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Review

Climate-Smart Agriculture and Food Security in Southern Africa: A Review of the Vulnerability of Smallholder Agriculture and Food Security to Climate Change

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Abstract: Southern Africa is facing chronic food insecurity mainly because of the multistressor context in which agriculture is practiced in this region. Climate-change-related constraints are fueling food shortages for marginalized rural communities. Climate-smart agriculture (CSA) has been recognized as a key strategy for mitigating the effects of climate change. However, there has been a minimal level of adoption of CSA among smallholder farmers in southern Africa. Factors contributing to the limited adoption of CSA include poor access to resources by smallholder farmers, poverty, poor infrastructure, and an inadequate level of farmer advisory and resource service provision. These are the same factors that have resulted in the increased vulnerability of smallholder farmers to climate shocks in southern Africa. Currently, there are a limited number of reviews that simultaneously address the impacts of climate change and CSA on southern Africa's smallholder agricultural sector. The current review synthesizes information on the contribution of smallholder agriculture to food security in southern Africa, highlighting the vulnerability of smallholder agriculture to climate shocks and the effect of CSA activities practiced in the region. To come up with this writeup, we reviewed information from reliable, published journal articles, institutional reports, and our knowledge of agricultural systems in southern Africa. The adoption of CSA agriculture can be enhanced by the advancement of favorable policies by national governments. This includes adequate participation from smallholders, particularly women, in governance via bottom-up policymaking.

Keywords: adaptation; mitigation; crop production; livestock production; farmers; SADC; greenhouse gas

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Citation: Mutengwa, C.S.; Mnkeni, P.; Kondwakwenda, A. Climate-Smart Agriculture and Food Security in Southern Africa: A Review of the Vulnerability of Smallholder Agriculture and Food Security to Climate Change. *Sustainability* **2023**, *15*, 2882. https://doi.org/10.3390/su15042882

Academic Editor: Hossein Azadi

Received: 10 November 2022
Revised: 15 January 2023
Accepted: 31 January 2023
Published: 5 February 2023

1. Introduction

Climate change, combined with increased population growth, poses a threat to global food security. Hence, a corresponding increase in sustainable food production is required to meet the rising food demand and manage the effects of climate change. Southern Africa is the region most vulnerable to the effects of climate change, owing to its low adaptability and its reliance on agriculture. In this region, food demand continues to rise due to rapid growth in the population coupled with urbanization [1,2]. Southern Africa's population is currently estimated to be 224 million, and it is expected to rise to 241 million by 2050. Similar to the rest of the developing world, southern Africa should double its food production to meet the rising demand in both the quality and quantity of food.

According to the FAO [3], food security is the condition in which all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. However, it is a huge task for southern Africa to achieve food security given the multiplestressor environment within which agriculture is practiced in this region. It is well-acknowledged that climate change largely contributes to poor agricultural productivity and food insecurity in southern Africa and other developing nations [4,5]. Extreme weather events, such as unpredictable weather, heat stress, frequent droughts, floods, temperature increases, and pest invasions, are all manifestations of climate change that have negative effects on southern Africa's agriculture [4–6].

In southern Africa, heavy reliance on rainfed agriculture, particularly in rural areas, and limited adaptation ability expose the region to different climate shocks [7,8]. In southern Africa and in the majority of Africa, there are weak institutional, financial, and technological capabilities that increase the possibility of adverse effects from climate change [8,9]. There is little knowledge on how climate change interacts with various developmental factors in smallholder agricultural systems in southern Africa. Such knowledge is becoming more crucial for assessing the evolution of farming systems in response to climate change [10]. It is critical for advising sound policies that influence the sustainability of agriculture in the face of climate change [5]. The implementation of sound policies will, in turn, reduce the impact of climate change on the livelihoods of smallholder farmers in the region. Countries can devise short-, medium-, and long-term adaptation and mitigation plans relating to national food security and other developmental objectives. Such plans strengthen agricultural systems by enabling appropriate and timely climate action [11].

Some of the challenges posed by climate change to food security can be addressed through climate-smart agriculture (CSA), which is becoming more widely recognized as a sustainable solution to the effects of climate change on agriculture [12,13]. CSA aims to improve the attainment of national food security and strategic development goals by sustainably boosting outputs and incomes, promoting resilience (adaptation), and reducing greenhouse gas emissions (mitigation) [14]. CSA encourages the development of innovative agricultural methods and systems, and it paves the way for more-sustainable policies that incorporate environmental stewardship. Although CSA is widely known in southern Africa, its promotion and adoption are still in their infancy, and consequently, smallholder farmers in the region have been left exposed to the adverse effects of climate change [15].

There are few reviews evaluating smallholder agriculture in southern Africa within the context of the threats posed by climate change and potential CSA approaches that are applicable to the region. Current reports on this topic are either disjointed or have a narrow scope. Therefore, the present review aims to (i) compile information on the status, significance, and contribution of smallholder agriculture to food security in southern Africa; (ii) assess the vulnerability of southern African smallholder farmers to climate shocks; and (iii) identify the CSA activities most suited to southern African smallholder farming systems.

2. Status and Importance of Smallholder Agriculture in Southern Africa

The majority of the Southern African Development Community (SADC) member states depend heavily on agriculture to sustain rural livelihoods and economic growth. Apart from South Africa, smallholder farmers constitute the bulk of farmers in the rest of the SADC states. In most SADC nations, the agricultural sector provides food, income, and employment for almost 70% of the population [1]. Additionally, agriculture is one of the main drivers of the gross domestic product (GDP) of most SADC nations. When South Africa is excluded from the analysis, the estimated contribution of agriculture to SADC nations' GDPs rises to 16%, and for low-income nations, it can even reach 21% [1]. Agriculture in southern Africa also accounts for roughly 13% of the region's total export revenue. Clearly, the performance of the agricultural sector in southern Africa significantly impacts the region's food security, economic growth, and social and political stability [1]. However, for most SADC countries, it is difficult to attain food security because of poor agricultural outputs and limited development. Poor agricultural performance results from several factors, including poor market access, limited incentives for agricultural intensification, poor soil fertility, and unfavorable policies [16]. Climate change adds more strain to this already-struggling sector in southern Africa. Therefore, unless adequate, sustainable measures are taken, food and nutritional insecurity will most likely continue to rise in southern Africa, posing a threat to the livelihoods of millions of marginalized people who are directly or indirectly reliant on agriculture.

