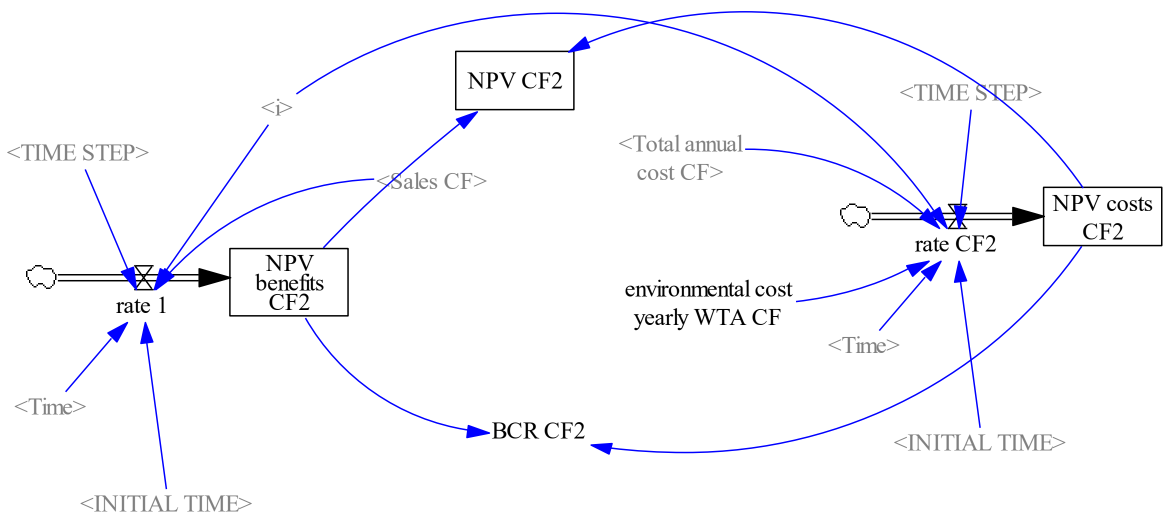

FIGURE 3: Stock Flow Diagram for Cf2 Scenario

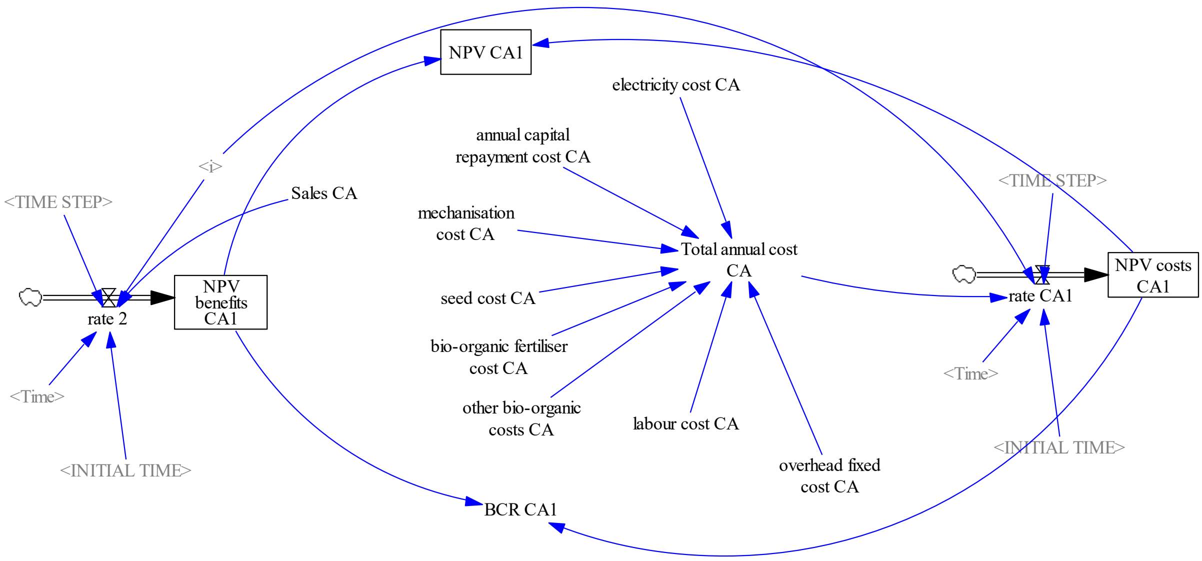

FIGURE 4: Stock Flow Diagram for the CA1 Scenario

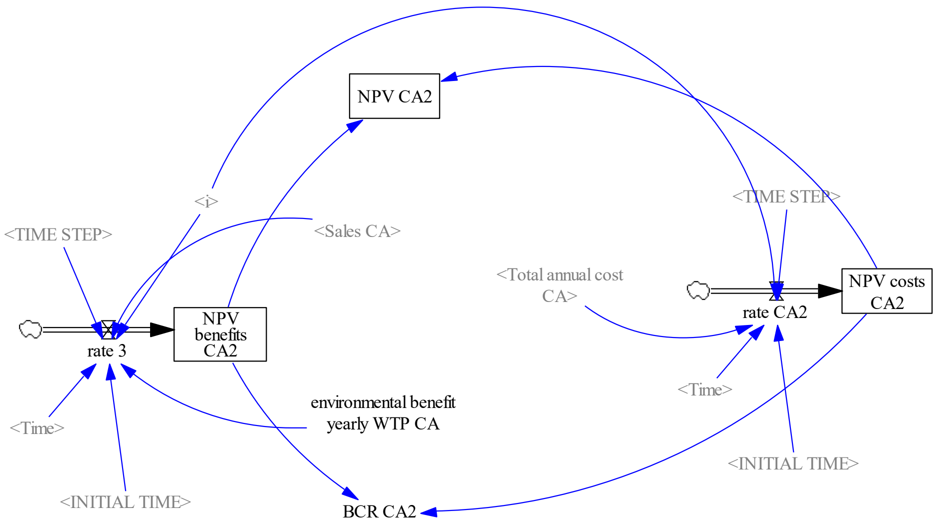

FIGURE 5: Stock Flow Diagram for the CA2 Scenario

3. DATA DESCRIPTION

3.1. Data Methodology

Primary data were collected for the ECBA. The environmental costs were estimated by asking participants to state what they would accept as compensation for environmental damage resulting from unsustainable (CF) farming practices. Participants were also asked to express their willingness to pay for an improved environment (CA). In addition to the CVM survey described previously, which was used to collect data on environmental costs and benefits, two

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additional groups of key informant interviews were conducted. The participants for data collection for the ECBA analysis were divided into two categories: those who provided data on current productions at MIF (MIF employees themselves) and those who provided data on the CA component (people knowledgeable about CA in Namibia outside MIF). Key informant interviews of four participants were used to collect data at MIF. The criteria used to select participants were based solely on their direct involvement in MIF's operations.

