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Assessing the Sustainability of Climate Smart Agriculture (CSA) through Conservation Agriculture in Zimbabwe: A Multi Case Study Approach

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ABSTRACT

A transition to Climate Smart Agriculture (CSA) is an obligatory task to ensure food security for an anticipated nine billion people by 2050. Despite the significance that CSA through conservation agriculture (CA) in particular received, there has been an increase in disenchantment with the approach due to its intangible rigour. The sustainability of CSA remains shrouded in mystery. CA sustainability among smallholder communal farmers has remained untheorised. It is against this backdrop that the paper sought to assess the sustainability of CSA through Conservation farming by smallholder farmers in Zimbabwe through a cross-country multi-case study approach. This paper highlighted the limiting factors of agricultural production in Zimbabwe and critically examines conservation agriculture as a potential solution to address many of these challenges. The various dimensions of CA were examined to understand the factors that influence the spread of the technology across spatial and temporal contexts. The paper concluded that CA excludes marginal groups like child-headed households, widows and the chronically ill. Environmentally, CSA minimizes adverse externalities, preserves soils with favourable micro-climatic effects, and sequesters an amount of carbon that would otherwise be released into the atmosphere, thereby mitigating temperature changes. Therefore, CSA is environmentally sustainable but economically, institutionally and socially compromised. This study contributes to social science scholarship by addressing a theoretical gap in the sustainability of CA practice, especially among smallholder farmers, bringing to the fore inclusivity, social exclusion and multidimensionality in CSA practice and providing a nuanced, evidence-based comparative critique.

Keywords: Climate Smart Agriculture (CSA), Conservation Agriculture (CA), Conservation, Sustainability

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INTRODUCTION

The developing world in general and Africa, in particular, are at the nexus of climate change and food security-related challenges. Sustainability in Climate Smart Agriculture (CSA) concerns depend on technological development and practices environmentally sensitive practices. Environmental sensitivity implies, *inter alia*, averting long-term adverse effects on environmental goods and services accessible

to and effective for farmers' productivity transformation.[1] Climate-Smart Agriculture (CSA) tackles fundamental agricultural development challenges by synergistically boosting output sustainably, diminishing greenhouse gas emissions, and securing domestic food supply. Therefore, CSA methods can help agriculture reduce climate change, adapt to it, and continuously increase productivity.[2] The rising realization that agriculture must both adapt to the changing climate and reduce its environmental impact gave rise to the idea of CSA. CSA is fundamentally grounded in sustainable agriculture's core principle: fulfilling current agricultural needs without jeopardizing the ability of future generations.[3]

Alexander argue that the Food and Agriculture Organization of the United Nations (FAO) first proposed the idea of climate-smart agriculture (CSA), which has been promoted as a way to address the interconnected problems of food security and climate change.[4] The remarkable growth of CSA has also been guided by the Global Alliance for Climate-Smart Agriculture (GACSA), whose development will continue to influence CSA's future [5]. These agencies have applauded CSA as a critical instrument for achieving the Sustainable Development Goals (SDGs) 1 and 2. At the global level, many countries have participated and exhibited efforts to institutionalise CSA through international conferences organised by global institutions and companies that already deal with climate change. These summits have enhanced the capacity of these institutions and they have projected to protect 500 million farmers from climate change while increasing agricultural productivity and reducing carbon emissions. 'More than 20 Governments, 30 organizations and companies announced they would join the newly launched Global Alliance for Climate-Smart Agriculture.'[6] Evaluations of CSA have proven the benefits to large and small-scale farmers in different regions through an increase in soil fertility, input cost reduction, labour and fuel savings, water conservation, erosion prevention, and gains in farm profitability.

Modernization has changed the nature of agriculture, even if some parts of the world still engage in traditional farming. While modern agriculture depends on technologically advanced tools and machinery, traditional agriculture uses traditional and indigenous knowledge systems, labor-intensive equipment, and organic fertilizers. As the pressures of industrialization and globalization grow, the merits of traditional farming methods and knowledge diminish.[7] Nevertheless, agrobiodiversity has long been promoted by traditional farming methods, which emphasise raising a variety of crops and locally adapted animals to improve food security and ecosystem resilience. These practices, rooted in agroecology, use strategies, including crop rotation, intercropping, and genetic resource conservation, to preserve soil fertility and promote biodiversity. In addition to preserving important biological diversity, traditional systems are crucial for promoting farming systems that accommodate marginal groups like women and the resource poor groups, fostering soil health, which is defined by a variety of plant species, root systems, and organic matter that enhance water retention and nutrient cycling and minimise the need for inorganic fertilisers.[8]

Indigenous and rural populations have been able to raise the land in balance with their ecosystems for many generations thanks to indigenous agricultural knowledge, which is frequently firmly anchored in local values, norms, and institutions that express themselves in collective environmental stewardship. High yields and early maturity are prioritised in modern agricultural practices, which emphasise high efficiency, productivity, and technical innovation. The ecological integrity of agroecosystems was put at greater risk by the overuse of fossil fuels, natural resources,

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[1] World Bank, "Small and Medium Enterprises (SMEs). Improving SMEs' Access to Finance and Finding Innovative Solutions to Unlock Sources of Capital," 2020, https://www.worldbank.org/en/topic/smefinance.

[2] Bikalpa Neupane et al., "Integrating Climate-Smart Agriculture for Sustainable Agriculture: Opportunities, Challenges and Future Directions," *Archives of Agriculture and Environmental Science* 9, no. 3 (September 25, 2024): 449–58, https://doi.org/10.26832/24566632.2024.090307.