2.1. Rainfed and Irrigated Agriculture

In southern Africa, most agricultural activities are carried out under a rainfed system. Therefore, agricultural productivity is subject to significant seasonal rainfall variations induced by climate change. For nations where agriculture is a major economic driver, inter-annual rainfall variability has been linked to variations in agricultural GDP [5]. Thus, in SADC states, irrigation is linked to increased agricultural GDP growth and productivity [17]. Consequently, one of the agricultural production goals outlined in the SADC Regional Indicative Strategic Development Plan (RISDP) is to double the average area of cropland under irrigation in the SADC region from 3.5% to 7% [17]. However, according to Chilonda et al. [17], Madagascar (37%), Mauritius (20%), Swaziland (28%), and South Africa (30%) were the only countries that met the SADC RISDP irrigation target. At least 15% of cropland is under irrigation in Madagascar, Swaziland, and Mauritius. In contrast, less than 5% of cropland in Angola, Botswana, DRC, Malawi, Namibia, Tanzania, Lesotho, Mozambique, and Zimbabwe is irrigated [17].

2.2. Crop Production

Cereal crops are the most-commonly traded agricultural commodities in southern Africa. They are the main source of sustenance for the majority of people. Cereals take up more than 50% of the region's agricultural land, with maize making up more than 40% of the total harvested area [18]. Other significant crops include millet and sorghum, particularly in arid regions, while wheat is grown under irrigation in most SADC states. If the productivity of the aforementioned grains does not increase to meet the rising demand, sustained levels of food security and economic growth will not be possible in the SADC region. The per capita cereal production in the SADC region has progressively decreased over the past 5 years by 15.3% due to both slower growth rates for cereal production and population growth, which has increased the demand for food imports [19]. On average, a typical sub-Saharan African (SSA) farmer only produces 1 t/ha of cereals annually [19]. Between 2020 and 2022, cereal yields were forecast to increase in Madagascar by 3.6%, while they were expected to decrease in Malawi by 14.1%, in Mozambique by 4.5%, in South Africa by 8.5%, in Zambia by 22.2%, and in Zimbabwe by 42.3% [19]. Thus, USAID [20] has indicated that a keyway to enhance food security, improve incomes, combat poverty, and reduce food-importation costs in southern Africa is to increase cereal productivity.

2.3. Animal Production

Since crop production has been compromised by various climate-change-related factors, including unpredictable rainfall and marginal soils, animal production is a suitable alternative in around 70% of the agricultural area in the majority of subtropical nations [21]. The livelihoods of rural communities significantly benefit from the production of livestock, both directly and indirectly. Up to 50% of the household income in rural African communities comes from livestock, with beef and dairy cattle, goats, sheep, and poultry accounting for 92% of the total income [22]. Excluding cattle-holding for savings, the net annual worth of the direct benefits from livestock in a communal region of South Africa was calculated to be USD 656 per household. This contribution's net worth was equal to 22.7% of the total value of the other sources of revenue that were taken into account [23]. In Mozambique, cattle production contributes 6% of agriculture's ~26% contribution to the national GDP [24].

3. Vulnerability of Smallholder Agriculture to Climate Change

Climate-induced vulnerability refers to the degree to which a farming system is susceptible and unable to cope with the effects of climate change, including variability and extremes in the weather [25]. Southern Africa has a low capacity for appropriate response, which contributes to its high vulnerability to climate change. Agriculture is subject to a multistressor setting linked to global environmental, economic, and sociopolitical change processes. Mapfumo et al. [26] list the following as the main factors that cause smallholder agricultural communities in many southern African countries to be particularly vulnerable to climate change: (i) a high reliance on crop production systems that are sensitive to climate change; (ii) low and declining soil productivity; (iii) land degradation and a declining natural resource base; (iv) the weakening of local institutions and conventional social safety-net systems; (v) an inadequate and dwindling capital resource base; (vi) a lack of timely access to crop production input and output markets; and (vii) a high prevalence of HIV/AIDS, malaria, and other diseases.

Implications of Climate Change on Smallholder Agriculture and Food Security

Considering that Africa's agriculture industry is the most vulnerable to climatic extremes, all four aspects of food security—availability, accessibility, utilization and stability—are impacted by climate change [27]. The CDKN [27] projected that, because of their high sensitivity, underprivileged groups in Africa, including women, children, the elderly, and people living with disabilities, will experience the adverse effects of climate change more than others. In the worst situations, the relative economic cost of climatic extremes might reach 8% of the GDPs of developing nations [5]. For instance, Namibia may incur yearly losses of 1 to 6% of its GDP, with the most severe effects anticipated to be experienced by fisheries, traditional agriculture, and animal production, resulting in a total annual loss of USD 461–2045 million by 2050 [27]. Food availability, accessibility, nutrition, and stability would all suffer from decreased agricultural production [28]. Global food prices are expected to increase as a result of unpredictable food production brought on by climate change [28]. Increased food demand due to population expansion, rapid urbanization, and increasing wealth in developing nations will likely exacerbate this situation [28].

4. Climate-Smart Agriculture: A Response to the Global Challenge of Climate Change

It is understood that anthropogenic greenhouse gas (GHG) emissions are primarily to blame for global warming, its associated effects on the overall climate, and its detrimental implications for agricultural production. Ironically, agriculture also plays a part in the production of greenhouse gases and global warming. According to estimates, the production of crops and animal products, along with related changes in land use and cover, contributes roughly 10 to 12 Gt CO_2 equivalents per year, which is 24% of the world's GHG emissions [28,29]. Southern Africa, with 27%, is the second-largest producer of agriculture-related GHG emissions on the African continent, after East Africa, which is responsible for 34% [30]. Climate-smart agriculture (CSA) not only provides a strategy for tackling the escalating food security crisis in southern Africa, but it can also contribute to reducing GHG emissions. In a triple win, CSA presents an opportunity to simultaneously reduce agricultural GHG emissions, contribute to sustainable improvements in agricultural productivity, and contribute to increased incomes and food security (Figure 1). There is evidence that this strategy can improve farmers' ability to adjust to long-term climatic shocks and reduce the negative consequences of climate change on food value chains [31,32].

