sustainability

MDPI

Review

Contribution of Conservation Agriculture to Soil Security

Raymond Mugandani [1,*], Liboster Mwadzingeni [2] and Paramu Mafongoya [2]

[1] Faculty of Agriculture, Environment and Natural Resources Management, Midlands State University, Gweru 9055, Zimbabwe
[2] School of Agriculture, Earth and Environmental Sciences, University of KwaZulu-Natal, Carbis Road, Scottsville, Pietermaritzburg 3201, South Africa; libomwadzi@gmail.com (L.M.); Mafongoya@ukzn.ac.za (P.M.)
* Correspondence: mugandanir@gmail.com; Tel.: +263-772493267

Abstract: Soil securitization is increasingly becoming a quintessential currency for attaining sustainable development given the mounting global concerns of land degradation, loss of biological diversity and associated ecosystem services, climate change, food insecurity, and water stress. A well-functioning soil is a panacea to address these global concerns. This paper describes the contribution of conservation agriculture (CA) to biological diversity protection, climate change adaptation and mitigation, ecosystem service delivery, food security, and water security as a potential entry point for soil securitization. Using a review of literature, we share some insights into the contribution of CA to the soil security discourse. In our review, we also make key recommendations for good practices under each soil security pillar. Thus, we conclude that empirical research is required to deepen our understanding of the benefits of CA in soil security, especially in developing countries.

Keywords: conservation agriculture; soil security; sustainable development

check for updates

Citation: Mugandani, R.; Mwadzingeni, L.; Mafongoya, P. Contribution of Conservation Agriculture to Soil Security. *Sustainability* **2021**, *13*, 9857. https://doi.org/10.3390/su13179857

Academic Editor: Kevin Murphy

Received: 23 May 2021
Accepted: 27 July 2021
Published: 2 September 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

1. Introduction

Soil health is central to biodiversity protection, climate change adaptation and mitigation, provision of ecosystem services, food security, and water security, yet land degradation has affected up to 30% of land globally [1]. The process of land degradation undesirably disturbs the livelihoods of 3.2 billion people and signifies an economic loss of about of 10% of the annual global gross domestic product, mainly in loss of biodiversity and ecosystem services [2]. The challenge is particularly widespread in sub-Saharan Africa (SSA) [3], where an estimated USD 68 billion is lost annually due to the deployment of unsustainable land management practices [4]. Thus, this enormous loss requires action given that adoption of sustainable land management practices would substantially reduce the loss to USD 126 million [4]. Paradoxically, soil on the African continent only gets attention from the public when governments fail to provide essential services [1]. Considering the importance of healthy soils for human well-being, key to securitizing the soil are the deployment of land management practices that maintain soil fertility, curb land degradation, reduce biodiversity loss, and abate climate change impacts, particularly water stress.

Practical solutions exist and there are indeed, throughout the world, good examples of well-tested traditional and modern agricultural practices that can be employed to evade, lessen, and reverse soil degradation in many ecosystems [2], thereby securing soil health. Conservation agriculture (CA) is one such approach that can protect soils against degradation. Globally, there has been increased pressure from different actors to place soil security on the global agenda [5], particularly in sustainable development [6–8]. In this paper, we define soil security as the "ability for soil to sustain functions to provide planetary services and human well-being" [9]. This is an area that has not attracted significant attention outside the soil science corridors; yet it is difficult to achieve biodiversity protection, ecosystem service provision, and food and water security in the absence of soil security [10]. Soil securitization is also vital given that healthy soils bring global peace and harmony on Earth.

This is summed up by Borlaug, who said: “If you desire peace, cultivate justice; but at the same time cultivate the fields (soils) to produce more bread; otherwise there will be no peace” [11]. Meanwhile, the notion that “a nation that destroys its soil destroys itself” implies that a well-managed soil is an asset for peace [12]. Therefore, within the framework of sustainable development and human security, creating awareness of soil security is vital, particularly to governments and environmentally conscious international organizations. Thus, robust scientific evidence on the soil security-CA nexus is important in sustainable development and human security. Consequently, international organizations such as the United Nations, which runs the United Nations Environmental Programme (UNEP) and United Nations Development Programmes (UNDP), and environmental conventions that include the United Nations Framework Convention on Climate Change (UNFCCC), Convention on Biodiversity (CBD), United Nations Convention to Combat Desertification (UNCCD), and the Paris Agreement, may see the justification in promoting agricultural practices that improve soil health.

2. Conservation Agriculture and Global Environmental Challenges

Biodiversity loss and declines in water quality and quantity arising from land degradation are some of the major challenges faced by smallholder farmers in SSA [13]. Consequently, CA, based on three interconnected pillars of minimum soil tillage, permanent soil cover, and crop rotation and/or intercropping, has huge potential to deliver multiple benefits in harmony with the principles of sustainability [14–18]. Conservation agriculture has been promoted to address the land degradation concerns in SSA [19]. It is an antidote to conventional agriculture, which results in land degradation through removal of crop residue or soil cover, excessive tillage, and monoculture [20]. It has massive potential to sustainably improve soil health (for example soil structure, soil organic matter (SOM), soil fertility, soil water infiltration and retention), and increase biodiversity and ecosystem services while advancing food security in a changing climate [21,22]. When practiced judiciously, CA can help restore degraded land and sequester carbon, thereby reducing the environmental footprint of agriculture and making agriculture resilient to the vagaries of climate change. Thus, the adoption of CA is imperative to address some of the major global concerns such as biodiversity loss, climate change, and water stress and food insecurity, which are intricately linked to land degradation. These challenges are particularly relevant in Africa, where there is a strong connection between climate, biodiversity, the natural ecosystems, and agriculture [23]. Smallholder farmers, who own about 75% of the 525 million farms globally [24], are important players in soil management and addressing global soil-related environmental challenges. In SSA alone, there are 43.55 million smallholder farmers, who constitute 80% of farmers in the region and contribute about 69% of the food produced [25]. Thus, the smallholder farmers will be expected to play a major role in sustainably increasing agricultural productivity to feed the rising population, currently at about 900 million [26], but projected to rise to 2 billion by 2050 [26].