[3] Shivam Satyawan Madrewar et al., "Evaluating Climate-Smart Agriculture: Effects on Productivity, Sustainability, and Farmer Resilience in India," *International Journal of Integrative Research(IJIR)* 2, no. 9 (2024): 741–60.

[4] Shinnola Alexander, "What Climate-Smart Agriculture Means to Members of the Global Alliance for Climate-Smart Agriculture," *Future of Food: Journal on Food, Agriculture and Society* 7, no. 1 (2019): 21–30.

[5] Beverley Oliver and Trina Jorre de St Jorre, "Graduate Attributes for 2020 and beyond: Recommendations for Australian Higher Education Providers," *Higher Education Research & Development* 37, no. 4 (2018): 821–36. 34

[6] David Armstrong, "Addressing the Wicked Problem of Behaviour in Schools," *International Journal of Inclusive Education* 22, no. 9 (2018): 997–1013.

[7] D. Princy, "A Comparative Study of Modern and Traditional Agricultural System in India," *International Journal of Novel Research and Development* 7, no. 8 (2022): 830–34.

[8] Mark Otieno, "Traditional and Industrial Farming Practices," 2024, 85–99, https://doi.org/10.1007/978-3-031-70472-7_6.

agrochemicals, and machinery. Despite success at generating food for sizable populations, contemporary agricultural methods occasionally ignore ecological balance, the marginalised and resource-poor households. By integrating traditional and modern systems, the drawbacks of each strategy can be overcome and new and productive farming practices that are also resilient, culturally aware, and environmentally friendly can be created.[9] Sustainable food production is therefore urgently needed in light of the escalating environmental problems, including climate change, population growth, the depletion of natural resources, and the loss of biodiversity. In times of environmental crisis, traditional farming is gaining attention globally as a source of sustainable food production. In order to preserve biodiversity, it is beneficial to preserve the indigenous knowledge of traditional farming.[10]

Swanepoel, *et al* conducted a systematic review of available literature on conservation agriculture initiatives as captured in peer-reviewed publications, reports, dissertations, proceedings and projects.[11] Jesse, *et al* examined the effects of three tillage practices [conventional moldboard ploughing (CT), hand hoeing (MT) and no-tillage (NT)], and three cropping systems (continuous maize, soybean–maize annual rotation, and soybean/maize intercropping) on soil quality, crop productivity, and profitability in researcher and farmer-managed on-farm trials from 2010 to 2013 in northwestern Ghana.[12] Mango *et al* studied the impact of the adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa.[13] Despite all the aforementioned CSA studies on conservation agriculture, there has been an increase in disenchantment with this approach due to its intangible rigour.[14] The sustainability of conservation agriculture among smallholder communal farmers has not been theorised. Little has been theorized on its implications for agricultural sustainability. The rest of this paper, therefore, seeks to assess the sustainability of CSA through CA by smallholder farmers in Zimbabwe through a cross-country multi-case study approach.

Conservation Agriculture: A Climate Smart Agriculture Approach

To ensure sustainability and food security in the face of climate change, climate-smart agriculture (CSA) has become a strategic approach to reshaping food supply networks and agricultural production systems. The three main objectives of CSA are to: increase agricultural income and productivity sustainably, promote climate change adaptation and resilience, and, where practical, reduce or eliminate greenhouse gas emissions. Agroforestry, integrated nutrient management, precision agriculture, regenerative agriculture, and effective water resource management are some of the agricultural techniques that fit within this paradigm. CSA is a key tactic for combating climate change since it uses innovation and appropriate technology to improve food production while simultaneously lessening the environmental impact of agriculture.[15] The CSA pillars are three goals that can be achieved by taking an integrated strategy. This integrated method offers the chance to improve synergy, produce co-benefits between the pillars, and detect and minimize potential trade-offs *ex-ante*. Starting with the evidence base and progressing to field-level implementation after improving enabling policies, institutions, and funding choices, the CSA implementation process is organized into five action points.[16] The purpose of the CSA approach is to operationalize and identify sustainable agricultural development within the specific

[9] Adebimpe Oluwabukade Adefila et al., "Integrating Traditional Knowledge with Modern Agricultural Practices: A Sociocultural Framework for Sustainable Development," *World Journal of Biology Pharmacy and Health Sciences* 20, no. 2 (November 30, 2024): 025–135, https://doi.org/10.30574/wjbphs.2024.20.2.0850.

[10] H. Hamadani et al., "Traditional Farming Practices and Its Consequences," in *Microbiota and Biofertilizers, Vol 2* (Cham: Springer International Publishing, 2021), 119–28, https://doi.org/10.1007/978-3-030-61010-4_6.

[11] Corrie M Swanepoel, Lourens H Swanepoel, and Hendrik J Smith, "A Review of Conservation Agriculture Research in South Africa," *South African Journal of Plant and Soil* 35, no. 4 (2018): 297–306. 71

[12] Jesse B Naab et al., "Conservation Agriculture Improves Soil Quality, Crop Yield, and Incomes of Smallholder Farmers in North Western Ghana," *Frontiers in Plant Science* 8 (2017): 996.

[13] Shephard Siziba et al., "Impact of Conservation Agriculture on Maize Yield and Food Security: Evidence from Smallholder Farmers in Zimbabwe," *African Journal of Agricultural and Resource Economics* 14, no. 2 (2019): 89–105.

[14] Frédéric Baudron et al., "Failing to Yield? Ploughs, Conservation Agriculture and the Problem of Agricultural Intensification: An Example from the Zambezi Valley, Zimbabwe," *Journal of Development Studies* 48, no. 3 (2012): 393–412.

