Received Date: 7 September 2025
Accepted Date: 27 December 2025
DOI: https://doi.org/10.3126/jiaas.v39i1.88279

CLIMATE-SMART AND INNOVATIVE AGRICULTURE TO ACHIEVE SUSTAINABLE AND RESILIENT AGRI-FOOD SYSTEMS

Nischal Kafle[1*]
[1]Institute of Agriculture and Animal Science, Tribhuvan University, Nepal
*Corresponding author: nkafle26@gmail.com
Nischal Kafle: 0009-0006-9339-2251

ABSTRACT

Climate-Smart Agriculture (CSA) offers strategies to enhance productivity, resilience, environmental sustainability, and livelihoods in diverse agro-ecological contexts. This review synthesizes evidence from purposively selected case studies, including peer-reviewed research and institutional reports from FAO, the World Bank, CIAT, and CGIAR partners, to examine CSA adoption, practices, and outcomes. Seven CSA domains—water, energy, nutrient, carbon, weather, knowledge, and planting—were analyzed, with associated technologies and interventions evaluated for their impact on productivity, food security, environmental health, income, and climate resilience. Regional patterns of adoption varied: water-smart interventions dominated in Africa, energy-smart and renewable solutions were prominent in Latin America, and diversification and irrigation efficiency prevailed in Asia. Water-smart practices demonstrated strong gains in productivity and resilience, while energy-, nutrient-, and carbon-smart interventions primarily improved environmental sustainability. Knowledge- and weather-smart strategies significantly enhanced food security and income, and planting-smart approaches supported climate-adapted cropping. Despite progress, CSA adoption remains concentrated on a limited set of crops and technologies, highlighting opportunities for innovation, diversification, and scaling, particularly in livestock and aquaculture systems. The review underscores the potential of CSA to transform agricultural systems toward sustainability and climate resilience and provides evidence-based insights for policy and practice.

Key words: *Climate-smart agriculture (CSA), innovative technologies, sustainable food systems, climate resilience*

INTRODUCTION

Climate change has emerged as a critical challenge for agricultural systems worldwide. Although climate change is a natural phenomenon, it has been greatly accelerated by human activities, particularly the emission of greenhouse gases (GHGs). As a result, the Earth's average surface temperature increased by approximately 1.1°C above the 1850–1900 baseline during the period from 2011 to 2020 (IPCC, 2023). Rising temperatures, erratic and intense rainfall, and shifting seasonal patterns have disrupted crop and livestock production across regions. These changes have elevated pest and disease incidence, increased the frequency of floods and droughts, accelerated soil degradation, and reduced crop productivity (Habib-ur-Rahman, 2022; Arora, 2019). Reports indicate increased evaporation rates, rapid surface runoff, declining soil fertility, and heightened pest pressure in many agro-ecological zones. Crop simulation models such as DSSAT and APSIM predict substantial yield reductions in major cereals, including rice and wheat, under future climate scenarios (Habib-ur-Rahman, 2022).

Agriculture, which operates within a delicate ecological system shaped by soil, climate, and biological interactions, is particularly vulnerable to these climatic disturbances. Climate change disrupts the balance among crops, pests, pathogens, and weeds, while exacerbating existing challenges such as water scarcity, declining pollinator populations, ground-level ozone concentration, and fisheries degradation (Maciejczak et al., 2018). Projections suggest that warming will reduce yields of major staple crops, with tropical regions facing the most severe impacts. A significant share of studies anticipates yield declines by the 2030s, ranging from 10% to as high as 50% in some contexts (Zougmoré et al., 2021). Livestock systems are also adversely affected through reduced feed and forage quality, lower milk production, and deteriorating animal health and reproductive performance (Rojas-Downing et al., 2017). At the same time, the agricultural sector remains a major contributor to climate change, accounting for a substantial share of global GHG emissions, reinforcing its dual role as both a victim and a driver of climate change.

In response to these challenges, a range of agronomic and resource management practices have been proposed, including crop diversification, improved soil and water management, water harvesting, biochar and biostimulant application, and precision-based technologies (Malhi, 2021; Bibi, 2023). However, the effectiveness of these approaches is strongly influenced by local environmental conditions, scale of implementation, and institutional support. This has underscored the need for more comprehensive and integrated frameworks capable of simultaneously addressing productivity, climate adaptation, and mitigation objectives.