Despite this, crop yields have stagnated or collapsed in smallholder farming systems of SSA [27], which makes the adoption of CA imperative. Regrettably, the adoption of CA is very low and fragmented in SSA [28]. The call for promoters of CA to interrogate the institutional and socioeconomic factors limiting its adoption in the region is very noble. It is also imperative for CA farmers to get adequate recognition for the off-farm benefits of CA, particularly those centered on soil security. Despite the need to recognize farmers and increase economic viability of CA [29] by addressing some of the barriers that prevent its adoption, to the best of our knowledge, there is no suitable domestic regulatory framework for explicitly promoting soil security in agriculture, leading to lack of funding for this critical issue in many countries in SSA, including Zimbabwe. The lack of a suitable regulatory framework could be a result of the dearth of literature underpinning the importance of CA in soil security. Within the context of the need to promote a soil security regulatory framework, the purpose of this review is to deepen our understanding of the contribution of CA to the soil security pillars and hence global environmental concerns. To do this, we use the literature to illustrate the potential contribution of CA to soil security and the need to securitize soils. Given the severity of land degradation and opportunities for CA in SSA, much of the literature from the region has been used in this work.

2.1. Contribution of CA to Biological Diversity Protection

Soil biodiversity, which is at the heart of sustainable agriculture in general and CA in particular, is threatened by agricultural intensification, particularly intensive application of agricultural chemicals (such as inorganic fertilizers and pesticides) and overreliance on mono-cropping systems [30]. CA, which enhances soil biodiversity, is a departure from agricultural intensification. This is particularly so if legumes are incorporated into CA rotation systems. Thus, the rotation enhances nutrient cycling in addition to breaking pest and disease cycles [31], leading to reduced inorganic fertilizer and pesticide application [22]. Some studies have observed an increase in earthworm numbers under CA in comparison with conventional tillage [32–35] This is not surprising given that crop residue and tillage management practices that improve soil organic matter provide a favorable natural habitat for a range of beneficial soil organisms [33]. In contrast, tillage and removal of soil cover disturbs the natural environment, thereby depriving the soil biota of energy sources [35]. However, under the CA paradigm, there is reduced mechanical tilling, which is important for building soil organic carbon, hence improving soil biodiversity. It should however be noted that when farmers practice zero tillage and crop residue retention without crop rotation, there is a risk of increasing the abundance of termites [36], whose population increases under monoculture [37,38] Termites have severe consequences for retention of crop residues [39], harvesting of maize [40] at physiological maturity [41], and earthworm prevalence [35]. In order to address the challenges posed by termites, there is a need to revisit the problems impeding the incorporation of rotation systems (particularly legumes) in southern Africa. These include the higher value attached to maize by farmers as a food security crop [42], limited markets for legumes, non-availability of legume seed in smallholder farming systems due to greater focus on maize improvement at the expense of legumes [43], low and unreliable yields, and high sensitivity to climate stress in general [44]. In light of the challenges preventing the adoption of all the principles of CA, there is need for government(s) to address these structural challenges through an enabling policy environment that supports crop rotation and the simultaneous application of all three principles of CA. Meanwhile, there is also need to equip agricultural extension officers to enable them to deliver appropriate CA messages that may aid farmers to make appropriate decisions.

2.2. Contribution of CA to Climate Adaptation and Mitigation

Climate change is a serious existential threat [45] to human and natural ecosystems [46], particularly for SSA, the location of all fifteen climate “hotspot” countries in Africa, characterized by high population growth rates, low adaptive capacity and high projected sensitivity to climate with regards to agricultural yields [47]. Several studies [48–52] suggest that CA has been promoted for building climate resilience in the region. Crop yields are projected to decline in a warming climate [53,54] through several mechanisms, including exacerbating plant nutrition in soils with inherent low fertility [55] and extensive mining of nutrients, particularly those in developing countries. Soil management strategies that enhance SOM are required to build climate resilience. However, the role of soil in climate-proofing crop yields, hence enhancing food security, has been confined to the discipline of soil science. Soil carbon sequestration, whose brand is building courtesy of the global interest precipitated by the “4 per 1000” [56], global initiative is slowly changing the perceived roles of soils in enhancing climate resilience, thus improving food security. Thus, enhancement of soil carbon stocks is one of the major objectives for using CA practices. SOM plays a critical role in nutrient cycling, climate change mitigation, and enhancing water use efficiency [57]. Thus, smallholder farming systems in SSA stand to benefit more from CA adoption given that soils in the region have low SOM content [58]. Furthermore, simultaneous reduced tillage, retention of crop residues, and crop rotation or intercropping have the potential to improve soil organic carbon by more than 4% per year in SSA soils [52], demonstrating the importance of CA to support global initiatives such as the "4 per 1000 Initiative: Soils for Food Security and Climate", particularly in soils with depleted soil organic carbon [59]. In fact, a recent study by Valkama et al. indicates that conservation agriculture offers a more realistic entry point to achieve the "4 per 1000 Initiative" [60]. CA also reduces the harmful effects of conventional tillage [61] by promoting reduced tillage [61,62], which improves soil carbon stocks [58], thereby improving soil aggregate stability [63], hence increasing soil water retention [61]. Meanwhile, retained crop residues increase soil water infiltration [64] while reducing runoff [64,65] and evapotranspiration [64], leading to improved soil moisture retention under CA. All these lead to improved water use efficiency and climate resilience in previously degraded soils associated with low water use efficiency. This is the reason why the yield benefits of CA are more pronounced in climate-stressed regions [15], especially in the drier climates of southern Africa, where climate-proofing yields is vital to improve food security given a highly variable climate in the region [35,66–68].