On the other hand, a key informant interview with a further 7 participants was conducted to collect data on CAs. One criterion for selecting these participants was that they be actively involved with the specific CAs at the time of the study. A further criterion was the expertise and knowledge of the participants of a specific CA needed for the ECBA. These participants were farmers, agronomists, irrigation experts, suppliers and service providers of CA. The criterion for selecting key informants was that they were knowledgeable about CA.

3.2. Conservation Agriculture Component

Conventional Crop farming systems (CFs) are known to cause environmental degradation. Therefore, it is essential to explore the benefits of transitioning to CA at MIF to prevent pollution of the surrounding agroecosystem and to mitigate and adapt to climate change. The main sources of GHG emissions and pollution at MIF are the use of diesel for mechanised operations, the use of synthetic fertilisers and chemical inputs, coal-based electricity, and the absence of CA practices. Reducing electricity usage through solar power also mitigates climate change, since 60 percent of electricity in Namibia is generated by coal-fired power stations. To overcome these negative effects, the following CA measures were selected for their ability to prevent, mitigate, and reduce pollution emanating from the aforementioned activities (Table 3). Further details on several of these CA interventions are provided in the Supplementary Material (Tables S1–S4). The Tables were used to estimate the costs of CA interventions, such as solar energy (Table S1), minimal tillage (Tables S2 and S3), and irrigation monitoring (Table S4).