Food systems, encompassing all activities related to production, distribution, and consumption, lie at the center of this challenge. The current global food system relies heavily on mass production models and has struggled to ensure equitable access to affordable and nutritious food amid rapid population growth (United Nations, 2023). At the same time, food systems are increasingly recognized for their far-reaching impacts on diets, livelihoods, biodiversity, and climate change (Dengerink et al., 2022). While public awareness of environmental degradation and health concerns linked to natural resource overexploitation has grown (Bernardi & Azucar, 2020), small-scale producers, who play a vital role in food production, remain highly vulnerable to climate-related shocks (Zougmoré et al., 2021). Consequently, food system transformation has become an imperative. Such transformation is not merely about change itself, but about guiding the pace and direction in which food systems evolve to balance sustainability, equity, and resilience (Dengerink et al., 2022).

The vulnerability of agriculture and food systems is further shaped by socio-economic factors and historical development pathways. The transition from conventional to industrial agriculture in the twentieth century, driven by rising food demand, initially improved productivity through mechanization, monocropping, and large-scale farming (Akamani, 2021). However, this model failed to achieve long-term food security and revealed significant drawbacks, including water depletion, fossil fuel dependence, increased GHG emissions, biodiversity loss, displacement of rural communities, and degradation of land resources (Matson & VanderBrook, 2021). Unsustainable land management practices adopted to meet growing food demand have intensified land degradation and undermined agricultural productivity in many regions (Dougill et al., 2021).

Within this context, Climate-Smart Agriculture (CSA) has emerged as a prominent framework aimed at reconciling food security goals with climate adaptation and mitigation needs. Recognizing the complex interplay of environmental and socio-economic factors affecting agricultural vulnerability, CSA has gained global recognition as a development priority (Maciejczak et al., 2018). Introduced by the Food and Agriculture Organization in 2010, CSA seeks to sustainably increase agricultural productivity, enhance resilience to climate variability, and reduce greenhouse gas emissions where feasible (Akamani, 2021; Molieleng et al., 2021). CSA represents a comprehensive strategy that integrates short-term adaptation measures with long-term mitigation efforts to address the intertwined challenges of climate change and food security (Maciejczak et al., 2018; Chandra et al., 2018).

CSA is structured around three interrelated pillars: production, adaptation, and mitigation. The productivity pillar emphasizes Sustainable Production Intensification, which optimizes crop yields through ecosystem-based approaches that improve nutrient, water, and input-use efficiency. The adaptation pillar focuses on reducing vulnerability and enhancing resilience through strategies such as drought-tolerant varieties and system modifications that account for cumulative climate risks. The mitigation pillar addresses environmental impacts through practices such as sustainable land management and agroforestry (CCARDSA, 2023). CSA promotes a range of cost-effective practices, including integrated crop–livestock systems, renewable energy use, legumes and cover crops, and soil carbon-enhancing techniques, while placing strong emphasis on soil health as a foundation for resilient food systems and smallholder empowerment (Dougill et al., 2021).

However, CSA too receive criticisms. Critics argue that CSA faces substantial challenges due to the lack of conceptual clarity about agricultural practices and its focus on individual farms rather than on the landscape. The integration of its three objectives is often criticized saying that it leads to imbalanced project implementations (Zougmoré et al., 2021). Failure to engage stakeholders from essential sectors and its heavy reliance on agrichemicals and the global market system is also condemned (Akamani, 2021). Major constraints associated with the use of CSA options are the inappropriateness of practices, the lack of adequate information, the limited technical capacity, and the low literacy level among farmers (Zougmoré et al., 2021). Weak policy integration, limited institutional support, and conflicting agricultural advice have been linked to the restricted adoption of CSA practices, particularly in conservation agriculture (Dougill et al., 2021). Communal livestock farmers encounter barriers such as old age, low education, meager income, limited experience, inadequate resources, and infrequent contact with extension officers, impeding the widespread adoption of CSA practices in this context (Molieleng et al., 2021). Addressing these challenges is crucial for enhancing the uptake of climate-smart agricultural approaches regionally and globally.