As a new paradigm built on the principle of ecological sustainability, CA is also important in reducing the environmental footprint of agriculture. This is critical given that agriculture contributes about 60% of total anthropogenic nitrous oxide input into the atmosphere [69], mainly through the use of nitrogen-based fertilizers. Nitrous oxide emissions could be reduced under CA due to reduction in the amount of inorganic fertilizers applied arising from improved soil fertility through enriched SOM [70] and increased soil nutrient cycling. This is particularly so if legumes are incorporated in the rotational systems. Furthermore, a global review of literature on life cycle assessment (LCA) highlights that, in contrast to other crops, legumes have exceptionally low global warming potential values [71]. The inclusion of legumes in cropping systems also contributes to weed control and breaking the pest and disease cycles, thereby limiting the application of pesticides and herbicides in subsequent crops [72]. Land under CA can attain a 25% increase in productivity with lower energy inputs [73] than conventional tillage due to lower demand for fertilizers, agrochemicals, and power [74]. Soil carbon sequestration, which is important for food security, adaption to climate change, and reducing greenhouse gas emissions [75,76], is affected by a complexity of numerous variables [7,77]. Thus, one of the key challenges is the contrasting literature on the impacts of CA on soil carbon sequestration, especially in southern Africa [78]. Thus, research is required to tap into existing initiatives such as the "4 per 1000 Initiative", to develop, test, and validate site-specific tools and models for measuring soil organic carbon dynamics under locally adapted soil management practices. Additionally, there is a need to develop markets for legumes, improve research funding for these crops, and improve perceptions of farmers regarding the value of legumes.

2.3. Contribution of CA to Ecosystem Service Delivery

Addressing environmental degradation and enhancing environmental ecosystem services is one of the principal goals of CA. This is achieved through enhancement of the soil health-related properties of CA. Globally, enhancing the health status of degraded soils is one of the major motives for practicing reduced tillage systems [79], including in Zimbabwe [80]. Specifically, farmers in Chimanimani in eastern Zimbabwe were already using ripper-tines (planting basins) in the 1960s to reduce soil erosion (capture rainfall) [81]. Elsewhere, including in North America, farmers were forced to adopt reduced tillage systems following severe soil degradation as a result of the 1930s dust bowls [82]. Farmers in China were forced to leave crop residue on the soil surface (one of the CA pillars), in order to reduce air pollution caused by burning of the residues [80]. Although the original objective for the development of no-till systems, and later CA systems, was curbing soil degradation, the agenda has expanded to include environmental sustainability, climate change adaptation and mitigation, and delivery of ecosystem services. The latter is achieved through reduced application of chemicals such as herbicides, improved nutrient cycling and biological diversity, and provision of clean water [31]. Thus, CA is a vehicle for improved soil health and ecosystem resilience. Therefore, soil scientists and agronomists need to take a leading role in detailed studies that are required to inform decision makers on the benefits and synergies between CA (or any other good land management practices) and land restoration for improved ecosystem services in smallholder farming systems dependent on agriculture for food and nutritional security.

2.4. Contribution of CA to Food Security

Healthy soils are directly linked to Sustainable Development Goal 2 "End hunger, achieve food security and improve nutrition and promote sustainable agriculture" [8]. Yet, deteriorating soil fertility and the increasing impacts of climate variability threaten food security in southern Africa [68,83,84]. Despite years of research and promotion of CA in southern Africa by national and international organizations, the region remains on the cusp of rising food and nutritional insecurity, as the cupboard remains bare. For example, Zimbabwe reported maize yields ranging from 0.5–1.2 t/ha in 2020 [85], which was not enough to meet its food security requirements [86]. Besides, maize, the major staple crop in Zimbabwe [85] and most southern African countries, is a heavy feeder [84] and can worsen soil fertility challenges in the absence of any rotations. Numerous publications, for example, by Nyanga [87]; Nyamangara et al. [88]; Thierfelder et al. [89]; Thierfelder et al. [34]; Thierfelder, Matemba-Mutasa, and Rusinamhodzi [67]; Mazvimavi [90]; Mango, Siziba, and Makate [91] and Nyagumbo et al. [92], show that CA is important for improving food security in southern Africa. CA improves soil fertility and climate resilience in these predominantly maize-based cropping areas. From the soil security perspective, this is achieved through increased soil quality brought about by improved SOM under CA [93]. SOM, which affects nutrient retention and cycling and soil water dynamics, is the key determinant of soil health in smallholder cropping systems [94]. Thus, improved soil fertility is beneficial for a majority of farmers in sub-Saharan Africa, especially in Zimbabwe given the inherent low soil fertility coupled with soil nutrient mining [4]. However, some studies have reported contrasting results on the role of CA in improving SOM under different environmental conditions in southern Africa [50,88,95–97]. Thus, in light of the heterogeneity in farming systems in southern Africa, hence inconclusive evidence on soil carbon changes under CA, we recommend the development of a rigorous and systematic ground-based framework for monitoring SOM dynamics under different land use systems. We could use the ground data to calibrate and validate data collected through satellite images to develop algorithms for SOM assessment at temporal and spatial scales.

2.5. Contribution of CA to Water Security

Globally, enhancing soil health is critical to attain SDG 6 (on water and sanitation). Thus, enhancing the capability of soils to provide clean, fresh water is a low-hanging fruit in attainment of SDG 6. In Zimbabwe, water pollution is a serious concern and might be a challenge in the attainment of some SDGs [98], including SDG 6 and SDG 14 (life below water). Of particular relevance to our discussion is the increase in water pollution from agriculture [99]. However, CA offers a credible entry point to partly address this challenge by reducing pollution and improving clean water supplies with lower treatment costs [100,101]. Under the CA paradigm, improved nutrient cycling, particularly of nitrogen, is guaranteed through improved SOM and inclusion of legumes as part of the rotational strategy, thereby reducing added mineral fertilizers [70]. Meanwhile, crop rotation, one of the principles of CA, is a cost-effective strategy to prevent the outbreak of pests and diseases [102], particularly in smallholder farming systems [102]. The inclusion of several crops attracts various microorganisms in the soil [20], promoting biological diversity. Some of the organisms might actually be the natural enemies of crop pests. All these reduce the intensive application of agro-chemicals and hence water pollution [70]. Paradoxically, even though legumes are important in CA rotation systems, they remain economically unattractive to most farmers [103] due to the structural challenges discussed in other parts of the article. CA also reduces runoff and soil erosion. Water runoff carries with it soil sediments and agrochemicals, leading to groundwater pollution. According to Wall, CA reduces soil erosion by 90% compared to conventional tillage [104]. The contribution of CA to improved water use efficiency is discussed in the earlier section on the contribution of CA to improved climate action. Soil scientists need to take a leading role in creating multidisciplinary teams that create awareness of the importance of CA to the attainment of SDG6 to justify a business case in the CA–SDG 6 nexus.