TABLE 3: Rationale and Description of Different CA Measures Used in the Study

SELECTED CA PRACTICES	REASONS FOR INTERVENTION
Bio-Organic Fertilisers	To prevent pollution and reduce carbon footprint
Bio-Organic Remedies	To prevent pollution and human health-related concerns

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Biotech Seeds	To prevent pollution
Solar Energy	To reduce carbon footprint
Minimal Tillage	To conserve the environment
Irrigation Monitoring	To conserve water resources

3.3. Summary of Data Used in the Study

Table 4 summarises the values and sources of data for the conventional farming (CF) and conservation agriculture (CA) components of the study. The quantities are all annual values, expressed in Namibian dollars (N$). The quantities reported include revenues, variable costs, fixed costs, and environmental costs and benefits (i.e., the results from the CVM surveys). The study assumes a 8 percent discount rate for the CBA and ECBA analyses. The study's time frame is 20 years, from 2023 – 2042.

TABLE 4: Summary of Costs and Benefits

SUMMARY OF COST AND BENEFITS			
NO	**DESCRIPTION**	**AMOUNT (N$)**	**REFERENCES**
ANNUAL COST OF CF PRACTICES			
1	**CAPITAL REPAYMENT**	**9 233 121**	MAWLR & Lithon Project Consultant
2	**DIRECT INPUT COST**	**25 349 451**	Mashare Farm (Pty) Ltd
2.2	Mechanisation	589 190	Mashare Farm (Pty) Ltd
2.3	Seeds	1 487 293	Mashare Farm (Pty) Ltd
2.4	Synthetic Fertilisers	13 272 259	Mashare Farm (Pty) Ltd
2.5	Synthetic Chemical Remedies	4 543 691	Mashare Farm (Pty) Ltd
2.6	Pumping Cost (Electricity)	3 259 335	Mashare Farm (Pty) Ltd
2.7	Labour and Wages	226 743	Mashare Farm (Pty) Ltd
2.8	Overhead	1 970 938	Mashare Farm (Pty) Ltd
3	**EXTERNAL ENVIRONMENTAL COST**	**6 116 000**	CVM Survey
ANNUAL ECONOMIC BENEFITS OF CF			
4	**REVENUE OF GRAIN SALES**	**35 682 570**	Mashare Farm (Pty) Ltd

ANNUAL COST OF CA PRODUCTION			
5	**CAPITAL REPAYMENT**	**11 285 561**	MAWLR & GTs Sources
6	**DIRECT INPUT COST**	**33 998 838**	Various Sources
6.1	Conservation Agriculture Mechanisation	354 540	Detailed Calculations
6.2	Maize Biotech Seeds & Hybrid Wheat Seeds	2 955 067	Shadow Prices & Mashare (Pty) Ltd
6.2	Bio-organic Fertilisers	19 665 000	Agri Grow Namibia
6.4	Bio-organic Remedies	6 643 660	Agri Grow Namibia
6.5	Electricity Cost for Pumping (After Solar Installation)	2 129 094	Detailed Cost Calculations
6.6	Labour and Wages	226 743	Mashare (Pty) Ltd
6.7	Overhead	2 024 733	Mashare (Pty) Ltd
ANNUAL ECONOMIC BENEFITS OF PRODUCTION UNDER CA INTERVENTIONS			
7	**REVENUE OF GRAIN SALES**	**45 763 818**	Market Price and Mashare (Pty) Ltd
8	**CAs' EXTERNAL ENVIRONMENTAL BENEFITS**	**4 441 28**	CVM Survey