In this context, innovation plays a critical role in strengthening the effectiveness of CSA. Addressing climate challenges in agriculture requires innovative approaches that enhance resilience, mitigate impacts, and improve productivity (Gancone et al., 2021). Innovation encompasses the creation and application of new ideas, technologies, and processes that improve agricultural practices, services, and markets (Maciejczak et al., 2018). Within CSA, precision agriculture enables more efficient use of fertilizers and water through site- and rate-specific management, while digitalization supports access to climate information, market linkages, and risk management tools, including weather forecasting and pest surveillance systems (Gancone et al., 2021; Trendov et al., 2019).

Advances in technologies such as satellites, drones, sensors, robotics, and data analytics are facilitating the development of precision farming systems. These tools assist in farm planning, nutrient management, pest and disease detection, and remote input application, with potential benefits including higher yields, increased farm income, and reduced environmental harm (Usman et al., 2021). Despite these advances, existing reviews often examine CSA practices and technological innovations separately, providing limited insight into their combined effects on agri-food system performance.

Reviewing global CSA practices alongside technological innovations therefore offers an opportunity to better understand their transformative potential and identify pathways for scaling sustainable solutions. This study seeks to synthesize available evidence on how coupling CSA practices with modern innovations can reshape agri-food systems to address current and future challenges. The findings aim to support policymakers, researchers, development agencies, and farmers by providing evidence-based insights to guide the transition toward more sustainable, inclusive, and resilient global food systems.

MATERIALS AND METHODS

This study employed a systematic qualitative review to synthesize evidence on Climate-Smart Agriculture (CSA) interventions across regions, focusing on how CSA practices and technologies influence dimensions of sustainable and resilient agri-food systems like productivity, resilience, environmental performance, and livelihoods. Both peer-reviewed empirical research and high-quality institutional reports from FAO, the World Bank, CIAT, and CGIAR partners were included to provide comprehensive coverage of implementation processes and measurable outcomes. Case studies were purposively selected to ensure they were relevant to CSA adoption and interventions, reported measurable outcomes related to productivity, resilience, and sustainability, and represented diverse geographic, socio-economic, and agro-ecological contexts. Data were systematically extracted across several categories, including CSA domains (water, energy, nutrient, carbon, weather, knowledge, and planting), CSA practices and technologies (specific interventions and innovative tools within each domain), and outcomes (productivity, food security and nutrition, environmental health, income or livelihood, and resilience to climate risks). Outcomes were assessed qualitatively and assigned scores from low (1) to high (5) based on reported effectiveness. Finally, a table was constructed to provide structured comparisons of CSA domains, practices, technologies, and outcomes, offering a clear visualization of how interventions contribute to sustainable and climate-resilient agricultural systems.

RESULTS AND DISCUSSION

Case studies of climate-smart agriculture across regions

Evidence from selected case studies illustrated the potential of Climate-Smart Agriculture (CSA) to enhance productivity, resilience, and environmental performance across diverse agro-ecological and socio-economic contexts. Patterns of CSA adoption differed markedly across regions, reflecting context-specific constraints and priorities. In Africa, CSA interventions were largely centered on land restoration, soil and water conservation, and integrated crop–livestock systems, responding to widespread land degradation and rainfall variability. In Asia, diversification strategies, irrigation efficiency, and water-saving technologies dominate, while energy transitions, including improved cookstoves and renewable energy solutions, were more prominent in Latin America and the Caribbean (Sova et al., 2018). These regional differences underscored that CSA outcomes were strongly shaped by baseline resource conditions, institutional capacity, and access to complementary technologies.