[15] Wogene Kabato et al., "Towards Climate-Smart Agriculture: Strategies for Sustainable Agricultural Production, Food Security, and Greenhouse Gas Reduction," *Agronomy* 15, no. 3 (February 25, 2025): 565, https://doi.org/10.3390/agronomy15030565.

[16] F. Matteoli, J. Schnetzer, and H. Jacobs, "Climate-Smart Agriculture (CSA): An Integrated Approach for Climate Change Management in the Agriculture Sector," in *Handbook of Climate Change Management* (Cham: Springer International Publishing, 2020), 1–29, https://doi.org/10.1007/978-3-030-22759-3_148-1.

constraints of climate change. By enhancing the management and utilization of natural resources and implementing suitable techniques and technologies for the production, processing, and marketing of agricultural products, this strategy also seeks to improve livelihoods and food security, particularly for smallholders. CSA considers the social, economic, and environmental context in which it will be implemented in order to optimize the benefits and minimize costs.[17]

Table 1: African Adoption of CSA Approach from 2015-2022

	YEAR							
CSA Mode	2015	2016	2017	2018	2019	2020	2021	2022
Conservation Agriculture	2	3	4	7	17	23	29	33
Wetlands	3	5	5	12	20	26	30	40
Organic Manure	5	6	10	17	26	34	50	60
Drought Resistant Crops	2	3	5	9	16	19	22	34
Soil Conservation techniques	5	6	10	17	26	34	50	60
Crop Diversification	1	3	7	14	17	20	21	22
Cover Crops	2	6	5	9	12	17	19	20
Mulching	2	3	9	10	13	15	17	19

Source: ICRISAT, Zimbabwe Conservation Task Force modified (2023:15)

The level of food insecurity in Zimbabwe skyrocketed in 2003. For example, according to the IFAD Report, food insecurity caused the percentage of households in the extremely poor group (those below the FPDL) to rise from almost 20% in 1995 to roughly 48% in 2003.[18] There was actual widespread starvation by the end of 2005. Approximately 6,074,000 people, or nearly half of the country's population, were in critical need of food assistance, according to the WFP. The situation in urban areas has drastically worsened, mostly due to the deteriorating macro environment, particularly hyperinflation, negative GDP growth, and the reduction of formal job prospects.[19] To resuscitate the agricultural sector, the government of Zimbabwe initiated: Operation Feed the Nation *"Maguta"*, the Presidential Input Scheme and the current Command Agriculture Program. Command Agriculture was aimed at mobilizing sustainable and affordable funding for the new farmers who lack collateral to access credit lines from financing institutions. Initial programs failed to boost agricultural productivity due to, *inter alia*, rent seeking, elite capture and politicization of the programme.[20] It is crucial to remember that a wealth of scientific research, starting in the 1980s, has emphasized small grains as the best crop to alleviate food insecurity in Africa, and Zimbabwe specifically, due to their drought and pest resistance and nutritious qualities. Various agricultural specialists recommended encouraging the production of native drought-resistant crop varieties, mainly small grains, in order to maximize agricultural potential and revitalize existing institutions. This would lessen the mounting financial strain brought on by excessive investments in grain imports and maize cultivation.[21]

Nyandoro and Anderson stipulated that the 1980s revolution in smallholder agricultural output set the stage for Zimbabwe's deteriorating food security crisis.[22] The burden of producing maize has been transferred to the Communal Areas' degraded soils, where rainfall is frequently unpredictable, as a result of significant government investment in smallholder farming. Because crop production on the sandy soils of the Communal Areas needed ongoing investment in soil fertility, such as fertilizers and

[17] Gayatri Sahu et al., "Climate Smart Agriculture: A New Approach for Sustainable Intensification," *Current Journal of Applied Science and Technology*, August 18, 2020, 138–47, https://doi.org/10.9734/cjast/2020/v39i2330862.

[18] International Fund for Agricultural Development (IFAD), *Rural Poverty Report 2001: The Challenge of Ending Rural Poverty* (Oxford: Oxford University Press, 2001).

[19] P P Maruve and L Chitongo, "Fast Track Land Reform Programme and Food Security in Zimbabwe: A Case of Datmoor Farm in Seke District," *International Journal of Current Research* 9, no. 8 (2017): 55985–92.

[20] T. F. F. Chisango and F Tichakunda, "Challenges and Prospects of Zimbabwe's Command Farming in Unlocking the Country's Smallholder Agricultural Economy," *Int. J. Agric. Econ* 3, no. 4 (2018): 76–82.

[21] Bryan Kauma and Sandra Swart, "Hunger and Power: Politics, Food (in)Security and the Development of Small Grains in Zimbabwe, 2000-2010," *Historia* 67, no. 1 (July 8, 2022): 144–76, https://doi.org/10.17159/2309-8392/2022/v67n1a6.

[22] Mark Nyandoro and Jens A Andersson, "Zimbabwe's Agriculture and Food Security: Past, Present and Future (1960–2050)," in *Pathways to African Food Security* (Routledge, 2025), 59–72.

manure, maize production became increasingly susceptible to climate unpredictability and broader macroeconomic trends[23]. At the same time, conventional agriculture was associated with the use of organic fertilizers and the monocultures of clean fields, which gained momentum, resulting in an increased loss of fertile soils in the southeastern low veld of Zimbabwe, like Bikita and Chiredzi districts. The food insecurity situation attracted the attention of food aid agencies and the state organs involved in CA.[24] Beginning in 2004, ICRISAT promoted CA in Zimbabwe using planting basins made by hand with a hoe. A variety of techniques make up conservation agriculture. It is based on three key principles: 1) minimal soil disturbance, 2) permanent soil cover, and 3) crop rotation. Reduced water runoff from greater infiltration, improved soil organic matter content, and higher soil biological activity are all made possible by minimal soil disturbance and permanent soil cover. For infiltration and evaporation reduction, mulching is very crucial. Crop yields are predicted to rise steadily as a result of the biophysical changes countered by conservation agriculture.