Notes: Sc1 comprises line items 1, 2, 4; Sc2 comprises line items 1, 2, 3, 4; Sc3 comprises line items 5, 6, 7; Sc4 comprises line items 5, 6, 7, 8

4. RESULTS

4.1. "Dynamic" NPV

Figure 3 summarises the results of the "dynamic" NPV for the four scenarios. The results show that where compensation for environmental costs and payments for environmental benefits are excluded, conventional farming (CF) performs better than conservation agriculture (CA) at MIF in Namibia. However, if MIF is required to compensate residents for environmental damage caused by conventional agricultural practices, then NPV is negative; if MIF is compensated for transitioning to CA and other sustainable practices, then this is the best outcome from an NPV perspective.

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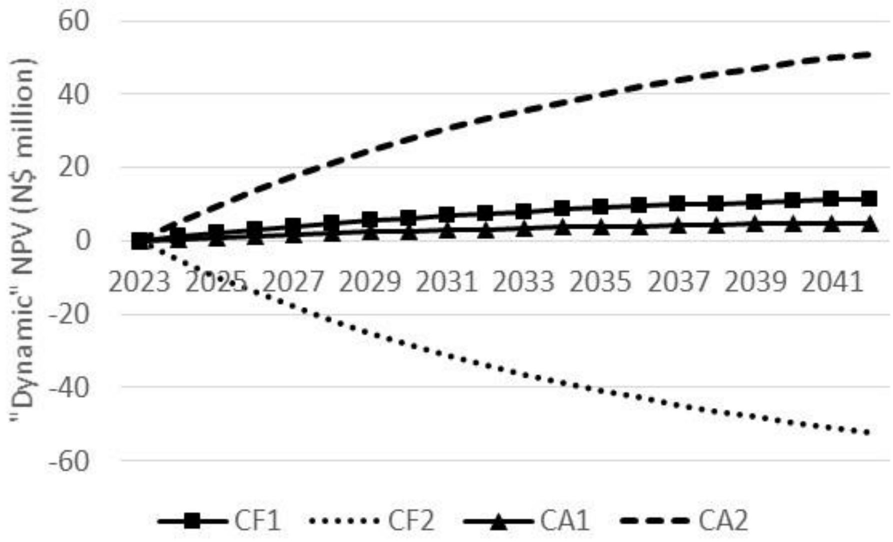

FIGURE 6: "Dynamic" NPV for the Four Scenarios in the Model. The Value at the Final Time Step is the Same as the Value of the Static NPV Over the 20 Years

4.2. Static NPV and BCR

Table 5 presents the static NPV and BCR values for the different model scenarios. NPV values are expressed both on aggregate and on a per-hectare basis. Sc4 is the best scenario with a BCR of 1.11, and Sc2 performs worse with an NPV of -N$136,900 per hectare.

TABLE 5: NPV and BCR for the Four Scenarios Under the Static Model

	CF1	CF2	CA1	CA2
NPV (N$ million)	11.4	-52.0	5.0	51.0
NPV ('000 N$/ha)	30.0	-136.9	13.1	134.3
BCR	1.03	0.88	1.01	1.11

Values are for an 8 percent discount rate over a 20-year project lifespan.

4.3. Sensitivity Analysis

A Monte Carlo simulation was run on the model to test its sensitivity to the discount rate. The discount rate was drawn from a Uniform Distribution ~ (0;1) from an ensemble of 200 realisations. The results, given in the Supplementary material (Figures S1 to S4), show that the CBA and ECBA are not sensitive to changes in the discount rate. Irrespective of the alternative discount rates, if an NPV is positive at an 8 percent level, it is positive for other values of i, and if an NPV is negative at an 8 percent level, it is negative for other values of i.

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4.4. Barriers to Adopting CA

A further 14 stakeholders were interviewed about their views on barriers to adopting CA. Six of the participants were farmers, four were agricultural engineers, one was an agronomist, a crop scientist, an irrigation expert and an environmentalist. One of those participating farmers was from MIF. The rest were other farmers in the constituency. Most had not adopted CA. Only one respondent had. The information gathered was qualitative and contextual.