3. Soil Security and the Global Environmental Agenda

Understanding the values of soils in sustainable development and soil securitization in particular is a prerequisite for addressing global environmental challenges. Such an understanding might lead to the recognition of farmers for their role in soil security, which might be a good entry point for addressing the barriers to adoption of CA in developing countries. However, since not much empirical evidence is available on the conservation agriculture–soil security nexus, scholars in developing countries are highly encouraged to explore further this topic in order to influence decision-making processes.

Despite the importance of soil health for environmental protection and sustainable development, a majority of global environmental conventions tend to neglect the soil. For example, the final texts of the UNFCCC and the CBD do not clearly mention the important role of soils. Even though the UNCCD discusses the critical role of soils, the focus is on soils located in drylands [7], particularly in Africa [105]. Similarly, the landmark Paris Agreement is silent on the important contribution of soils in climate mitigation and adaptation, notwithstanding the fact that soils can be a significant source or sink of greenhouse gases, while agriculture could be a victim or culprit of climate change, depending on soil use and management. On the other hand, no sufficient attention has been paid to soils in the crafting of the SDGs, despite the critical role of sustainable soil management practices in achieving many of the SDGs [106]. Soil scientists have a role to play in raising awareness on the role of soils and good soil management practices in sustainable development and the global environmental agenda.

4. Conclusions and Recommendations

This review article sought to deepen our understanding of the contribution of CA to soil security and hence the global environmental agenda. The review shows that CA has massive potential to contribute to soil security. Thus, developing countries, particularly those in SSA, need to put in place a soil security strategy in agriculture, for reducing land degradation in order to improve human well-being. This is only possible if policy makers in these countries buy into the soil security idea. This is critical given the role of sustainable soil management practices and soil security in addressing many global environmental issues and the advancement of sustainable development goals. Thus, empirical research is required to improve our understanding of the benefits of CA in soil security, especially in developing countries, where CA adoption is constrained by various socioeconomic and institutional challenges. At the global level, there is a need to improve awareness on soil security issues in international environmental organizations, particularly the UNDP, UNEP, and environmental conventions such as the CBD, UNCCD, UNFCCC, and the Paris Agreement. There is also a need to identify areas where CA knowledge is unclear/remains untapped and to detect areas where more research investigation could promise to achieve the soil security objective while improving food security. Part of the inquiry needs to address fully the "what happened, and why" issues under each land management practice. Such research should take on board the major CA shareholder, the farmer, to improve decision-making.

Author Contributions: Conceptualization, L.M. and P.M.; methodology, R.M.; validation, R.M., L.M. and P.M.; formal analysis, R.M.; investigation, R.M.; resources, P.M.; data curation, R.M.; writing—original draft preparation, R.M. and L.M.; writing—review and editing, P.M.; visualization, R.M.; supervision, P.M.; project administration, P.M.; funding acquisition, P.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Research Foundation of South Africa, grant number 86893 and The APC was funded by 86893.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank two anonymous reviewers for reviewing the original draft manuscript.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. *Status of the World's Soil Resource—Main Report*; FAO: Rome, Italy, 2015.
2. Scholes, R.; Montanarella, L.; Brainich, A.; Barger, N.; ten Brink, B.; Cantele, M.; Erasmus, B.; Fisher, J.; Gardner, T.; Holland, T.G. *Summary for Policymakers of the Assessment Report on Land Degradation and Restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*; IPBES Secretariat: Bonn, Germany, 2018.
3. Nkonya, E.; Johnson, T.; Kwon, H.Y.; Kato, E. Economics of land degradation in Sub-Saharan Africa. In *Economics of Land Degradation and Improvement—A Global Assessment for Sustainable Development*; Springer: Cham, Switzerland, 2016; pp. 215–259.
4. Zingore, S.; Mutegi, J.; Agesa, B.; Tamene, L.; Kihara, J. Soil degradation in sub-Saharan Africa and crop production options for soil rehabilitation. *Better Crops* **2015**, *99*, 24–26.
5. Koch, A.; McBratney, A.; Lal, R. Global soil week: Put soil security on the global agenda. *Nature* **2012**, *492*, 186. [CrossRef]
6. Bouma, J.; McBratney, A. Framing soils as an actor when dealing with wicked environmental problems. *Geoderma* **2013**, *200*, 130–139. [CrossRef]
7. Keesstra, S.D.; Bouma, J.; Wallinga, J.; Tittonell, P.; Smith, P.; Cerdà, A.; Montanarella, L.; Quinton, J.N.; Pachepsky, Y.; van der Putten, W.H. The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. *Soil* **2016**, *2*, 111–128. [CrossRef]
8. Bouma, J. Soil security in sustainable development. *Soil Syst.* **2019**, *3*, 5. [CrossRef]
9. Morgan, C.; McBratney, A. Editorial: Widening the disciplinary study of soil. *Soil Secur.* **2020**, *1*, 100003. [CrossRef]
10. Holt, A.R.; Alix, A.; Thompson, A.; Maltby, L. Food production, ecosystem services and biodiversity: We can't have it all everywhere. *Sci. Total Environ.* **2016**, *573*, 1422–1429. [CrossRef] [PubMed]
11. Borlaug, N.E. *The Green Revolution, Peace and Humanity: Speech Delivered upon Receipt of the 1970 Nobel Prize, Oslo, Norway, 1970*; CIMMYT: Texcoco, Mexico, 1972.
12. Roosevelt, F.D. Letter to all State Governors on a Uniform Soil Conservation Law. Available online: https://www.presidency.ucsb.edu/documents/letter-all-state-governors-uniform-soil-conservation-law (accessed on 29 June 2021).
13. Andersson, J.A.; D'Souza, S. From adoption claims to understanding farmers and contexts: A literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agric. Ecosyst. Environ.* **2014**, *187*, 116–132. [CrossRef]
14. Giller, K.E.; Witter, E.; Corbeels, M.; Tittonell, P. Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Res.* **2009**, *114*, 23–34. [CrossRef]
15. Pittelkow, C.M.; Liang, X.; Linquist, B.A.; van Groenigen, K.J.; Lee, J.; Lundy, M.E.; van Gestel, N.; Six, J.; Venterea, R.T.; van Kessel, C. Productivity limits and potentials of the principles of conservation agriculture. *Nature* **2015**, *517*, 355–368. [CrossRef] [PubMed]
16. Hobbs, P.; Gupta, R.; Jat, R.K.; Malik, R. Conservation agriculture in the Indogangetic plains of India: Past, present and future. *Exp. Agric.* **2019**, *55*, 339–357. [CrossRef]
17. Nyanga, P.; Umar, B.; Chibamba, D.; Mubanga, K.; Kunda-Wamuwi, C.; Mushili, B. Reinforcing ecosystem services through conservation agriculture in sustainable food systems. In *The Role of Ecosystem Services in Sustainable Food Systems*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 119–133.
18. Wall, P.; Thierfelder, C.; Hobbs, P.; Hellin, J.; Govaerts, B. Benefits of Conservation Agriculture. In *Advances in Conservation Agriculture Volume 2: Practice and Benefits*; Kassam, A., Ed.; Burleigh Dodds and Publishing Science: London, UK, 2020; Volume 2, p. 40.
19. Nyathi, P.; Moyo, T.; Posthumus, H.; Stevens, J. Impact of Social and Institutional Factors on the Uptake of Conservation Agriculture: A Case of Zambia and Zimbabwe. *Sustain. Agric. Res.* **2020**, *9*, 67–79. [CrossRef]