The typical elements of conservation agriculture that are being extended to smallholder farmers in Zimbabwe include crop rotation, timely weeding (usually done by hand), the use of chemical and organic fertilizers, and reduced tillage, which is mostly accomplished by using planting basins or minimum tillage equipment and leaving plant residues on the surface to act as mulch.[25] This study was designed to evaluate trends in technology adoption after several changes to CA were made through ICRISAT research and field trials. Although the benefits differ by crop, households that experience rainfall shocks benefit from the application of CA in terms of yields. Compared to smallholders who employ traditional farming methods, yields from CA tend to be more tolerant to both abnormally high and low rainfall. For maize, for example, returns are only positive when rainfall is either one standard deviation above or one and a half standard deviations below the average. Yield returns for CA in maize are negative when a season's total rainfall is closer to average. Irrespective of how high the rainfall deficit is, the yield gain for sorghum with CA is positive, and for above-average rainfall, it is nearly negative.[26]

Conservation Agricultural (CA) practices are a suitable technology that can address some of the underlying crop management issues faced by farmers in Zimbabwe. This is because farmers in the country's marginal rainfall regions must adopt new technologies that preserve fragile soils and prolong the period of water availability to the crop, be it grain or forage. Tillage and planting combinations that leave at least 30% or more mulch or crop residue cover on the surface are operationally referred to as conservation agriculture. Conservation agriculture is defined as tillage sequences that minimize or reduce the loss of soil and water.[27] The Conservation Task Force for, and Kunzekweguta *et al* analysed factors affecting the adoption and intensity of conservation agriculture techniques in Masvingo district, Zimbabwe, and noted that technologies developed and tested under researcher-managed trials tend to fail because of their neglect for sociological problems and priorities of the smallholder farmer.[28] For instance, studies showed that the majority of the vulnerable households cannot afford hired labour even though the digging part of the technology required a lot of energy.[29]

[23] Chisango and Tichakunda, "Challenges and Prospects of Zimbabwe's Command Farming in Unlocking the Country's Smallholder Agricultural Economy."

[24] World Bank, "Small and Medium Enterprises (SMEs). Improving SMEs' Access to Finance and Finding Innovative Solutions to Unlock Sources of Capital."

[25] Siziba et al., "Impact of Conservation Agriculture on Maize Yield and Food Security: Evidence from Smallholder Farmers in Zimbabwe."

[26] Jeffrey D Michler et al., "Conservation Agriculture and Climate Resilience," *Journal of Environmental Economics and Management* 93 (2019): 148–69.

[27] P. Cosmas et al., "Effect of Planting Basin Depth on the Growth and Performance of Maize (Zea Mays)," *Scientia Agriculturae* 13, no. 1 (January 20, 2016), https://doi.org/10.15192/PSCP.SA.2016.13.1.3036.

[28] Machiweyi Kunzekweguta, Karl M. Rich, and Michael C. Lyne, "Factors Affecting Adoption and Intensity of Conservation Agriculture Techniques Applied by Smallholders in Masvingo District, Zimbabwe," *Agrekon* 56, no. 4 (October 2, 2017): 330–46, https://doi.org/10.1080/03031853.2017.1371616; Zimbabwe Conservation Agriculture Task Force, *Farming for the Future. A Guide to Conservation Agriculture in Zimbabwe* (ICRISAT Press, 2009).

[29] Christian Thierfelder et al., "Where Is the Limit? Lessons Learned from Long-Term Conservation Agriculture Research in Zimuto Communal Area, Zimbabwe," *Food Security* 7, no. 1 (February 26, 2015): 15–31, https://doi.org/10.1007/s12571-014-0404-y.

Conservation Agriculture and Sustainability

Agriculture, rural development and conservation organizations have all been working in recent decades to support farmers across the developing world to improve productivity in ways that avoid the environmental damage conventionally associated with farming. [30] As climate changes threaten productivity in agriculture and food security, many groups are taking a new look at the potential of conservation agriculture within the context of a "CSA" approach to farming.[31] As part of conservation agriculture initiatives, the Zimbabwean government introduced the "*Pfumvudza*". The word "*pfumvudza*" in Zimbabwean vernacular refers literally to the springtime sprouting of new leaves and symbolically to the lush regeneration of hope that marks the start of a new growing season. The Foundation of Farming (FF), a local non-governmental organization in Zimbabwe , hatched the idea of using a small plot of land to provide enough cereal for a typical household of six people over a year. FF's strategy is founded on four fundamental ideas: basic food security for marginal groups, crop rotation, intercropping cover crops with primary crops, minimizing soil disturbance or tillage, and excavating holes exclusively for planting. Permanent soil cover is achieved by applying organic mulch. When tasks are completed on schedule, according to standards, without waste, with the anticipated accuracy, and with delight, household food security should be achieved.[32]