One of the main themes identified in the stakeholder interview was the barriers to the adoption of CA by farmers. From this main theme, other sub-themes emerged, which include (1) lack of institutional support, (2) lack of awareness and knowledge, (3) reluctance to change by farmers, and (4) cost of CA implements.

The first sub-theme that emerged from this main theme is the lack of institutional support. Some stakeholders felt that there is no government support for commercial farmers to adopt CA. One stakeholder mentioned that it is difficult to obtain bio-organic remedies (pesticides, herbicides, and fungicides) locally compared to chemical inputs. Farmers prefer to use the available chemical inputs in their local market. The farmers further complained that organic remedies are widely marketed but no effort is being made to make them available in local markets. One stakeholder mentioned the lack of internet connectivity to enable the use of irrigation monitoring devices as one factor hindering their use by some farmers.

The second sub-theme that emerged from the data was the lack of awareness of and knowledge about CA. One participant noted that, in general, farmers do not understand the benefits of conservation agriculture. Awareness and education in CA are crucial in promoting adoption. The participant further explained that sometimes farmers have the resources to acquire CA implements, but because of their limited knowledge and unawareness of the benefits of CA, they choose not to acquire them. It is evident that a lack of awareness and knowledge is among the factors hindering the adoption of conservation agriculture.

The third sub-theme that emerged from this main theme is farmers' reluctance to change. Two stakeholders expressed concern about farmers' resistance to adopting new farming methods. Given that some farmers are familiar with specific conventional methods that work perfectly for them, they find it difficult to adapt to new methods they know little about. Farmers are reluctant to adopt CA if they are unsure of its benefits and are comfortable with their current practices.

The fourth sub-theme is the cost of transitioning to CA. Many stakeholders cited the high cost of CA implements and irrigation monitoring as the main reason for resistance to their use in irrigated agriculture. The cost of acquiring CA implementations has been cited as one of the main reasons hindering their adoption. One farmer stated that they are interested in adopting minimal tillage, but they do not have the implements nor the financial resources to acquire them; therefore, they would continue with conventional tillage using the equipment they have until they can afford to buy CA implements.

5. DISCUSSION

Conservation agriculture (CA) is increasingly being perceived as a complex system in Southern Africa. For example, Banda *et al*. (2025) found that promoting a social-ecological systems perspective is required in order to effectively implement CA in Southern Malawi. The present study proposes a systemic approach to understanding CA uptake in Namibia, combining survey data at the village and farm levels (bottom-up approaches) with systemic modelling and cost-benefit analysis (top-down approaches). The study sought to offer extension advice to farmers in the Mashare district, whilst also providing a rationale for promoting CA in Namibia and beyond.

To evaluate the benefits vis-à-vis the costs of a conventional farming (CF) system compared with a more sustainable and environmentally friendly conservation agriculture (CA) system, the capital and operating costs of these two systems were compared using data from MIF and published sources to inform a CBA. Environmental costs and benefits were also included in some scenarios in an extended Environmental Cost-Benefit Analysis (ECBA) to evaluate the effects of adopting the chosen CA on the environmental and economic viability of maize and wheat production, using the CBA economic indicators, i.e., NPV, and B/C ratio. The chosen technologies are known to have environmental benefits, making them ideal for the study.

The study found that conservation agriculture is economically viable (results in an NPV greater than 0) even in the absence of environmental external benefits. The rules of CBA, therefore, indicate that it should be adopted. Other studies in Africa have also noted that conservation agriculture is economically viable. In Zambia, for example, Omulo *et al.* (2024) found that maize and soybean margins were higher under CA than under CF. Our study is the first in Namibia and further confirms their conclusion that conservation agriculture is a viable option for small- and medium-scale farmers in Sub-Saharan Africa.