20. Kassam, A. *Advances in Conservation Agriculture: Practice and Benefits*; Burleigh Dodds Science Publishing: London, UK, 2020.
21. Friedrich, T.; Derpsch, R.; Kassam, A. Chapter 3 Overview of the Global Spread of Conservation Agriculture. *Sustain. Dev. Org. Agric.* **2017**, 53–68.
22. Kassam, A.; Friedrich, T.; Derpsch, R.; Kienzle, J. Overview of the worldwide spread of conservation agriculture. *J. Field Actions* **2015**, *8*.
23. Sintayehu, D.W. Impact of climate change on biodiversity and associated key ecosystem services in Africa: A systematic review. *Ecosyst. Health Sustain.* **2018**, *4*, 225–239. [CrossRef]
24. Lowder, S.K.; Skoet, J.; Raney, T. The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Dev.* **2016**, *87*, 16–29. [CrossRef]
25. Gomez y Paloma, S.; Riesgo, L.; Louhichi, K. *The Role of Smallholder Farms in Food and Nutrition Security*; Springer: Basingstoke, UK, 2020.
26. FAO. *The Future of Food and Agriculture–Trends and challenges. Annual Report 2017*; FAO: Rome, Italy, 2017; p. 296.
27. Ray, D.K.; Mueller, N.D.; West, P.C.; Foley, J.A. Yield trends are insufficient to double global crop production by 2050. *PLoS ONE* **2013**, *8*, e66428. [CrossRef]
28. Friedrich, T.; Derpsch, R.; Kassam, A. Overview of the Global Spread of Conservation Agriculture. In *Sustainable Development of Organic Agriculture: Historical Perspectives*; Apple Academic Press: Palm Bay, FL, USA, 2017; pp. 53–68.
29. Giller, K.E.; Andersson, J.A.; Corbeels, M.; Kirkegaard, J.; Mortensen, D.; Erenstein, O.; Vanlauwe, B. Beyond conservation agriculture. *Front. Plant Sci.* **2015**, *6*, 870. [CrossRef]
30. Matson, P.A.; Parton, W.J.; Power, A.G.; Swift, M.J. Agricultural intensification and ecosystem properties. *Science* **1997**, *277*, 504–509. [CrossRef] [PubMed]
31. Kassam, A.; Friedrich, T.; Shaxson, F.; Pretty, J. The spread of conservation agriculture: Justification, sustainability and uptake. *Int. J. Agric. Sustain.* **2009**, *7*, 292–320. [CrossRef]
32. Mcinga, S.; Muzangwa, L.; Janhi, K.; Mnkeni, P.N.S. Conservation Agriculture Practices Can Improve Earthworm Species Richness and Abundance in the Semi-Arid Climate of Eastern Cape, South Africa. *Agriculture* **2020**, *10*, 576. [CrossRef]
33. Baldivieso-Freitas, P.; Blanco-Moreno, J.M.; Gutiérrez-López, M.; Peigné, J.; Pérez-Ferrer, A.; Trigo-Aza, D.; Sans, F.X. Earthworm abundance response to conservation agriculture practices in organic arable farming under Mediterranean climate. *Pedobiologia* **2018**, *66*, 58–64. [CrossRef]
34. Thierfelder, C.; Wall, P. Rotation in conservation agriculture systems of Zambia: Effects on soil quality and water relations. *Exp. Agric.* **2010**, *46*, 309–325. [CrossRef]
35. Thierfelder, C.; Rusinamhodzi, L.; Ngwira, A.R.; Mupangwa, W.; Nyagumbo, I.; Kassie, G.T.; Cairns, J.E. Conservation agriculture in Southern Africa: Advances in knowledge. *Renew. Agric. Food Syst.* **2015**, *30*, 328–348. [CrossRef]
36. Mutsamba, E.F.; Nyagumbo, I.; Mafongoya, P. Termite prevalence and crop lodging under conservation agriculture in sub-humid Zimbabwe. *Crop Prot.* **2016**, *82*, 60–64. [CrossRef]
37. Zida, Z.; Ouédraogo, E.; Mando, A.; Stroosnijder, L. Termite and earthworm abundance and taxonomic richness under long-term conservation soil management in Saria, Burkina Faso, West Africa. *Appl. Soil Ecol.* **2011**, *51*, 122–129. [CrossRef]
38. Sithole, N.J.; Magwaza, L.S.; Mafongoya, P.L. Conservation agriculture and its impact on soil quality and maize yield: A South African perspective. *Soil Tillage Res.* **2016**, *162*, 55–67. [CrossRef]
39. Mutema, M.; Mafongoya, P.; Nyagumbo, I.; Chikukura, L. Effects of crop residues and reduced tillage on macrofauna abundance. *J. Org. Syst.* **2013**, *8*, 5–16.
40. Mulugetta, M.; Dimes, J.; Dixon, J.; Potgieter, A.; Prasanna, B.; Rodriguez, D.; Shiferaw, B.; Wall, P. The sustainable intensification of maize-legume farming systems in eastern and southern Africa (SIMLESA) program. In Proceedings of the 5th World Congress on Conservation Agriculture, Brisbane, Australia, 26–29 September 2011.
41. Thierfelder, C.; Bunderson, W.T.; Jere, Z.D.; Mutenje, M.; Ngwira, A. Development of conservation agriculture (CA) systems in Malawi: Lessons learned from 2005 to 2014. *Exp. Agric.* **2016**, *52*, 579–604. [CrossRef]
42. Thierfelder, C.; Cheesman, S.; Rusinamhodzi, L. Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa. *Int. J. Agric. Sustain.* **2013**, *11*, 108–124. [CrossRef]
43. Mhlanga, B.; Mwila, M.; Thierfelder, C. Improved nutrition and resilience will make conservation agriculture more attractive for Zambian smallholder farmers. *Renew. Agric. Food Syst.* **2021**, 1–14. [CrossRef]
44. Widyarani, R. Biorefinery of Proteins from Rubber Plantation Residues. Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands, 2016.
45. Myers, T.C. Understanding climate change as an existential threat: Confronting climate denial as a challenge to climate ethics. *De Ethica* **2014**, *1*, 53–70. [CrossRef]
46. Lee, T.M.; Markowitz, E.M.; Howe, P.D.; Ko, C.-Y.; Leiserowitz, A.A. Predictors of public climate change awareness and risk perception around the world. *Nat. Clim. Chang.* **2015**, *5*, 1014–1020. [CrossRef]
47. Mutunga, C.; Zulu, E.M.; de Souza, R.-M. *Population Dynamics, Climate Change and Sustainable Development in Africa*; PAI: Washington, DC, USA, 2012.
48. Milder, J.C.; Majanen, T.; Scherr, S. *Performance and Potential of Conservation Agriculture for Climate Change Adaptation and Mitigation in Sub-Saharan Africa*; EcoAgriculture Partners: Washington, DC, USA, 2011.