Many rural households in Zimbabwe rely heavily on smallholder agriculture for their livelihoods, with almost 70% of the population engaged in this type of work. In order to improve food security and solve low productivity among smallholder farmers, the Zimbabwean Ministry of Agriculture and several nongovernmental organizations (NGOs) have been promoting Conservation Agriculture (CA) since 2004 through a variety of donor-funded initiatives. By implementing three principles: minimum soil disturbance, permanent soil cover, and crop rotations and associations. CA is a sustainable farming method that seeks to maximize output while protecting the environment. There is substantial evidence of CA's agronomic effects and biophysical advantages.[33] Despite all these positives, its sustainability remained veiled in obscurity.[34]

Dimensions of Sustainability in Conservation Agriculture

Sustainability in CA comprises four dimensions, which are social, economic, environmental and institutional. These are explained below.

a. Social Dimension

Social dimensions include how conservation agriculture promotes gender equality, integration, reciprocity, networking and innovation among farmers. Social sustainability incorporates health and safety of workers, impact on local communities, quality of life, benefits to disadvantaged groups, alienation and enhances civility and a sense of community and place attachment. The social aspect also refers to the adoption of all measures of adaptation and security to prevent exclusion by gender, ageism, and power. Social dimension explores the mode of consuming, producing and gaining values in and towards socially and environmentally responsible ways. It reveals the efforts and responsibility of a society built on principles of empowerment of women and men, child rights to food, play and decent work. The concept of equity is critical in social sustainability as it seeks to prevent unequal policies that for instance, overburden women with work, and promote public involvement through an intersectionality and gender empowerment lense. A desired physical form should promote a sense of community, safety, health, and place attachment, among other sociological objectives.[35] It is these

[30] Armstrong, "Addressing the Wicked Problem of Behaviour in Schools."
[31] Elirea Bornman, Pedro Álvarez-Mosquera, and Vuyo Seti, "Language, Urbanisation and Identity: Young Black Residents from Pretoria in South Africa," *Language Matters* 49, no. 1 (2018): 25–44.
[32] Never Mujere, "Assessing the Potential Contribution of <Em>Pfumvudza</Em> Towards Climate Smart Agriculture in Zimbabwe: A Review," January 29, 2021, https://doi.org/10.20944/preprints202101.0619.v1.
[33] Joe Stevens, P Nyathi, and M Salomons, "Sustainability of Conservation Agriculture Adoption and the Role Lead Farmers Play in Zimbabwe," *South African Journal of Agricultural Extension (SAJAE)* 49, no. 2 (December 9, 2021): 1–14, https://doi.org/10.17159/2413-3221/2021/v49n2a12783.
[34] Tarisayi Pedzisa et al., "Abandonment of Conservation Agriculture by Smallholder Farmers in Zimbabwe," *Journal of Sustainable Development* 8, no. 1 (2015): 69.
[35] Efrat Eizenberg and Yosef Jabareen, "Social Sustainability: A New Conceptual Framework," *Sustainability* 9, no. 1 (2017): 68.

precepts that the study used to measure the social sustainability of conservation agriculture in Zimbabwe.

b. Economic Dimension

For the main stakeholders in sustainable agriculture, such as farmers, legislators, and consumers, conservation agriculture is crucial. Since it eliminates the need for expensive inputs like fertilizer and herbicides, conservation agriculture can boost farmers' productivity and profitability. Additionally, CA helps to lessen the consequences of climate change by lowering greenhouse gas emissions and storing carbon in the soil. Conservation agriculture can assist policymakers in achieving sustainable development objectives pertaining to poverty alleviation, environmental preservation, and food security.Encouraging more environmentally friendly farming methods can also aid in rural development. By preserving soil health and minimizing the use of hazardous pesticides and fertilizers, conservation agriculture can guarantee the supply of wholesome and safe food for consumers.[36] This economic dimension assists in measuring the economic sustainability of CA as a climate-smart agriculture in Zimbabwe.

c. Environmental Dimension

The environmental dimension has the environmental components, such as reduction in waste, effluent generation, and emission into the environment by CA in place. It also captures how CA reduces the negative impact of practices on human health, utilization of renewable raw materials and elimination of toxic substances that can be detrimental to human and domestic animal welfare. This paper uses these variables to assess the environmental sustainability of CA.

d. Institutional Dimension

Last but not least is the institutional dimension, which looks at the norms and values of the CA. CA involves the interaction of multiple actors and different levels. For instance, outside players like NGOs contribute to the shaping of CA, and locally traditional and modern institutions also contribute to how CA practices. Given these complex inter-organisational and institutional dynamics, this paper examines how norms and values are shaped in the ensuing interactions. The nature of the culture that CA creates or reinforces is of key interest. This theme is further discussed below.

Conservation Agriculture and Institutional Sustainability

Although CA has a lot of promise to advance sustainable farming, obstacles, including gender bias, the high cost of technology, low farmer awareness, and the requirement for region-specific research, still prevent CA from being widely adopted. First and foremost, households in regions that are vulnerable to climate change and experiencing resource degradation should give priority to scaling integrated CA practices. Policy strengthening is also essential, with incentives for crop diversification and residue retention as well as targeted subsidies and support networks for CA equipment. To highlight the long-term advantages of CA, research and demonstration initiatives should concentrate on carrying out on-farm experiments in rainfed regions. Introspective participatory research on levels of technology uptake and dropout is necessary to monitoring, evaluation and learning, as well as evidence-based strategy revision. By including female and male farmers in participatory knowledge transfer methods, CA practices will be refined for regional circumstances.[37] The development agenda in sub-Saharan Africa is dominated by the creation and promotion of alleged new agricultural advances, although poverty and hunger are still pervasive. These initiatives require a supportive policy environment. Studies have frequently ignored the importance of national policies in farmers' adoption of agricultural inventions, even though they are a crucial part of how an agricultural innovation system operates. Improving

[36] Pushkar Dev et al., "Conservation Agriculture for Sustainable Agriculture," *International Journal of Plant & Soil Science* 35, no. 5 (March 10, 2023): 1–11, https://doi.org/10.9734/ijpss/2023/v35i52828.