Table 1: CSA domains contributing differently to dimensions of sustainable and resilient agri-food systems

CSA Domain	Productivity / Yield	Food Security / Nutrition	Environmental Health	Income / Livelihood	Resilience to Climate / Risk
Water Smart	5	3	3	3	5
Energy Smart	3	2	5	3	3
Nutrient Smart	3	2	5	3	1
Carbon Smart	3	1	5	3	3
Weather Smart	2	2	2	1	5
Knowledge Smart	5	5	3	5	3
Planting Smart	5	3	2	3	3

Note: Low = 1, Low to Moderate = 2, Moderate = 3, Moderate to high = 4, High = 5

Water-smart interventions primarily focused on irrigation efficiency, land restoration, and water-saving technologies. In Tigray, Ethiopia, coordinated public investment in large-scale land restoration and irrigation infrastructure enabled farmers to cultivate high-value crops even during drought periods, demonstrating substantial productivity gains and climate resilience (Zougmoré et al., 2021). In Nepal, solar-powered irrigation systems supported early rice establishment and a shift toward commercial vegetable production, increasing cropping intensity by 200–300 percent (CIAT et al., 2017). In Sri Lanka, FAO's Save and Grow initiative reduced irrigation water requirements by 10–20 percent and facilitated dry-season expansion of irrigated land (FAO, 2021). These examples illustrate that water-smart CSA contributed strongly to productivity, moderate improvements in food security and income, and enhanced resilience to climate variability.

Energy-smart CSA interventions include household biogas, renewable energy systems, and improved cookstoves. In Tanzania, biogas adoption reduced dependence on wood fuel and paraffin, lowered carbon emissions, and generated slurry to substitute for chemical fertilizers, yielding moderate productivity gains, environmental benefits, and cost savings (CIAT and World Bank, 2017a). In Latin America, renewable energy adoption in agriculture also supported mitigation and improved operational efficiency (Sova et al., 2018). These interventions highlight that energy-smart CSA primarily strengthened environmental sustainability while supporting moderate improvements in income and resilience.

Nutrient- and carbon-smart interventions optimized fertilizer use, improve soil quality, and enhance carbon sequestration. In Mexico, agroforestry-based coffee systems improved soil quality, reduced yield losses from pests and diseases, and contributed to higher farm income, although benefits accrued gradually due to longer investment horizons (World Bank et al., 2015). Similarly, in Sri Lanka, fertilizer efficiency practices reduced chemical fertilizer use by 27 percent, improving soil health alongside moderate gains in productivity (FAO, 2021). These practices primarily enhanced environmental health while providing moderate productivity and income benefits.

Knowledge- and weather-smart interventions emphasized access to extension services, climate advisory systems, and integrated CSA packages. In Ethiopia, CSA adoption was associated with enhanced dietary diversity and reduced food insecurity, especially among households with access to extension services and markets (Ali et al., 2023). In Kenya, integrated CSA packages combining crop, soil, and risk management practices led to a 56.83 percent increase in food security (Wekesa et al., 2018). Pakistan and South Africa also reported income and food security improvements from CSA adoption, although knowledge gaps, limited input access, and institutional capacity constrained uptake (CIAT and World Bank, 2017b; Abegunde et al., 2022). In Senegal, government-led weather and climate information services reached millions, improving farm-level risk management (Zougmoré et al., 2021). These examples showed that knowledge- and weather-smart CSA strongly enhance food security, income, and resilience, with moderate gains in productivity and environmental performance.

Planting-smart interventions involved crop diversification, early planting, and high-value crop adoption. In Nepal, early rice establishment and diversified vegetable production under solar-powered irrigation contributed to high productivity and moderate improvements in food security and income (CIAT et al., 2017). These practices supported resilience to climate shocks by aligning planting with favorable conditions.

Opportunities with CSA

In the upcoming three decades, a critical 30-70% surge in food availability is imperative to meet the escalating demands of an increasingly crowded, urbanized, and affluent global society. The food system must change profoundly for easy accessibility of healthy food, grown sustainably through resilient farming practices (Herrero et al., 2019). The transition towards more inclusive and resilient food systems requires radical change in food system components: production, consumption, trade, and governance (Ruben et al., 2021). Improving agricultural productivity by reducing yield gaps and changing land use patterns from calorie-rich to nutrient-rich food would be instrumental in this regard (Ruben et al., 2021). The implementation of CSA emerges as a viable solution to meet these requirements.