49. Stevenson, J.R.; Serraj, R.; Cassman, K.G. *Evaluating Conservation Agriculture for Small-Scale Farmers in Sub-Saharan Africa and South Asia*; Elsevier: Amsterdam, The Netherlands, 2014.
50. Powlson, D.S.; Stirling, C.M.; Thierfelder, C.; White, R.P.; Jat, M.L. Does conservation agriculture deliver climate change mitigation through soil carbon sequestration in tropical agro-ecosystems? *Agric. Ecosyst. Environ.* **2016**, *220*, 164–174. [CrossRef]
51. Corbeels, M.; Sakyi, R.K.; Kühne, R.F.; Whitbread, A.M. *Meta-Analysis of Crop Responses to Conservation Agriculture in Sub-Saharan Africa*; CCAFS Report No. 12; CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS): Copenhagen, Denmark, 2014.
52. Corbeels, M.; Cardinael, R.; Naudin, K.; Guibert, H.; Torquebiau, E. The 4 per 1000 goal and soil carbon storage under agroforestry and conservation agriculture systems in sub-Saharan Africa. *Soil Tillage Res.* **2019**, *188*, 16–26. [CrossRef]
53. Asseng, S.; Foster, I.; Turner, N.C. The impact of temperature variability on wheat yields. *Glob. Chang. Biol.* **2011**, *17*, 997–1012. [CrossRef]
54. Lobell, D.B.; Schlenker, W.; Costa-Roberts, J. Climate trends and global crop production since 1980. *Science* **2011**, *333*, 616–620. [CrossRef]
55. Clair, S.B.S.; Lynch, J.P. The opening of Pandora's Box: Climate change impacts on soil fertility and crop nutrition in developing countries. *Plant Soil* **2010**, *335*, 101–115. [CrossRef]
56. Minasny, B.; Malone, B.P.; McBratney, A.B.; Angers, D.A.; Arrouays, D.; Chambers, A.; Chaplot, V.; Chen, Z.-S.; Cheng, K.; Das, B.S. Soil carbon 4 per mille. *Geoderma* **2017**, *292*, 59–86. [CrossRef]
57. Owuor, S.O.; Butterbach-Bahl, K.; Guzha, A.; Jacobs, S.; Merbold, L.; Rufino, M.C.; Pelster, D.E.; Díaz-Pinés, E.; Breuer, L. Conversion of natural forest results in a significant degradation of soil hydraulic properties in the highlands of Kenya. *Soil Tillage Res.* **2018**, *176*, 36–44. [CrossRef]
58. Swanepoel, C.M.; Swanepoel, L.H.; Smith, H.J. A review of conservation agriculture research in South Africa. *S. Afr. J. Plant Soil* **2018**, *35*, 297–306. [CrossRef]
59. Chopin, P.; Sierra, J. Potential and constraints for applying the "4 per 1000 Initiative" in the Caribbean: The case of Guadeloupe. *Reg. Environ. Chang.* **2021**, *21*, 1–10. [CrossRef]
60. Valkama, E.; Kunypiyaeva, G.; Zhapayev, R.; Karabayev, M.; Zhusupbekov, E.; Perego, A.; Schillaci, C.; Sacco, D.; Moretti, B.; Grignani, C. Can conservation agriculture increase soil carbon sequestration? A modelling approach. *Geoderma* **2020**, *369*, 114298. [CrossRef]
61. Indoria, A.; Rao, C.S.; Sharma, K.; Reddy, K.S. Conservation agriculture–a panacea to improve soil physical health. *Curr. Sci.* **2017**, 52–61. [CrossRef]
62. Margenot, A.J.; Paul, B.K.; Sommer, R.R.; Pulleman, M.M.; Parikh, S.J.; Jackson, L.E.; Fonte, S.J. Can conservation agriculture improve phosphorus (P) availability in weathered soils? Effects of tillage and residue management on soil P status after 9 years in a Kenyan Oxisol. *Soil Tillage Res.* **2017**, *166*, 157–166. [CrossRef]
63. Sithole, N.J.; Magwaza, L.S.; Thibaud, G.R. Long-term impact of no-till conservation agriculture and N-fertilizer on soil aggregate stability, infiltration and distribution of C in different size fractions. *Soil Tillage Res.* **2019**, *190*, 147–156. [CrossRef]
64. Turmel, M.-S.; Speratti, A.; Baudron, F.; Verhulst, N.; Govaerts, B. Crop residue management and soil health: A systems analysis. *Agric. Syst.* **2015**, *134*, 6–16. [CrossRef]
65. Zhang, S.; Zhang, G.; Wang, D.; Liu, Q.; Xu, M. Investigation into runoff nitrogen loss variations due to different crop residue retention modes and nitrogen fertilizer rates in rice-wheat cropping systems. *Agric. Water Manag.* **2021**, *247*, 106729. [CrossRef]
66. Mazvimavi, K.; Ndlovu, P.V.; Nyathi, P.; Minde, I.J. Conservation agriculture practices and adoption by smallholder farmers in Zimbabwe. Proceedings of Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, 19–23 September 2010.
67. Thierfelder, C.; Matemba-Mutasa, R.; Rusinamhodzi, L. Yield response of maize (Zea mays L.) to conservation agriculture cropping system in Southern Africa. *Soil Tillage Res.* **2015**, *146*, 230–242. [CrossRef]
68. Nyagumbo, I.; Mkuhlani, S.; Pisa, C.; Kamalongo, D.; Dias, D.; Mekuria, M. Maize yield effects of conservation agriculture based maize–legume cropping systems in contrasting agro-ecologies of Malawi and Mozambique. *Nutr. Cycl. Agroecosyst.* **2016**, *105*, 275–290. [CrossRef]
69. Reay, D.S.; Davidson, E.A.; Smith, K.A.; Smith, P.; Melillo, J.M.; Dentener, F.; Crutzen, P.J. Global agriculture and nitrous oxide emissions. *Nat. Clim. Chang.* **2012**, *2*, 410–416. [CrossRef]
70. González-Sánchez, E.; Kassam, A.; Basch, G.; Streit, B.; Holgado-Cabrera, A.; Triviño-Tarradas, P. Conservation Agriculture and its contribution to the achievement of agri-environmental and economic challenges in Europe. *AIMS Agric. Food.* **2016**, *1*, 387–408. [CrossRef]
71. Clune, S.; Crossin, E.; Verghese, K. Systematic review of greenhouse gas emissions for different fresh food categories. *J. Clean. Prod.* **2017**, *140*, 766–783. [CrossRef]
72. Zander, P.; Amjath-Babu, T.; Preissel, S.; Reckling, M.; Bues, A.; Schläfke, N.; Kuhlman, T.; Bachinger, J.; Uthes, S.; Stoddard, F. Grain legume decline and potential recovery in European agriculture: A review. *Agron. Sustain. Dev.* **2016**, *36*, 26. [CrossRef]
73. Goss, M.J.; Carvalho, M.; Brito, I. *Functional Diversity of Mycorrhiza and Sustainable Agriculture: Management to Overcome Biotic and Abiotic Stresses*; Academic Press: Cambridge, MA, USA, 2017.
74. Kassam, A.; Brammer, H. Combining sustainable agricultural production with economic and environmental benefits. *Geogr. J.* **2013**, *179*, 11–18. [CrossRef]