[37] B B Nayak and Saithala Mounika, "Conservation Agriculture-A Sustainable Approach for Enhancing Small and Marginal Farmers' Livelihoods," *AgroScience Today* 6, no. 1 (2025): 1056–65.

knowledge of how policies impact the long-term adoption of agricultural technologies meant to boost smallholder farmers' incomes and productivity is critically needed.[38]

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which is comparable to the Intergovernmental Panel on Climate Change (IPCC), was established in 2012 in response to this need. The IPBES is the intergovernmental organization that, upon request from decision-makers, evaluates the condition of biodiversity and the environmental services it offers to society. Identification and prioritization of necessary scientific data, as well as the recommendation and support of policies pertaining to biodiversity and ecosystem services, are the responsibilities of IPBES. However, scientists and funding organizations must also stress this link between biodiversity and ecosystem function in relation to sustainability if progress is to be made in this field. It is important to take into account the various issues that have arisen in the study of indigenous knowledge. Research has shown that knowledge gleaned from indigenous communities frequently results in significant financial gains for northern firms without providing any restitution to the people who provided the information.[39] Policies for CA promotion at the national level that are appropriate for various agricultural regions must be developed. It is crucial to research and test CA's tax subsidies for CA businesses, as well as its ecological advantages and subsidy programs. Optimizing and promoting various technology integration systems is crucial for putting CA's core ideas into practice and determining its long-term impacts. For applications like direct sowing, crop diversification, fertilizer and water management, and plant protection (e.g. for weed, insect, and disease control), it is also essential to optimize key technologies.[40]

A proper enabling environment and long-term, sustainable resource availability are necessary for the development, implementation, and scaling up of CA systems. In actuality, supporting CAof entails removing structural barriers that confine traditional methods of agricultural improvement, requiring significant changes in the structure and operation of food systems. Whether the appropriate policies can be put in place to enable the adoption at scale and in a transformative fashion is one of the main impediments preventing CA transformations beyond the availability of context-fitting technology solutions. To put it another way, starting points, target visions, and context-specificities all influence the instruments and designs used in policies for the shift to CA systems. There, persuasion and sensitization primarily through educational campaigns and information-sharing platforms (e.g., strengthening CA messaging in extension and learning systems)for diverse stakeholders, including policymakers and opinion leaders, are crucial, . However, actionable initiatives, which are defined by tools, regulations, budget, human resources, and social engagement, are required and must be tailored to specific settings. Furthermore, the availability of brokers, incentives, and social skills for collaboratively adopting CA at the local level frequently presents a significant difficulty.[41]

Conservation Agriculture and Economic Sustainability

By lowering input costs while preserving or increasing crop yields, CA raises farm profitability. Small and marginal farmers who struggle with high production costs will especially benefit from this strategy. Reduced expenses for pesticides and fertilizers are among the main advantages.[42] CA has many economic advantages. Reducing the price of fuel, fertilizer, and pesticides can significantly minimize production expenses. Improved soil fertility and health lead to increased agricultural yields and higher-quality produce. Additionally, employing agroforestry and crop diversification can boost food security

[38] Edna Chinseu, Lindsay Stringer, and Andrew Dougill, "Policy Integration and Coherence for Conservation Agriculture Initiatives in Malawi," *Sustainable Agriculture Research* 7, no. 4 (August 8, 2018): 51, https://doi.org/10.5539/sar.v7n4p51.

[39] Richard A. Niesenbaum, "The Integration of Conservation, Biodiversity, and Sustainability," *Sustainability* 11, no. 17 (August 28, 2019): 4676, https://doi.org/10.3390/su11174676.

[40] J. He and S. Jiang, *Conservation Agriculture in China: Innovations, Investment Opportunities and Challenges.* (Rome: FAO: Investment Centre Country Highlights No. 19. , 2023), https://doi.org/10.4060/cc2091en.

[41] Rachid Mrabet, Akashdeep Singh, and Tarun Sharma, "Conservation Agriculture as Sustainable and Smart Soil Management," in *Agroecological Approaches for Sustainable Soil Management* (Wiley, 2023), 339–56, https://doi.org/10.1002/9781119911999.ch15.

[42] Nayak and Mounika, "Conservation Agriculture-A Sustainable Approach for Enhancing Small and Marginal Farmers' Livelihoods."

and generate new sources of income. CA can therefore increase resilience to market fluctuations and climate change-related risks, providing farmers with more steady revenue streams.[43]

Table 2 below shows that the yields under conservation agriculture are superior to those under conventional tillage, as it reveals the benefits accumulated over the years. Farmers are encouraged to note that some of the benefits, such as reduced labour, are incremental and felt in the second and subsequent years. The superiority of conservation agriculture reveals the economic viability and sustainability of the CSA approach for agricultural transformation.