Table 2. Climate-Smart Agricultural (CSA) practices, innovative technologies and potential outcomes

CSA Domain	CSA Practices	Innovative Technologies to Couple With	Potential Outcomes	Sources
Water Smart	Improved irrigation, water harvesting, soil & water conservation, mulching	Precision irrigation sensors, automated drip/sprinkler systems, IoT-based soil moisture monitoring, remote sensing for water management	Efficient water use, reduced drought risk, improved yields, reduced conflicts over water	CIAT et al., 2017; FAO, 2021
Energy Smart	Zero/minimum tillage, conservation agriculture, solar-powered irrigation	Solar micro-grids, bio-digesters, energy-efficient pumps, drones for reduced fuel-intensive operations	Lower energy costs, reduced carbon footprint, sustainable mechanization	Sova et al., 2018; Abegunde et al., 2022
Nutrient Smart	Organic farming, integrated nutrient management, composting, intercropping	Digital soil testing kits, AI-based nutrient recommendation systems, biofertilizers, nano-fertilizers	Improved soil fertility, higher nutrient-use efficiency, reduced chemical pollution	Malhi et al., 2021; Gancone et al., 2021
Carbon Smart	Agroforestry, plastic tunnels/greenhouses, Integrated Pest Management (IPM)	Climate-controlled greenhouses, carbon-mapping with remote sensing, UAVs (Unmanned Aerial Vehicles) for precision pesticide application	Increased carbon sequestration, reduced GHG emissions, resilient crop production	World Bank et al., 2015; Zougmoré et al., 2021
Weather Smart	Crop insurance, climate information services	Satellite-based weather forecasting, mobile-based advisory apps, blockchain-enabled index insurance	Improved risk management, reduced crop losses, stronger farmer resilience	FAO, 2021; CIAT & World Bank, 2017b
Knowledge Smart	Resistant & improved varieties, adjusted planting seasons, farmer training	Genomic breeding & CRISPR technology, digital farmer advisory platforms, e-learning tools, decision-support systems	Stress-tolerant crops, better decision-making, faster knowledge transfer	Trendov et al., 2019; Usman et al., 2021
Planting Smart	Crop rotation, diversification, mixed cropping, shade nets, windbreaks	GIS-based cropping pattern planning, smart greenhouses, sensor-equipped shade nets, digital market-link platforms	Diversified income sources, reduced pest/disease outbreaks, stable production systems	Sova et al., 2018; CIAT & World Bank, 2017a

While CSA is diverse, the number of technologies applied, and the different sub-sectors of agriculture included are limited. Reports have shown that water management, crop stress tolerance, intercropping, organic inputs, and conservation agriculture are the technologies under CSA that have been adopted across 33 countries. They account for almost

50 percent of all CSA technologies identified by experts as climate-smart (Sova et al., 2018). Similarly, CSA is concentrated on food crops such as maize, wheat, and rice or cash crops (perennials) that account for two-thirds of all climate-smart technologies. Only 18 percent of technologies considered climate-smart were analyzed for livestock systems and just 2 percent for aquaculture systems (Sova et al., 2018). This potential for innovation, adoption, and diversification of CSA technologies highlights the scope of CSA at present. Table 2 summarizes how selected CSA domains align with innovative technologies and the potential outcomes they can generate for building sustainable and climate-resilient agriculture.

CONCLUSION

The review demonstrates that Climate-Smart Agriculture (CSA) has significant potential to enhance productivity, resilience, environmental health, and livelihoods across diverse agro-ecological and socio-economic contexts. Evidence from case studies shows that adoption patterns are shaped by regional priorities, resource availability, and institutional capacity, with water-, energy-, nutrient-, carbon-, knowledge-, weather-, and planting-smart interventions contributing differently to outcomes. While water- and knowledge-smart practices show strong gains in productivity, resilience, and food security, energy- and carbon-smart interventions primarily support environmental sustainability. Despite notable successes, CSA adoption remains concentrated on a limited set of crops and technologies, with livestock and aquaculture largely underrepresented. This highlights opportunities for innovation, diversification, and broader application of CSA practices. Scaling up CSA requires integrated approaches, combining context-specific technologies, extension services, and policy support, to build sustainable and climate-resilient agricultural systems capable of meeting future food security demands.

REFERENCES

Abegunde, V. O., Sibanda, M., & Obi, A. (2022). Effect of climate-smart agriculture on household food security in small-scale production systems: A micro-level analysis from South Africa. *Cogent Social Sciences*, *8*(1), 2086343. doi: 10.1080/23311886.2022.2086343.