At the same time, there are several problems with CA in Namibia. Firstly, it is not more profitable than CF when environmental costs (to CF) and environmental benefits (to CA) are included. The study found that there are several other barriers to adopting CA in Namibia. These included financial barriers, a lack of institutional support for adoption, and a lack of knowledge about the benefits of CA. A number of these issues also limit the adoption of CA in other Southern African countries (Tufa *et al*. 2023; Lee and Gambiza 2022). Limited knowledge about CA adoption was also reported in Zambia, while in Zimbabwe the labour-intensive nature of CA limits it adoption (Tufa *et al*. 2023). Other studies have also documented limited uptake of CA in other Sub-Saharan African countries (Araya *et al.*, 2024). It is notable that the farmers at MIF, the study site, are currently not prepared to implement CA.

Education of farmers is important but not enough, although it is recognised as important in facilitating the adoption of CA throughout Southern Africa (Ngoma *et al*., 2024). Secondly, it is important to consider environmental "externalities" (environmental benefits and costs to the broader community, not just the production process) in studies evaluating whether CA is a viable option compared with conventional farming. Failure to do this will probably not indicate that CA is preferable to CF. Incorporating environmental externalities in CA studies is still rare (but see Lorenzetti & Fiorini, 2024).

The study has shown that consumers are willing to pay extra for maize meal and bread grown in safe, healthy, and environmentally friendly ways. This further highlights the need to encourage farmers to adopt environmentally friendly farming practices and improve their incomes. Improved incomes are critical for farmers to acquire the CA implements and bio-organic inputs needed to sustain their agricultural production. An appropriate eco-labelling system could be implemented for sustainable agricultural products, similar to or in conjunction with the one developed by the Namibian Organic Association (NOA), as these are closely related.

At the same time, farmers are unlikely to shift to CA farming without appropriate legislative incentives. The best solution for the environment is not the best for farmers' profits. This legislation could take the form of a 'carrot' approach (for example, subsidising CA farming equipment) or a 'stick' approach (for example, imposing a penalty for environmental damage). The aim of this legislation would be to ensure that conservation agriculture is more profitable for farmers than conventional farming.

Conservation agriculture is not a panacea that solves all problems. For example, CA is not suitable for marginal lands in mid latitudes that are rain-fed (Laker & Nortje, 2025). At the same time, CA is gaining increased relevance in Southern Africa as a means to enhance food security and combat climate change (Omulo *et al.*, 2024).

6. CONCLUSIONS

Maize and wheat are the staple crops in Namibia. Maize specifically is the staple food in Mashare Constituency. Therefore, sustainable production of safe, healthy maize and wheat grains at affordable prices might enhance the country's food security. To date, large-scale production of maize and wheat is taking place nationwide using conventional farming systems, with negative consequences for the environment and consumers.

This study evaluates the potential for implementing CA in the Mashare Constituency of North-Eastern Namibia. The findings are mixed. Although many participants believe that implementing CA is costly and beyond their financial capabilities, the cost-benefit analysis indicates that it is financially feasible, even if environmental benefits to the community are not compensated for. CA has the potential to enhance countries' food security by providing safe and healthy maize and wheat grains at an affordable price and also being profitable for farmers.

The Namibian Agricultural Board (NAB) should introduce a premium market structure for maize and wheat grains grown in safe, environmentally friendly ways, so that the economic benefits of adopting environmentally friendly farming practices (CA production) can be transferred and nurtured by farmers.

Agricultural institutions in Namibia should ensure that their strategies devote greater attention to assisting farmers in transitioning to CA and adopting environmentally friendly production practices. Further, training farmers on the benefits of CA would increase the likelihood that they will adopt these technologies. Therefore, farmers should be provided with financial incentives and training in CA, and encouraged to adopt CA to run their farms sustainably and more profitably.

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REFERENCES

ANDERSSON, J.A. & D'SOUZA, S., 2014. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Ag. Eco. Env.*, 187: 116–132.