75. Hayduk, D.; Satoyama, S.; Vafadari, K. *Soils Help to Combat and Adapt to Climate Change by Playing a Key Role in the Carbon Cycle*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2015; pp. 1–4.
76. Lal, R. Food security impacts of the "4 per Thousand" initiative. *Geoderma* **2020**, *374*, 114427. [CrossRef]
77. Xu, S.; Sheng, C.; Tian, C. Changing soil carbon: Influencing factors, sequestration strategy and research direction. *Carbon Balance Manag.* **2020**, *15*, 1–9. [CrossRef]
78. Thierfelder, C.; Chivenge, P.; Mupangwa, W.; Rosenstock, T.S.; Lamanna, C.; Eyre, J.X. How climate-smart is conservation agriculture (CA)?—Its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Secur.* **2017**, *9*, 537–560. [CrossRef]
79. Friedrich, T.; Kassam, A.; Taher, F. Adoption of Conservation Agriculture and the role of policy and institutional support. Invited keynote paper. In Proceedings of the International Consultation on No-Till with Soil Cover and Crop Rotation: A Basis for Policy Support to Conservation Agriculture for Sustainable Production Intensification, Astana-Shortandy, Kazakhstan, 8–10 July 2009.
80. Twomlow, S.; Delve, R.; Critchley, W. *Lessons Learned: Designing and Implementing Conservation Agriculture in Sub-Saharan Africa*; IFAD: Rome, Italy, 2016.
81. Mvumi, C.; Ndoro, O.; Manyiwo, S. Conservation agriculture, conservation farming and conventional tillage adoption, efficiency and economic benefits in semi-arid Zimbabwe. *Afr. J. Agric. Res.* **2017**, *12*, 1629–1638. [CrossRef]
82. Kassam, A.; Derpsch, R.; Friedrich, T. Global achievements in soil and water conservation: The case of Conservation Agriculture. *Int. Soil Water Conserv. Res.* **2014**, *2*, 5–13.
83. Silici, L. *Conservation Agriculture and Sustainable Crop Intensification in Lesotho*; Food and Agriculture Organization of the United Nations (FAO): Rome, Italy, 2010; Volume 10.
84. Madembo, C.; Mhlanga, B.; Thierfelder, C. Productivity or stability? Exploring maize-legume intercropping strategies for smallholder Conservation Agriculture farmers in Zimbabwe. *Agric. Syst.* **2020**, *185*, 102921. [CrossRef]
85. FAOSTAT. Available online: http://www.fao.org/faostat/en/#data (accessed on 20 March 2020).
86. Sommer, R.; Bossio, D.; Desta, L.; Dimes, J.; Kihara, J.; Koala, S.; Mango, N.; Rodriguez, D.; Thierfelder, C.; Winowiecki, L. *Profitable and Sustainable Nutrient Management Systems for East and Southern African Smallholder Farming Systems Challenges and Opportunities: A Synthesis of the Eastern and Southern Africa Situation in Terms of Past Experiences, Present and Future Opportunities in Promoting Nutrients Use in Africa*; CIAT, The University of Queensland, QAAFI, CIMMYT: Cali, Colombia, 2013.
87. Nyanga, P.H. Food security, conservation agriculture and pulses: Evidence from smallholder farmers in Zambia. *J. Food Res.* **2012**, *1*, 120. [CrossRef]
88. Nyamangara, J.; Nyengerai, K.; Masvaya, E.; Tirivavi, R.; Mashingaidze, N.; Mupangwa, W.; Dimes, J.; Hove, L.; Twomlow, S. Effect of conservation agriculture on maize yield in the semi-arid areas of Zimbabwe. *Exp. Agric.* **2014**, *50*, 159–177. [CrossRef]
89. Thierfelder, C.; Mutenje, M.; Mujeyi, A.; Mupangwa, W. Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal Area, Zimbabwe. *Food Secur.* **2015**, *7*, 15–31. [CrossRef]
90. Mazvimavi, K. *Assessing the Contributions of Conservation Agriculture to Building Resilience to Drought, Conservation Agriculture Literature Review*; Vuna Research Report; Vuna: Pretoria, South Africa, 2016.