4.1. CSA Initiatives in Southern Africa

Smallholder and commercial agriculture are the two categories of farming systems in southern Africa, with the smallholder sector predominating in the majority of the countries in the region. Dixon et al. [33] further describes smallholder farming practices as predominately "maize-mixed systems and rain-fed". Similar to other regions of SSA, crop yields from these smallholder farms typically vary from 0.5 to 2.0 tons per hectare for grains and legumes [28]. Adaptation and mitigation strategies for both crops and livestock are separately explored below as potential CSA management actions in SADC member states.

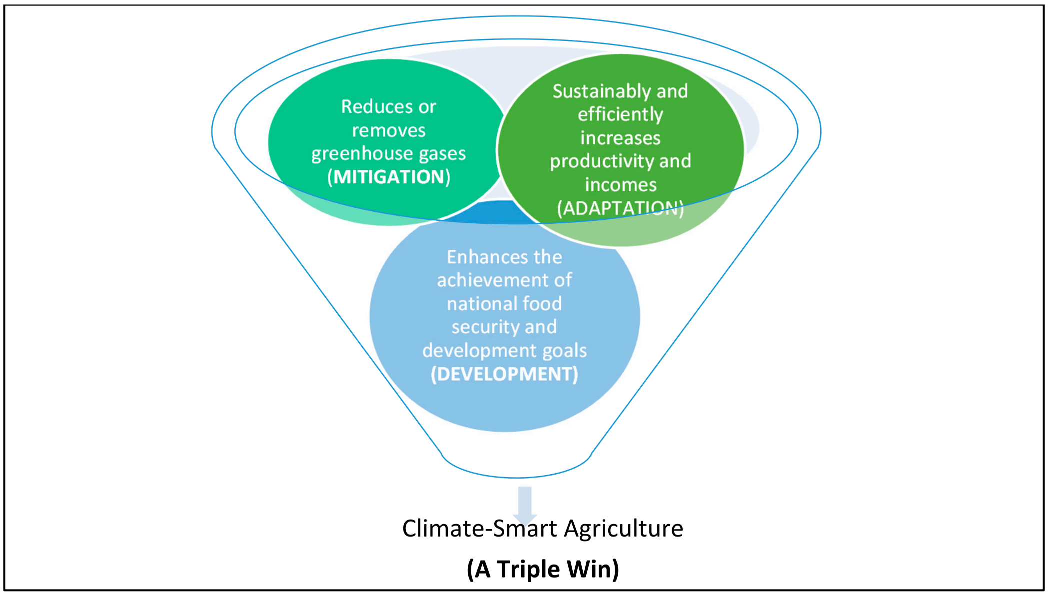

Figure 1. Climate-smart agriculture: a triple-win technology for enhancing food security in SSA. Adopted from the FAO [14].

4.1.1. Adaptation Strategies

Crop Management

Southern Africa urgently needs adaptation methods since climate change is expected to drastically diminish crop productivity, and particularly that of the key cereal crops [34,35]. The alternatives for crop-based climate-change adaptation studied in southern Africa are listed in [26]. These are also mentioned below in relation to scoping studies on CSA that the Food, Agriculture, and Natural Resources Policy and Analysis Network (FANRPAN) implemented in 2014.

Crop Diversification and the Use of Abiotic Stress-Tolerant Cultivars

Botswana, Namibia, South Africa, Swaziland, and Zimbabwe are among the countries that are pursuing crop diversification (cereals and legumes) and the utilization of stress-tolerant cultivars [36–40]. According to Munkeni and Mutengwa [38], crop cultivars that are resistant to heat and water stresses are continuously being developed in South Africa as a response to the country's periodic droughts and heat waves. Kondwakwenda et al. [41], indicated that open-pollinated maize types and hybrids and bean varieties that are tolerant to various stresses have been developed in SSA over the past few decades. The development of stress-tolerant crop varieties in Africa under various project code-names has been implemented by the International Research Centers, which are part of the Consultative Group on International Agricultural Research (CGIAR), in collaboration with the National Agricultural Research Systems (NARS) and private seed companies. For instance, the Water Efficient Maize for Africa (WEMA) project was carried out by South Africa's Agricultural Research Council (ARC) in collaboration with CIMMYT, the African Agricultural Technology Foundation (AATF), Monsanto, and other NARS institutions to produce drought-tolerant maize hybrids, some of which have been released in southern Africa [41]. The Improved Maize for African Soils (IMAS) project was a collaboration between the ARC, the Kenya Agricultural Research Institute, and the Pannar Seed company that aimed to create cultivars resistant to low nitrogen levels. The cultivars released under the above-mentioned projects are positively impacting livelihoods through food and nutrition security [41].

Studies on orphaned crops are increasing in South Africa and other parts of the SADC region. Orphaned crops give farmers a way to diversify their businesses, and they include various tuberous, leguminous, cereal, and root crops. Typical examples of orphaned crops include native green vegetables, such as Cleome *(Cleome gynandra)* and Amaranthus species, as well as cassava *(Manihot esculenta)*, pigeon pea (Cajanus cajan L.), and pearl millet [42]. Commercial and smallholder farmers in South Africa's Western Cape Province propagate the carob *(Ceratonia silliqua)*, a drought-resistant evergreen tree [38].

Management of Pests, Diseases, and Weeds

Another anticipated consequence of climate change in southern Africa and other regions is an increase in the spread and establishment of new diseases, weeds, and insect pests. It is anticipated that new insect pests and diseases will be more virulent than existing ones [6]. In their study, Mafongoya et al. [6] found that aphids, whiteflies, red spider mites, and thrips were becoming more prevalent in South Africa and Zimbabwe. The first emergence of the tomato torrado virus (ToTV) in Africa was also reported by Mafongoya et al. [6].