Akamani, K. (2021). An Ecosystem-Based Approach to Climate-Smart Agriculture with Some Considerations for Social Equity. *Agronomy, 11*(8), 1564. doi:10.3390/agronomy11081564.

Ali, H., Menza, M., Hagos, F., & Haileslassie, A. (2023). Impact of climate-smart agriculture adoption on food security and multidimensional poverty of rural farm households in the Central Rift Valley of Ethiopia. *Agriculture & Food Security*, *11*(1), 62. doi: 10.1186/s40066-022-00401-5.

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. *Environmental Sustainability*, *2*(2), 95–96. https://doi.org/10.1007/s42398-019-00078-w.

Bernardi, P.D. & Azucar, D. (2020). *Innovation in Food Ecosystems: Entrepreneurship for a Sustainable.* Retrieved from https://link.springer.com/book/10.1007/978-3-030-33502-1.

Bibi, F., & Rahman, A. (2023). An Overview of Climate Change Impacts on Agriculture and Their Mitigation Strategies. *Agriculture*, *13*(8), Article 8. https://doi.org/10.3390/agriculture13081508

CCARDSA. (2023). Climate Smart Agriculture (CSA) Handbook. Retrieved from https://www.ccardesa.org/sites/default/files/ickm-documents/Handbook_Climate%20Smart_GCCA%2B_final.pdf.

Chandra, A., McNamara, K. E., & Dargusch, P. (2018). Climate-smart agriculture: Perspectives and framings. *Climate Policy*, *18*(4), 526–541. https://doi.org/10.1080/14693062.2017.1316968.

CIAT & World Bank. (2017a). Climate-Smart Agriculture in Tanzania. CSA Country Profiles for Africa Series. Retrieved from https://climateknowledgeportal.worldbank.org/sites/default/files/2019-06/CSA-in-Tanzania.pdf

CIAT & World Bank. (2017b). Climate-Smart Agriculture in Pakistan. Retrieved from https://ccafs.cgiar.org/resources/publications/climate-smart-agriculture-pakistan.

CIAT, World Bank, CCAFS & LI-BIRD. (2017). Climate-Smart Agriculture in Nepal. CSA Country Profiles for Asia Series. https://climateknowledgeportal.worldbank.org/sites/default/files/2019-06/CSA_Profile_Nepal.pdf

Dengerink, J., Piters, B.S., Brouwer, H. & Guijt, J. (2022). Food Systems Transformation: an introduction (Publication No. WCDI-22-201). https://doi.org/10.18174/566868.

Dougill, A. J., Hermans, T. D. G., Eze, S., Antwi-Agyei, P., & Sallu, S. M. (2021). Evaluating Climate-Smart Agriculture as Route to Building Climate Resilience in African Food Systems. *Sustainability*, *13*(17). https://doi.org/10.3390/su13179909.

FAO. (2021). Climate-smart agriculture case studies 2021 – Projects from around the world. Retrieved from https://doi.org/10.4060/cb5359en.

Gancone, A., Pubule, J., & Blumberga, D. (2021). Valorization Methodology for Agriculture Sector Climate Change Mitigation Measures. *Environmental and Climate Technologies*, *25*(1), 944–954. https://doi.org/10.2478/rtuect-2021-0071.

Habib-ur-Rahman, M., Ahmad, A., Raza, A., Hasnain, M. U., Alharby, H. F., Alzahrani, Y. M., Bamagoos, A. A., Hakeem, K. R., Ahmad, S., Nasim, W., Ali, S., Mansour, F., & EL Sabagh, A. (2022). Impact of climate change on agricultural production; Issues, challenges, and opportunities in Asia. *Frontiers in Plant Science*, *13*, 925548. https://doi.org/10.3389/fpls.2022.925548.

Herrero, M., Thornton, P. K., Mason-D'Croz, D., Palmer, J., Benton, T. G., Bodirsky, B. L., West, P. C. (2020). Innovation can accelerate the transition towards a sustainable food system. *Nature Food, 1*(5), 266–272. doi:10.1038/s43016-020-0074-1.

IPCC. (2023). Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001.