91. Mango, N.; Siziba, S.; Makate, C. The impact of adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa. *Agric. Food. Secur.* **2017**, *6*, 1–8. [CrossRef]
92. Nyagumbo, I.; Mkuhlani, S.; Mupangwa, W.; Rodriguez, D. Planting date and yield benefits from conservation agriculture practices across Southern Africa. *Agric. Syst.* **2017**, *150*, 21–33. [CrossRef]
93. Reicosky, D.C. Conservation tillage is not conservation agriculture. *J. Soil Water Conserv.* **2015**, *70*, 103A–108A. [CrossRef]
94. Chan, K. The important role of soil organic carbon in future mixed farming systems. In Proceedings of the 25th Annual Conference of the Grassland Society of NSW, Dubbo, Australia, 28–29 July 2010; pp. 28–29.
95. Nyamangara, J.; Marondedze, A.; Masvaya, E.; Mawodza, T.; Nyawasha, R.; Nyengerai, K.; Tirivavi, R.; Nyamugafata, P.; Wuta, M. Influence of basin-based conservation agriculture on selected soil quality parameters under smallholder farming in Zimbabwe. *Soil Use Manag.* **2014**, *30*, 550–559. [CrossRef]
96. Thierfelder, C.; Wall, P. Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. *Soil Use Manag.* **2012**, *28*, 209–220. [CrossRef]
97. Cheesman, S.; Thierfelder, C.; Eash, N.S.; Kassie, G.T.; Frossard, E. Soil carbon stocks in conservation agriculture systems of Southern Africa. *Soil Tillage Res.* **2016**, *156*, 99–109. [CrossRef]
98. Chikodzi, D.; Tevera, D.; Mazvimavi, D. SDG 15 and Socioecological Sustainability: Spring Waterscapes and Rural Livelihoods in the Save Catchment of Zimbabwe. In *Scaling Up SDGs Implementation*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 59–71.
99. World Bank. *Climate Change and Water Resources Planning, Development and Management in Zimbabwe*; World Bank: Washington, DC, USA, 2014.
100. Hobbs, P.R.; Sayre, K.; Gupta, R. The role of conservation agriculture in sustainable agriculture. *Philos. Trans. R. Soc. B Biol. Sci.* **2007**, *363*, 543–555. [CrossRef]
101. Kassam, A.; Friedrich, T.; Shaxson, F.; Bartz, H.; Mello, I.; Kienzle, J.; Pretty, J. The spread of conservation agriculture: Policy and institutional support for adoption and uptake. *Field Action Sci. Rep. J. Field Actions* **2014**, *7*.
102. Rusinamhodzi, L. Managing Crop Rotations in No-till Farming Systems. In *No-Till Farming Systems for Sustainable Agriculture*; Springer: Berlin/Heidelberg, Germany, 2020; pp. 21–31.

103. Kirkegaard, J.A.; Conyers, M.K.; Hunt, J.R.; Kirkby, C.A.; Watt, M.; Rebetzke, G.J. Sense and nonsense in conservation agriculture: Principles, pragmatism and productivity in Australian mixed farming systems. *Agric. Ecosyst. Environ.* **2014**, *187*, 133–145. [CrossRef]
104. WALL, P.C. Conservation agriculture: Growing more with less-the future of sustainable intensification. In *Conservation Agriculture for Africa: Building Resilient Farming Systems in a Changing Climate*; CABI: Wallingford, UK, 2017; pp. 30–40.
105. Koch, A.; McBratney, A.; Adams, M.; Field, D.; Hill, R.; Crawford, J.; Minasny, B.; Lal, R.; Abbott, L.; O'Donnell, A. Soil security: Solving the global soil crisis. *Glob. Policy* **2013**, *4*, 434–441. [CrossRef]
106. Hou, D.; Bolan, N.S.; Tsang, D.C.; Kirkham, M.B.; O'Connor, D. Sustainable soil use and management: An interdisciplinary and systematic approach. *Sci. Total Environ.* **2020**, *729*, 138961. [CrossRef] [PubMed]