An effective technique for handling the pressure caused by insect pests and diseases that are climate-change related is continuous surveillance combined with integrated pest management (IPM). The Agricultural Research Council (ARC) of South Africa carries out yearly surveys to determine the virulence status of the pests and diseases of significant crops [38]. Breeding offers a long-term remedy for contemporary and historical pests. Plant breeders use both conventional and modern breeding techniques to increase a crop's resilience to particular pests and diseases [41,43].

Improving Access to and the Use of Soil, Water, and Natural Resource Management Technologies

Curbing the effects of climate change requires using cutting-edge and tried-and-true indigenous land farming methods, such as integrated soil fertility management (ISFM), conservation agriculture (CA), land restoration technology, and water management strategies and procedures. ISFM is a climate-smart approach because it enhances soil carbon and boosts crop outputs while judiciously integrating chemical fertilizers, organic inputs, and improved germplasm [28]. Nkonya et al. [44] have shown that applying nitrogen and manure together boosts returns by 58%, as compared to applying nitrogen alone. Several biophysical and socioeconomic factors impact how widely ISFM is used. However, the soil health program of the Alliance for a Green Revolution in Africa (AGRA) has shown through its "Going Beyond Demos" effort that the adoption of ISFM can be significantly boosted [28].

Zero- and minimum tillage techniques, for example, can increase soil organic matter levels and, as a result, water storage and retention. In addition, agroforestry systems that mix shallow-rooted plants with deep-rooted trees can be employed to better utilize the moisture in the soil [15]. Reverse-slope terraces and water-harvesting technologies are part of an integrated water management solution for rainfed systems. So far, it is too early to quantify the performance of these coping strategies with regard to climate-change mitigation in various regional ecological zones. Nevertheless, some of the strategies are under trial in a number of SSA countries, including Zimbabwe (CA, ISFM) [40], Lesotho (CA, relay cropping, intercropping, basin agriculture, and pit planting) [45], Malawi (CA and Agroforestry) [15], and South Africa (CA and infield rainwater collection) [38].

Developing Infrastructure for Irrigation in Smallholder Farming Areas

A large portion of southern Africa experiences water shortages that restrict the growth of dryland crops due to low and unpredictable rainfall coupled with high evaporative demand. Irrigated agriculture is a key choice for increasing crop productivity in these circumstances. Namibia and South Africa have made large expenditures in the construction of irrigation infrastructure [37,38]. About 30% of the irrigated area in southern Africa is located in South Africa, where irrigation has been developed the most [28]. Irrigation, however, is more advanced in South Africa's commercial sector than in the smallholder sector. Smallholder irrigation schemes in South Africa also function poorly, as seen by the low maize grain yields, which average less than 3 t/ha, a situation which is mostly the result of poor management [46]. Accordingly, Van Averbeke et al. [46] have concluded that investing in farmer capacity and competence-building should accompany the construction of irrigation infrastructure so as to increase scheme performance. Thus, other nations in the region that are considering investing in the development of irrigation for smallholders would find a valuable lesson in South Africa's experience.

Livestock Management

Because livestock production is so susceptible to climate change, adaptation methods are crucial for sustaining productivity in a rapidly changing climate. Additionally, this industry must implement strategies for mitigating erosion because livestock systems significantly contribute to greenhouse gas emissions, water depletion, and large soil losses [47]. The implementation of this strategy in southern Africa includes the readjustment of stocking rates and timing to coincide with pasture productivity and the application of additional feeds [48]. The use of adapted breeds, such as Afrikaner, Nguni, Boer goats, and hybrids of native and foreign breeds, is proving to be a smart strategy for increasing livestock's resistance to the harsh conditions caused by climate change [49].

Better Use of Short-Term and Seasonal Climate Forecasting

By promptly informing farmers and other stakeholders about disasters, effective early warning systems (EWSs) can improve farming communities' resilience to the effects of climate change. Many EWSs are utilized across the entire SADC area to provide daily and monthly extreme weather alerts. The Wide Area Monitoring Information System (WAMIS), which offers near real-time monitoring and mapping capabilities of natural events, including fires, floods, and droughts, and the Advanced Fires Information System (AFIS), a satellite-based fire information tool, are two examples of EWSs that are active in the SADC region [38].

4.1.2. Mitigation Strategies

Taruvinga et al. [49] have asserted that the following four major strategies can be used to reduce GHG emissions from agricultural ecosystems and are applicable to southern Africa in the context of CSA.

Cropland Management

Agroforestry, crop rotation, fertilizer management, residue management, water management, and land use are examples of excellent agricultural and water-management methods that contribute to climate-change mitigation [49]. These methods increase agricultural productivity and income in addition to reducing GHG emissions. For instance, by implementing zero- or minimum tillage, conservation agriculture can significantly cut CO_2 emissions through reduced fossil-fuel use. Lesser soil disturbance is also linked to lower atmospheric CO_2 emissions because it encourages less exposure of soil organic matter to oxidation. The retention of agricultural residues also increases soil carbon in the surface layers, which aids in the sequestration of CO_2. Low fertilization rates under CA technology contribute to reducing atmospheric N_2O emissions by increasing fertilizer-use efficiency.

Grazing Land Management and Pasture Improvement

Legumes can be planted to diversify pasture species on grazing and pasture land, which reduces CH_4 emissions [50]. Keeping animal density at appropriate levels in a grazing system lowers CH_4 emissions. However, farmers typically oppose this strategy because of the associated opportunity cost [5]. By rehabilitating unproductive areas, preventing further degradation, and improving veld conditions, the Red Meat Production Association (RPO) in South Africa promotes sound forage management techniques that maximize efficiency in livestock production systems with a minimal adverse impact on the environment [49].