ANKAMA, A.N., 2024. Environmental cost-benefit analysis of the use of green technologies in irrigated agriculture: A Case Study of Mashare Irrigation Farm in Kavango East Region, Namibia. Masters thesis, Stellenbosch University, South Africa.

ATKINSON, G. & MOURATO, S., 2008. Environmental cost-benefit analysis. *Ann. Rev. Environ. Resour.* 33(1): 317–344.

ARAYA, T., OCHSNER, T.E., MNKENI, P.N., HOUNKPATIN, K.O.L. & AMELUNG, W., 2024. Challenges and constraints of conservation agriculture adoption in smallholder farms in sub-Saharan Africa: A review. *Int. Soil Water Conserv. Res.*, *12*(4): 828-843.

BANDA, M.L.M., MLOZA BANDA, H.R., KIBIRIGE, D. & CORNELIS, W., 2025. Social-Ecological Attributes of Conservation Agriculture in Southern Malawi. *S. Afr. J. Agric. Ext.*, 53(3): 1-34.

BLIGNAUT, J.N., DE WIT, M.P., KNOT, J., MIDGLEY, S., CROOKES, D.J., DRIMIE, S. & NKAMBULE, N.P., 2014. *Sustainable agriculture: A viable option for enhanced food and nutritional security and a sustainable, productive resource base in South Africa: An investigation.* Baseline Review. Prepared for the Development Bank of Southern Africa. Pretoria: ASSET Research.

BOARDMAN, A., GREENBERG, D.H., VINING, A.R. & WEIMER, D.L., 2017. *Cost-benefit analysis: Concepts and practice.* 5th edn. Cambridge: Cambridge University Press.

BOARDMAN, A.E., MOORE, M.A. & VINING, A.R., 2022. Standing in cost-benefit analysis: Where, who, what (counts)? *J. Pol. Anal. Manag.*, 41(4): 1157–1176.

CROOKES, D.J., STRAUSS, J.A. & BLIGNAUT, J.N., 2017. The effect of rainfall variability on sustainable wheat production under no-till farming systems in the Swartland region, South Africa. *Afr. J. Agr. Resour. Econ.,* 12: 62–84.

CORTES, F. & MAYRHOFER, D.K., 2019. *Cost–benefit analysis-technical note.* The World Bank: Washington.

DE GRAAFF, J. & KESSLER, A., 2009. *Cost-benefit analysis for land and water management, Soil Protection in Sloping Mediterranean Agri-Environments: lectures and exercises,* 91. Available from https://core.ac.uk/download/pdf/153404718.pdf#page=109

DE WIT, M.P. & CROOKES, D.J., 2013. Improved decision-making on irrigation farming in arid zones using a system dynamics model. *S. Afr. J. Sci.,* 109: 11-12.

FOOD AND AGRICULTURE ORGANISATION (FAO)., 2022. *What is conservation agriculture?* Available from http://www.fao.org/ag/ca/1a.html

HOLLAND, D., SANCHIRICO, J., JOHNSTON, R. & JOGLEKA, D., 2012. *Economic analysis for ecosystem-based management: Applications to marine and coastal environments*. Abingdon: Routledge.

IITA, J., 2012. *Food Security Situation in Namibia.* Windhoek, Namibia: Ministry of Agriculture, Water and Forestry.

INTERNATIONAL INSTITUTE FOR MANAGEMENT DEVELOPMENT (IMD)., 2025. Seven steps to conduct a cost-benefit analysis. Available from https://www.imd.org/blog/strategy/cost-benefit-analysis/

ISRAEL, G.D., 2015. *Determining Sample Size*. IFAS Extension. University of Florida, United States of America.

JAMIL, N.I., 2018. *Probability Sampling Techniques*. Malaysia: MARA Technological University.

JONA, C.N. & TERBLANCHE, S.E., 2018. Proposed framework to improve the coordination of and to strengthen agricultural support services linkages in the Oshikoto region in Namibia. *S. Afr. J. Agr. Ext.,* 46(2): 24-35.