Table 2: Sensitivity Analysis for conservation agriculture package versus conventional Farming practices under normal and low rainfall situations in Zimbabwe

	Conservation Agriculture		**Conventional Agriculture**	
	First Year	Second +years	No fertilizer	With fertilizer
High rainfall				
Maize grain kg/ha	2 000.00	2 650. 00	670.00	1120.00
Normal rainfall				
Maize grain kg/ha	1750.00	2 200.00	560.00	728 00
Low rainfall				
Maize grain kg/ha	1520.00	1780.00	368.00	400.00

Source: ICRISAT, Zimbabwe conservation task force modified (2023:12)

One of the best agricultural strategies in the current era is CA. The effective use of cover crops and minimum tillage methods has been shown to result in significant fuel and labour savings when compared to regular tillage and may be crucial to reducing weed infestation and maintaining production. Minimum tillage techniques have been shown in particular to lower fuel consumption by 60–66% and labour requirements by 70–74%. As mentioned earlier labour-saving benefits accrue incrementally. The main players in value conservation and sustainable agriculture are farmers, legislators, and consumers.[44]

However, incentives presented to smallholder farmers to join CA have shown that the practice is a High External Input Agriculture (HEIA). HEIA systems are limited in that the pH, cation exchange capacity, soil structure, soil texture, and soil organisms are all negatively impacted by the use of artificial agrochemicals. As a result, the soil's microbial activity tends to decline, resulting in dead soil. Despite the requirement for significant capital investment, large-scale farmers profited while small-scale farmers who lacked funds faced financial difficulties. The introduction of hybrid varieties led to the demise of environmentally beneficial traditional seed varieties and their genetic resources. Traditional farming methods and wisdom were disregarded and eventually eradicated. The yield per unit is currently declining, and many of the benefits of high external input agriculture are gradually eroding. As a result, farmers, researchers, and extension agents must transition to a sustainable agricultural system devoid of significant foreign inputs.[45] The question now is for how long the funding organisation will persist in giving incentives for farmers to join. How will the poor farmers sustain themselves without incentives in the future? It is claimed that the excessive and unbalanced use of artificial inputs in HEIA can have serious ecological, economic and socio-political repercussions. Thus, liquidity and financial constraints experienced by communal farmers in Zimbabwe adequately reveal that conservation farming is uneconomically viable despite the profitability levels it has using the positive Net Present Value (NPV) test. Uncertainty also poses a major problem for economic evaluation. CA cannot maintain output at a level approximately equal to or greater than its historical average.

[43] F. Parapurath et al., " Conservation Agriculture: Techniques and Benefits," in *Current Trends in Agriculture & Allied Sciences*, vol. 4 (S P Publishing, India, 2024), 383–90.

[44] Prodipto Bishnu Angon, Shaharia Akter Suchi, and Arpita Rani Roy, "Challenges, Developments, and Perspectives of Conservation Agriculture (CA) in Modern Agricultural System," *International Journal of Agronomy* 2023 (November 22, 2023): 1–6, https://doi.org/10.1155/2023/1939379.

[45] Kamalpreet Kaur, Diksha Thakur, and V. Reeta, "Sustainable Agriculture: Impact of LEISA and HEIA," *International Journal of Advances in Agricultural Science and Technology* 9, no. 6 (June 30, 2022): 1–8, https://doi.org/10.47856/ijaast.2022.v09i06.001.

However, critics argue that specialization and investment does not guarantee competitiveness. Innovation (e.g., identifying niche markets and entering into specific contracts) might confer a temporary advantage. Under prevailing capitalist market institutions, political ecology questions if the sufficient capability to innovate can ever be re-distributed equitably. Facing this "market imperative," smallholders who cannot find ways to lower their unit costs (through specialization, investment, increased economies of scale, and associated innovations) will be unable to stay profitable as emerging capitalist farmers and face pressures to exit. Those able to invest in land, hired labour, and other inputs, or to access innovations, will accumulate at the expense of those who exit. The high labour requirement can be reduced significantly by the use of herbicides, but in many areas, these are unavailable or expensive. Smallholder communal farmers have no capacity to hire labour and even to buy herbicides frequently. This explains that the practice of CA cannot persist since local farmers are not resilient enough to sustain the pressure.

CA and Social Sustainability

The poor mechanization in conservation agriculture subsequently affects food production, and soil health continues to deteriorate, thereby affecting the food security status of communal farmers. Among the economically excluded households are the child-headed households and some needy single female heads of households without draught power and access to male-dominated networks. Child-headed households are mostly school-going age groups that could not attend demonstration workshops held during learning days, and they do not have the capacity and capability to erect basins. This would be child labour. Therefore, this CSA approach excludes some deserving households like widows and child-headed families without a workforce. So the secluded needy households are practising the traditional rol-pot-holing *(chihovo*) methods but with no incentive from the Non-Governmental Organisation. Socially, the quality of life has been affected, disadvantaged groups are alienated, and enhanced civility and a sense of community and place attachment are compromised. The right to not only save but also adopt all measures of adaptation and security to prevent future casualties and physical harm has been compromised, thereby compromising the CSA approach.[46] Conservation agriculture has a positive social impact, especially in rural areas. It ensures that arable land will be available for future generations by promoting sustainable land use practices. Adoption of conservation agriculture practices can empower farmers by increasing knowledge and skills, fostering innovation, and strengthening community collaboration.[47]

The application of conservation agriculture is not without difficulties, despite its advantages. These difficulties include institutional, socioeconomic, and technical aspects. Reduced-tillage techniques frequently call for specialized equipment with varying power levels that are tailored to local conditions (manpower, animal traction, mechanized equipment). Small-scale farmers in tropical nations encounter technological, social, and intellectual obstacles that prevent them from using conservation agricultural methods. Due to a lack of information and suitable resources, farmers who are not familiar with conservation agriculture have a difficult time comprehending and implementing the technology. Socioeconomic barriers may hinder the implementation of conservation agriculture. Smallholder farmers usually lack the funds necessary to buy the supplies or machinery they need. Notably, the adoption of conservation agriculture practices is impeded by intellectual, social, and technological barriers faced by small-scale farmers in poor-resourced communities. Long-standing farming practices and cultural preferences may also be factors in reluctance to change. These barriers may be removed with the help of training initiatives, financial aid, and subsidies.[48] It is understood that women are the majority in communal agricultural production; therefore, this burden would compromise smallholder productivity. With this outcome, the rate of adoption is likely to be compromised due to loss of interest and support, hence unsustainable.