Livestock Management

Methane emissions associated with the rearing of cattle can be decreased by controlling cattle diets, ruminal microbiota, feed processing, and feed intake. On the other hand, livestock productivity can be increased by enhancing diet quality, removing nutrient deficiencies, employing growth promoters, and selecting the right breeds [51]. This enables farmers to maintain a reasonable amount of cattle. Methane levels related to the rearing of ruminants' can be reduced by increasing their intake of tannin-rich vegetables. According to previous reports, the moringa plant *(M. oleifera Lam.)* has an excellent nutritional profile that could boost animal output [52]. The improved chemical composition, color, and lipid stability of meat have been attributed to the anti-oxidative potential of M. oleifera leaves [53]. It has been revealed that adding *Acacia karroo* to natural pastureland improved the quality and protein content of beef, while also giving it a fresher appearance [54].

Manure Management

Manure management as mitigation strategy aims to lower the CH_4 emissions in manure through wise use and management [49]. Ruminant cattle fed on high-protein concentrates produce manure that has a high methane-production capacity [55]. As a result, this type of manure is perceived as being ideal for anaerobic digesters.

5. Adoption of CSA Technologies by Smallholder Farmers in Southern Africa

The aforementioned adaptation and mitigation measures, along with others, have mostly undergone experimental testing. Their adoption and application in southern Africa vary depending on the size of farming operations. Commercial farmers have adopted CSA technologies more quickly than smallholder farmers because they have a larger capital base and stronger organizational capabilities. In southern Africa, only South Africa has a sizable commercial industry, and farmers of crops and livestock actively investigate and use CSA technologies [38]. In the rest of southern Africa, in which smallholder farmers dominate the agricultural sector, there has been a relatively low adoption of CSA methods, and those nations are most susceptible to the negative effects of climate change [26].

The main challenges associated with the implementation and promotion of CSA methods in southern Africa include the lack of human and material resources [8]. Financial and technological limitations place a limit on material capacity. The majority of the CSA technologies that are currently promoted in southern Africa, such as improved seeds and machinery for agroecological techniques, including conservation agriculture, are imported. This results in high costs for farmers at the community level and for the economy at the national level. Inadequate human resource capacity is caused by a shortage of extension personnel who have been trained in CSA technologies. Poor policy coherence, which is reflected in inadequate cross-sectoral coordination and occasional disagreement among several ministries or departments handling climate and agricultural policies, is another major challenge in the implementation of CSA. This challenge has led to a non-synergistic approach and perverse incentives that obstruct the promotion of CSA practices. For instance, conventional tilling receives greater subsidies than no-tillage farming in Botswana [36] and South Africa [38]. Other challenges that hamper the effective implementation of CSA are the limited incorporation of the of the smallholder sector and the lack of gender responsiveness in governance. This is evidenced by the top-down policymaking system and the traditional patriarchal institutions that discriminate against or forbid women from owning or inheriting land, claiming credit, or participating in decision-making [38]. Table 1 shows some of the CSA options or supporting measures of CSA that have been implemented in some of the SADC member states.

Table 1. Some of the CSA options or supporting measures of CSA implemented in some of the SADC member states.

SADC State	CSA Option or Supporting Measure	CSA Point of Action or Technology Summary Description	References
Botswana	Capacity-building	Building the capacity of national and local institutions to promote the integration of traditional practices with CSA into crop and livestock production systems	[56]
Mozambique	Climate-smart varieties	Biotic- and abiotic-stress-tolerant sweet potato varieties have shown increased yields over local ones under harsh condition such as drought and intense heat	[57]
	Use of organic manure and mulch	Most production systems and plantations across the country commonly use organic manure, particularly from poultry, pigs, and cows	[56]
	Crop production under shade houses	The use of shade houses as cropping environments was initiated decades ago in Seychelles. The main advantages of using shade houses over traditional farming is that crops grown under shaded environments are protected from harsh weather conditions and have minimal exposure to pests and diseases.	[56]
	Early warning systems	The use of weather information in agriculture activities was promoted by the World Meteorological Organization and the State Agency for Meteorology in Seychelles since 2000 through various projects. They are improving agriculture through seasonal forecasting and the use of climate information for making key decisions, such as the choice of planting dates	[56]
South Africa	Efficient water management	The use of more-efficient irrigation methods, such as drip irrigation and sensor-based technologies to ensure that only the required amount of water is applied since the water supply is limited. In addition, the use of efficient irrigation scheduling methods	[58]
Zambia	Conservation agriculture	Nongovernmental organizations have been instrumental in spearheading the promotion of conservation agriculture in Zambia for over 20 years. Minimum soil tillage, continuous soil cover, and crop rotation are practiced under this technology. Minimum tillage is implemented via hand-hoe basins, ox-drawn ripping, and tractor ripping.	[59–61]
Zimbabwe	Pfumvudza/Intwasa	The Zimbabwean government has recently adopted the Pfumvudza farming concept, which is a derivative of conservation agriculture in which farmers utilize small pieces of land and apply the correct agronomic practices to achieve higher returns. The agronomic practices follow the principles of conservation.	[62,63]

The meaningful application of CSA in southern Africa depends on the success in overcoming the issues discussed above. In order to achieve this, the FAO [56] has presented numerous proposals, the implementation of which could enhance the mainstreaming of

CSA methods in southern Africa to ensure sustainable food production in a changing environment. These include the following:

1. To boost human and technical development, promote sustainability and reduce overreliance on donor aid, there is a need for increased budgetary allocation and investments in CSA in southern Africa. This can be accomplished through technology transfer and capacity-building that go beyond the exporting of technological goods but aim to support endogenous African scientific and technological growth that builds on indigenous knowledge that is related to CSA.
2. Enabling government policies should be enacted in relation to CSA, its promotion, and implementation. To do this, existing policies, including those on subsidies, tax breaks, and credits, would need to be revised to remove skewed incentives and to better align them with CSA strategies. To minimize conflicts and establish synergies for the adoption of CSA, there should be coherence across policies from several ministries and sectors.
3. The equitable involvement of all stakeholder groups in agricultural governance and meaningful representation of smallholder farmers and other marginalized groups will ensure inclusion in the formulation of agendas, policies, and decisions related to agricultural development and adaptation to climate change. Additionally, the provision of extension services needs to be restructured into a "two-way" extension services system in which both farmers and extension officers have the opportunity to share their knowledge and experiences. This will encourage the mutual sharing of ideas and the continued improvement of scientific knowledge and skills that incorporate useful traditional indigenous knowledge [56].