KASSAM, A., FRIEDRICH, T. & DERPSCH, R., 2019. Global spread of conservation agriculture. *Int. J. Environ. Stud.,* 76(1): 29-51.

LAKER, M.C. & NORTJE, G.P., 2025. Exploring the challenges arising from soil management in no-till conservation agriculture. *Adv. Agron.,* 189: 193-210.

LEE, M. & GAMBIZA, J., 2022. The adoption of conservation agriculture by smallholder farmers in southern Africa: a scoping review of barriers and enablers. *J. Rural Stud.,* 92: 214–225.

LORENZETTI, L.A. & FIORINI, A., 2024. Conservation agriculture impacts on economic profitability and environmental performance of agroecosystems. *Env. Man.,* 73(3): 532 – 545.

NEUPANE, P., AFROZE, D. & PHOMMASONE, P., 2020. Cost-benefit analysis of green building: A case study of public office building in Nepal. *Saudi J. Eng. Tech.,* 5(10): 382–391.

NGOMA, H., MARENYA, P., TUFA, A., ALENE, A., MATIN, M.A., THIERFELDER, C. & CHIKOYE, D., 2024. Too fast or too slow: The speed and persistence of adoption of conservation agriculture in southern Africa. *Technol. Fore. Soc. Chang.,* 208: 123689.

OMULO, G., DAUM, T., KÖLLER, K. & BIRNER, R., 2024. Unpacking the behavioral intentions of 'emergent farmers' towards mechanized conservation agriculture in Zambia. *Land use pol.,* 136: 106979.

PEARCE, D., ATKINSON, G. & MOURATO, S., 2006. *Cost-benefit analysis and the environment: Recent developments.* Paris, France: Organisation for Economic Co-operation and Development [OECD].

SAJISE, A.J., NUELLA, G.S.A., LOTIS, Q., JASMIN, S., DAVID, A.R. & DIELDRE, H., 2021. *Contingent valuation of non-market benefits in project economic analysis: A guide to good practice.* Asian Development Bank, Manila, Philippines.

SANIKA, S., 2021. Conventional Farming Techniques. *Int. J. Appl. Sci. – Res. Rev.,* 8(7): 28.

SHAH, K.K., MODI, B., PANDEY, H.P., SUBEDI, A., ARYAL, G., PANDEY, M. & SHRESTHA, J., 2021. Diversified crop rotation: An approach for sustainable agriculture production. *Adv. Agric.,* 2021(1): 8924087.

SINGH, S., 2017. Sustainable vs. conventional agriculture. *Int. J. Eng. Dev. Res.,* 5(4): 582-586.

TENG, J., HOU, R., DUNGAIT, J.A., ZHOU, G., KUZYAKOV, Y., ZHANG, J., TIAN, J., CUI, Z., ZHANG, F. & DELGADO-BAQUERIZO, M., 2024. Conservation agriculture improves soil health and sustains crop yields after long-term warming. *Nat. comm.,* 15(1): 8785.

TUFA, A.H., KANYAMUKA, J.S., ALENE, A., NGOMA, H., MARENYA, P.P., THIERFELDER, C., BANDA, H. & CHIKOYE, D., 2023. Analysis of adoption of conservation agriculture practices in southern Africa: mixed-methods approach. *Front. Sust. Food Sys.,* 7: 1151876.

VAN NIEKERK, J.A., VENTER, P. & VAN DER WATT, E., 2024. Sustainability of new generation commercial farmers in South Africa: A North-West Province case study. *S. Afr. J. Agric. Ext.,* 52(3): 103-131.

VON LOEPER, W., MUSANGO, J., BRENT, A. & DRIMIE, S., 2016. Analysing challenges facing smallholder farmers and conservation agriculture in South Africa: A system dynamics approach. *S. Afr. J. Econ. Manag. Sci.,* 19(5): 747-773.

YAMANE, T., 2012. *Statistics, an Introductory Analysis*. New York: Harper and Row.