[46] Eizenberg and Jabareen, "Social Sustainability: A New Conceptual Framework."
[47] Parapurath et al., " Conservation Agriculture: Techniques and Benefits."
[48] Parapurath et al., " Conservation Agriculture: Techniques and Benefits."

For some, the benefits of the method are not worth the work it takes to prepare a plot with precise, evenly spaced holes. Sikhathele Moyo, a farmer in Esigodini, outside Bulawayo, said he had only used potholing once, during a drought in 1992.
"I remember digging holes when it was hot and this has affected my back until now," complained Moyo.[49]

CA and Environmental Sustainability

Nayak and Mounika assert that CA techniques can cut the amount of fertilizer needed by 20% for phosphorus and 25–30% for nitrogen.[50] Zero-tillage and residue retention have decreased fertilizer input in Indian rice-wheat systems by 20–25% without sacrificing output. Farmers can improve environmental sustainability, reduce input costs, and manage nutrients sustainably by implementing CA. Preservation of organic leftovers and little soil disturbance promotes a healthy ecosystem of soil microorganisms. This creates a healthy soil environment by encouraging the cycling of nutrients, the breakdown of organic matter, and the prevention of soil-borne illnesses. By decreasing losses and increasing nutrient-use efficiency through natural recycling processes, conservation agriculture maximizes nutrient management.

Through the integration of techniques such as crop residue retention, no-till, and agroforestry, which boost soil health, water retention, and nutrient efficiency, conservation agriculture (CA) improves climate resilience. In addition to improving water penetration by 25–30% and lowering flood damage, CA raises soil organic carbon by 0.3–0.5 tons/ha yearly, increasing drought tolerance. With methane and nitrous oxide reductions of 10–30%, it lowers greenhouse gas emissions. By recycling nutrients and suppressing pests, CA also lowers fertilizer consumption by 25–30% and pesticide expenditures by 10–15%. In harsh weather, agroforestry increases crop resilience by 20–30% and stabilizes production. In addition to supporting disease resistance and nutrient cycling, increased soil microbial activity guarantees sustainable and flexible farming practices.[51] By storing carbon in the soil and reducing greenhouse gas emissions, it also lessens the effects of climate change. It can also support rural development by promoting more ecologically friendly farming practices. California may be able to give consumers access to nutritious and safe food by maintaining soil health and reducing the use of harmful pesticides and fertilizers. CA is a biologically and ecologically sustainable practice that can renew and restore damaged agricultural lands while improving robustness and efficiency. It also improves the biological makeup and functioning of the soil, which benefits farmers and society at large. CA significantly affects the environment.[52]

RECOMMENDATIONS

The need to tailor CA packages according to the demographic, social, economic and physiological needs of individual farmers cannot be overemphasized. Conservation agriculture promoting organizations should come up with strategies for accommodating vulnerable households, such as child-headed households and the sick who cannot attend demonstration workshops, and who may not be able to erect the prescribed 15x15x15cm planting basins but could do the rol-pot-holing system that is less laborious and life strenuous. Smallholder farmers facing cyclical food shortages should come up with a 'grain bank' system that cushions them during the pre-planting food insecurity period that coincides with increased agriculture-related labour.

CONCLUSION

The objective of this paper was to assess the sustainability of CSA through CA by smallholder farmers in Zimbabwe through a cross-country multi-case study approach. Institutionally, CSA through CA has a higher germination rate of crops, resilience to moisture stress and increased productivity; however, the practice is rudimentary. The total area under conservation agriculture compared to conventional farming

[49] S. J. Ndlovu-Gatsheni, *Decolonization, Development and Knowledge in Africa: Turning over a New Leaf* (London: Routledge, 2020).
[50] Nayak and Mounika, "Conservation Agriculture-A Sustainable Approach for Enhancing Small and Marginal Farmers' Livelihoods."
[51] Nayak and Mounika, "Conservation Agriculture-A Sustainable Approach for Enhancing Small and Marginal Farmers' Livelihoods."
[52] Angon, Suchi, and Roy, "Challenges, Developments, and Perspectives of Conservation Agriculture (CA) in Modern Agricultural System."

is still insignificant. What increases is the number of households practising conservation agriculture and not the hectares per individual farmer. The idea of using planting basins, manually erected, as the only means for conservation agriculture practice led to compromised resilience. Economically, though substantial gross margins and profitability are realised in small hectares, CA is a high-external-input agriculture with liquidity and financial constraints for Zimbabwean communal farmers compromising its viability and sustainability. CA is socially excluded as child-headed households, widows and the chronically ill are thrown into the dustbin of development. It exposed women and children, as its labour requirements and is skewed towards them. Environmentally, CSA minimises adverse externalities, preserves soils with favourable micro-climatic effects and sequestrates an amount of carbon that would otherwise be released to the atmosphere affecting temperature changes. Consequentl, one can say CSA is environmentally sustainable but economically, institutionally and socially compromised.

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