6. Conclusions

Southern Africa's economic development and rural livelihoods rely heavily on agriculture as a source of food, income, and employment. Consequently, the performance of the agricultural sector has a significant impact on food and nutritional security, economic growth, and social and political stability. Smallholder agriculture is extremely vulnerable to climate change due to several stressors, such as a lack of knowledge about climate change and weak institutional, financial, and technological capabilities. Therefore, the livelihoods of millions of farmers who depend on the production of crops and livestock are in danger. The implementation and adoption of CSA in southern Africa can yield benefits in three ways: by reducing agricultural GHG emissions, by contributing to sustainable improvement in agricultural productivity, and by contributing to increased incomes and food security in the region. While some CSA technological packages have been implemented by the commercial farming sector, relatively few innovations have been embraced by the smallholder sector in the SADC region due to the several barriers highlighted in this review. Some of the key CSA technologies that are applicable or have been implemented in some SADC countries include the use of climate-smart crop varieties, CA, the use of organic manure and mulch, and efficient water management practices. The barriers to adoption can be overcome by coordinated efforts involving different stakeholders. Reducing overreliance on donor aid, enacting CSA-enabling polices, and ensuring the equitable involvement of all stakeholders can help to enhance the adoption of CSA technologies in southern Africa.

Author Contributions: C.S.M. wrote the first draft of the paper, while P.M. and A.K. critiqued, proofread, and improved the content and structure of the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study did not require ethical approval.

Informed Consent Statement: The study did not involve humans.

Data Availability Statement: Data sharing is not applicable to this article.

Acknowledgments: The authors would like to acknowledge the University of Fort Hare for funding the salary of the third author as a postdoctoral fellow through the Gavan Mbeki Research and Development Center.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Southern African Development Community (SADC). *Regional Indicative Strategic Development Plan (RISDP) 2020–2030*; Southern African Development Community (SADC): Gaborone, Botswana, 2020. Available online: https://www.sadc.int/sites/default/files/2021-08/RISDP_2020-2030.pdf (accessed on 15 January 2023).
2. Msangi, J.P. Population, Agriculture, Poverty and Food Security: An Overview. In *Food Security among Small-Scale Agricultural Producers in Southern Africa*; Msangi, J.P., Ed.; Springer International Publishing: Cham, Switzerland, 2014; pp. 1–19.
3. FAO. *Declaration on World Food Security and World Food Summit Plan of Action, 1996*; FAO: Rome, Italy, 1996; pp. 13–17.
4. Masipa, T. The impact of climate change on food security in South Africa: Current realities and challenges ahead. *Jàmbá J. Disaster Risk Stud.* **2017**, *9*, 1–7. [CrossRef] [PubMed]
5. Thornton, P.K.; Ericksen, P.J.; Herrero, M.; Challinor, A.J. Climate variability and vulnerability to climate change: A review. *Glob. Chang. Biol.* **2014**, *20*, 3313–3328. [CrossRef]
6. Mafongoya, P.; Gubba, A.; Moodley, V.; Chapoto, D.; Kisten, L.; Phophi, M. Climate Change and Rapidly Evolving Pests and Diseases in Southern Africa. In *New Frontiers in Natural Resources Management in Africa*; Ayuk, E.T., Unuigbe, N.F., Eds.; Springer International Publishing: Cham, Switzerland, 2019; pp. 41–57.
7. Parry, M.L.; Canziani, O.; Palutikof, J.; Van der Linden, P.; Hanson, C. *Climate Change 2007-Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the IPCC*; Cambridge University Press: Cambridge, UK, 2007; Volume 4.
8. Lima, M.G.B. *Policies and Practices for Climate-Smart Agriculture in Sub-Saharan Africa: A Comparative Assessment of Challenges and Opportunities across 15 Countries*; JSTOR: New York, NY, USA, 2016.
9. Shiferaw, B.; Prasanna, B.; Hellin, J.; Banziger, M. Feeding a hungry world: Past successes and future challenges to global food security in maize. *Food Secur.* **2011**, *3*, 307–327. [CrossRef]
10. Thornton, P.K.; van de Steeg, J.; Notenbaert, A.; Herrero, M. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agric. Syst.* **2009**, *101*, 113–127. [CrossRef]
11. Loboguerrero, A.M.; Campbell, B.M.; Cooper, P.J.; Hansen, J.W.; Rosenstock, T.; Wollenberg, E. Food and earth systems: Priorities for climate change adaptation and mitigation for agriculture and food systems. *Sustainability* **2019**, *11*, 1372. [CrossRef]
12. Brohm, K.-A.; Klein, S. The concept of climate smart agriculture—A classification in sustainable theories. *Int. J. Qual. Res.* **2020**, *14*, 291–302. [CrossRef]
13. Chandra, A.; McNamara, K.E.; Dargusch, P. Climate-smart agriculture: Perspectives and framings. *Clim. Policy* **2018**, *18*, 526–541. [CrossRef]
14. FAO. *Climate-SmartAgriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2010.
15. Amadu, F.O.; McNamara, P.E.; Miller, D.C. Understanding the adoption of climate-smart agriculture: A farm-level typology with empirical evidence from southern Malawi. *World Dev.* **2020**, *126*, 104692. [CrossRef]
16. Nhemachena, C.; Matchaya, G.; Nhemachena, C.R.; Karuaihe, S.; Muchara, B.; Nhlengethwa, S. Measuring baseline agriculture-related sustainable development goals index for Southern Africa. *Sustainability* **2018**, *10*, 849. [CrossRef]
17. Chilonda, P.; Matchaya, G.; Chiwaula, I.; Kambewa, P.; Musaba, E.; Manyamba, C. *Agricultural Growth Trends and Outlook for Southern Africa: Enhancing Regional Food Security Throughincreased Agricultural Productivity*; ReSAKSS-SA Annual Trends and Outlook Report; International Food Policy Research Institute (IFPRI) and the International Water Management Institute (IWMI): Pretoria, South Africa, 2011.
18. Hachigonta, S.; Nelson, G.C.; Thomas, T.S.; Sibanda, L.M. *Southern African Agriculture and Climate Change: A Comprehensive Analysis*; International Food Policy Research Institute: Washington, DC, USA, 2013; Volume 3.
19. FAO. *Crop Prospects and Food Situation—Quarterly Global Report No. 2, July 2022*; FAO: Rome, Italy, 2022. [CrossRef]
20. USAID/Southern Africa. Regional Development Cooperation Strategy 2011–2017. Available online: https://2012-2017.usaid.gov/sites/default/files/documents/1860/Southern_Africa_RDCS_2011-2017.pdf (accessed on 17 December 2022).
21. Scholtz, M.; van Ryssen, J.v.; Meissner, H.; Laker, M.C. A South African perspective on livestock production in relation to greenhouse gases and water usage. *S. Afr. J. Anim. Sci.* **2013**, *43*, 247–254. [CrossRef]
22. Rust, J.; Rust, T. Climate change and livestock production: A review with emphasis on Africa. *S. Afr. J. Anim. Sci.* **2013**, *43*, 255–267. [CrossRef]
23. Dovie, D.B.; Shackleton, C.M.; Witkowski, E.T. Valuation of communal area livestock benefits, rural livelihoods and related policy issues. *Land Use Policy* **2006**, *23*, 260–271. [CrossRef]
24. Karanja Ng'ang'a, S.; Ritho, C.; Herrero, M.; Fraval, S. Household-oriented benefits largely outweigh commercial benefits derived from cattle in Mabalane District, Mozambique. *Rangel. J.* **2018**, *40*, 565–576.

25. Field, C.B.; Barros, V.; Stocker, T.F.; Dahe, Q. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK, 2012.
26. Mapfumo, P.; Jalloh, A.; Hachigonta, S. Review of research and policies for climate change adaptation in the agriculture sector in Southern Africa. *Future Agric. Work. Pap.* **2014**, *100*, 59.
27. CDKN (Climate and Development Knowledge Network). Managing Climate Extremes and Disasters in Africa: Lessons from the SREX Report. 2012. Available online: www.cdkn.org/srex (accessed on 6 February 2015).
28. Alliance for a Green Revolution in Africa (AGRA). *Africa Agriculture Status Report: Climate Change and Smallholder Agriculture in Sub-Saharan Africa*; AGRA: Nairobi, Kenya, 2014; Available online: http://www.agra.org (accessed on 15 January 2015).
29. Tubiello, F.N.; Salvatore, M.; Cóndor Golec, R.D.; Ferrara, A.; Rossi, S.; Biancalani, R.; Federici, S.; Jacobs, H.; Flammini, A. *Agriculture, Forestry and Other Land Use Emissions by Sources and Removals by Sinks*; FAO: Rome, Italy, 2014.
30. Tongwane, M.I.; Moeletsi, M.E. A review of greenhouse gas emissions from the agriculture sector in Africa. *Agric. Syst.* **2018**, *166*, 124–134. [CrossRef]
31. Hasan, M.K.; Desiere, S.; D'Haese, M.; Kumar, L. Impact of climate-smart agriculture adoption on the food security of coastal farmers in Bangladesh. *Food Secur.* **2018**, *10*, 1073–1088. [CrossRef]
32. Nyasimi, M.; Amwata, D.; Hove, L.; Kinyangi, J.; Wamukoya, G. *Evidence of Impact: Climate-Smart Agriculture in Africa*; CCAFS Working Paper; CCAFS: Copenhagen, Denmark, 2014.
33. Dixon, J.A.; Gibbon, D.P.; Gulliver, A. *Farming Systems and Poverty: Improving Farmers' Livelihoods in a Changing World*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2001.
34. Wang, J.; Vanga, S.K.; Saxena, R.; Orsat, V.; Raghavan, V. Effect of climate change on the yield of cereal crops: A review. *Climate* **2018**, *6*, 41. [CrossRef]
35. Tesfaye, K.; Gbegbelegbe, S.; Cairns, J.E.; Shiferaw, B.; Prasanna, B.M.; Sonder, K.; Boote, K.; Makumbi, D.; Robertson, R. Maize systems under climate change in sub-Saharan Africa: Potential impacts on production and food security. *Int. J. Clim. Chang. Strateg. Manag.* **2015**, *7*, 247. [CrossRef]
36. Batisani, N. *A Comprehensive Scoping and Assessment Study of Climate Smart Agriculture Policies in Botswana Report*; A Study Commissioned; The Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN): Pretoria, South Africa, 2014.
37. Iijima, M.; Awala, S.K.; Nanhapo, P.I.; Wanga, A.; Mwandemele, O.D. Development of flood-and drought-adaptive cropping systems in Namibia. In *Crop Production under Stressful Conditions*; Springer: Singapore, 2018; pp. 49–70.
38. Mnkeni, P.; Mutengwa, C. *A Comprehensive Scoping and Assessment Study of Climate Smart Agriculture (CSA) Policies in South Africa*; FANRPAN: Pretoria, South Africa, 2014.
39. Manyatsi, A.; Mhazo, N. *A Comprehensive Scoping and Assessment Study of Climate Smart Agriculture policies in Swaziland*; Food, Agriculture and Natural Resources Policy Analysis Network: Pretoria, South Africa, 2014; Volume 38.
40. Manzungu, E. *A Comprehensive Scoping and Assessment Study of Climate Smart Agriculture (CSA) Policies in Zimbabwe*; FANRPAN: Pretoria, South Africa, 2014.
41. Kondwakwenda, A.; Mutari, B.; Simango, K.; Nchanji, E.B.; Chirwa, R.; Rubyogo, J.C.; Sibiya, J. Decades of Cultivar Development: A Reconciliation of Maize and Bean Breeding Projects and Their Impacts on Food, Nutrition Security, and Income of Smallholder Farmers in Sub-Saharan Africa. In *Food Security for African Smallholder Farmers*; Springer: Singapore, 2022; pp. 3–26.
42. Sogbohossou, E.; Achigan-Dako, E.G.; Maundu, P.; Solberg, S.; Deguenon, E.; Mumm, R.H.; Hale, I.; Van Deynze, A.; Schranz, M.E. A roadmap for breeding orphan leafy vegetable species: A case study of Gynandropsis gynandra (Cleomaceae). *Hortic. Res.* **2018**, *5*, 2. [CrossRef]
43. Sibiya, J.; Tongoona, P.; Derera, J.; van Rij, N. Genetic analysis and genotype × environment (G × E) for grey leaf spot disease resistance in elite African maize (*Zea mays* L.) germplasm. *Euphytica* **2012**, *185*, 349–362. [CrossRef]
44. Nkonya, E.; Koo, J.; Kato, E.; Guo, Z. *Trends and Patterns of Land Use Change and International Aid in Sub-Saharan Africa*; WIDER Working Paper; WIDER: Helsinki, Finland, 2013.
45. Gwimbi, P.; Likoetla, P.; Thabane, K.; Matebesi, P. *A Comprehensive Scoping and Assessment Study of Climate Smart Agriculture (CSA) Policies in Lesotho*; Food, Agriculture and Natural Resources Policy Analysis Network: Pretoria, South Africa, 2014.
46. Van Averbeke, W.; Denison, J.; Mnkeni, P. Smallholder irrigation schemes in South Africa: A review of knowledge generated by the Water Research Commission. *Water SA* **2011**, *37*, 797–808. [CrossRef]
47. Herrero, M.; Thornton, P.K.; Gerber, P.; Reid, R.S. Livestock, livelihoods and the environment: Understanding the trade-offs. *Curr. Opin. Environ. Sustain.* **2009**, *1*, 111–120. [CrossRef]
48. Campbell, B.M.; Mann, W.; Meléndez-Ortiz, R.; Streck, C.; Tennigkeit, T. Agriculture and Climate Change: A Scoping Report. 2011. Available online: https://agris.fao.org/agris-search/search.do?recordID=GB2013201604 (accessed on 21 January 2023).
49. Taruvinga, A.; Muchenje, V.; Mushunje, A. Climate change impacts and adaptations on small-scale livestock production. *Int. J. Dev. Sustain.* **2013**, *2*, 664–685.
50. Gurian-Sherman, D. *Raising the Steaks: Global Warming and Pasture-Raised Beef Production in the United States*; JSTOR: New York, NY, USA, 2011; Volume 3.
51. Haque, M.N. Dietary manipulation: A sustainable way to mitigate methane emissions from ruminants. *J. Anim. Sci. Technol.* **2018**, *60*, 15. [CrossRef]
52. Moyo, B.; Masika, P.J.; Hugo, A.; Muchenje, V. Nutritional characterization of Moringa (*Moringa oleifera* Lam.) leaves. *Afr. J. Biotechnol.* **2011**, *10*, 12925–12933.

53. Qwele, K.; Hugo, A.; Oyedemi, S.; Moyo, B.; Masika, P.; Muchenje, V. Chemical composition, fatty acid content and antioxidant potential of meat from goats supplemented with Moringa (*Moringa oleifera*) leaves, sunflower cake and grass hay. *Meat Sci.* **2013**, *93*, 455–462. [CrossRef]
54. Mapiye, C.; Chimonyo, M.; Dzama, K.; Muchenje, V.; Strydom, P. Meat quality of Nguni steers supplemented with *Acacia karroo* leaf-meal. *Meat Sci.* **2010**, *84*, 621–627. [CrossRef]
55. Wilkinson, J.; Lee, M. Use of human-edible animal feeds by ruminant livestock. *Animal* **2018**, *12*, 1735–1743. [CrossRef]
56. FAO. *Climate-Smart Agriculture Case Studies 2021—Projects from around the World*; FAO: Rome, Italy, 2021.
57. Parker, M.L.; Low, J.W.; Andrade, M.; Schulte-Geldermann, E.; Andrade-Piedra, J. Climate change and seed systems of roots, tubers and bananas: The cases of potato in Kenya and Sweetpotato in Mozambique. In *The Climate-Smart Agriculture Papers*; Springer: Cham, Switzerland, 2019; pp. 99–111.
58. Hengsdijk, H.; Verhagen, A. *Linking Climate Smart Agriculture and Good Agriculture Practices: Case Studies on Consumption Potatoes in South Africa, The Netherlands and Ethiopia*; Plant Research International: Wageningen, The Netherlands, 2013.
59. Ariom, T.O.; Dimon, E.; Nambeye, E.; Diouf, N.S.; Adelusi, O.O.; Boudalia, S. Climate-Smart Agriculture in African Countries: A Review of Strategies and Impacts on Smallholder Farmers. *Sustainability* **2022**, *14*, 11370. [CrossRef]
60. Kuntashula, E.; Chabala, L.M.; Mulenga, B.P. Impact of minimum tillage and crop rotation as climate change adaptation strategies on farmer welfare in smallholder farming systems of Zambia. *J. Sustain. Dev.* **2014**, *7*, 95. [CrossRef]
61. Komarek, A.M.; Kwon, H.; Haile, B.; Thierfelder, C.; Mutenje, M.J.; Azzarri, C. From plot to scale: Ex-ante assessment of conservation agriculture in Zambia. *Agric. Syst.* **2019**, *173*, 504–518. [CrossRef]
62. Phiri, K.; Nhliziyo, M.; Madzivire, S.I.; Sithole, M.; Nyathi, D. Understanding climate smart agriculture and the resilience of smallholder farmers in Umguza district, Zimbabwe. *Cogent Soc. Sci.* **2021**, *7*, 1970425. [CrossRef]
63. Mujere, N. An Assessment of the Contribution of The Pfumvudza Concept Towards Climate Smart Agriculture in Zimbabwe: A Review. *J. Agric. Hortic. Res.* **2022**, *5*, 69–76.