Maciejczak, M., Takács, I.& Takács-György, K. (2018). Use of Smart Innovations for Development of Climate Smart Agriculture. *Roczniki Naukowe SERiA, 20*(2*)*, 117-124. http://real.mtak.hu/83148/1/Maciejczak_et_al.2018_u.pdf.

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of Climate Change on Agriculture and Its Mitigation Strategies: A Review. *Sustainability*, *13*(3), 1318. https://doi.org/10.3390/su13031318.

Matson, J., & VandenBrook, J. (2021). Toward a sustainable food system. *SSRN Electron.* https://doi.org/10.2139/ssrn.3967155.

Molieleng, L., Fourie, P.& Nwafor, I. (2021). Adoption of Climate Smart Agriculture by Communal Livestock Farmers in South Africa. *Sustainability 2021, 13*(8), 10468. https://doi.org/10.3390/su131810468.

Rojas-Downing, M. M., Nejadhashemi, A. P., Harrigan, T., & Woznicki, S. A. (2017). Climate change and livestock: Impacts, adaptation, and mitigation. *Climate Risk Management*, *16*, 145–163. https://doi.org/10.1016/j.crm.2017.02.001.

Ruben, R., Cavatassi, R., Lipper, L., Smaling, E., & Winters, P. (2021). Towards food systems transformation—Five paradigm shifts for healthy, inclusive and sustainable food systems. *Food Security*, *13*(6), 1423–1430. https://doi.org/10.1007/s12571-021-01221-4.

Sova, C. A., G. Grosjean, T. Baedeker, T. N. Nguyen, M. Wallner, A. Jarvis, A. Nowak, C. Corner-Dolloff, E. Girvetz, P. Laderach, and Lizarazo. M. (2018). *Bringing the Concept of Climate-Smart Agriculture to Life: Insights from CSA Country Profiles Across Africa, Asia, and Latin America.* Retrieved from https://openknowledge.worldbank.org/server/api/core/bitstreams/06d3343c-4529-59a2-a9b2-45c93973321a/content

Spring, Ú. O. (2019). Climate-Smart Agriculture and a Sustainable Food System for a Sustainable-Engendered Peace. In H. G. Brauch, Ú. Oswald Spring, A. E. Collins, & S. E. Serrano Oswald (Eds.), *Climate Change, Disasters, Sustainability Transition and Peace in the Anthropocene* (pp. 95–123). Springer International Publishing. https://doi.org/10.1007/978-3-319-97562-7_5.

Trendov, N. M., Varas, S. & Zeng, M. (2019). *Digital technologies in agriculture and rural areas – Status report.* Retrieved from https://www.fao.org/3/ca4985en/ca4985en.pdf.

UNFCC. (2021). *Climate Smart Agriculture*. Retrieved November 25, 2023, from https://unfccc.int/news/climate-smart-agriculture.

United Nations. (2023). *Food Systems Transformation: Transforming food systems for a sustainable world without hunger* [Brochure]. https://hlpf.un.org/sites/default/files/2023-09/Food%20Systems%20Transformation%20Brochure.pdf.

Usman, M., Hameed, G., Saboor, A., Almas, L.K.& Hanif, M. (2021). R&D Innovation Adoption, Climatic Sensitivity, and Absorptive Ability Contribution for Agriculture TFP Growth in Pakistan. *Agriculture 2021, 11*, 1206. https://doi.org/10.3390/agriculture11121206.

Wekesa, B. M., Ayuya, O. I., & Lagat, J. K. (2018). Effect of climate-smart agricultural practices on household food security in smallholder production systems: Micro-level evidence from Kenya. *Agriculture & Food Security*, *7*(1), 80. https://doi.org/10.1186/s40066-018-0230-0.

World Bank, CIAT & CATIE. (2015). Climate-Smart Agriculture in Mexico. CSA Country Profiles for Latin America Series. 2nd ed. Washington D.C.: The World Bank Group. https://climateknowledgeportal.worldbank.org/sites/default/files/2019-06/CSA-in-Mexico.pdf

Zougmoré, R.B., Läderach, P. & Campbell, B.M. (2021). Transforming Food Systems in Africa under Climate Change Pressure: Role of Climate-Smart Agriculture. *Sustainability 2021, 13*, 4305. https:// doi.org/10.3390/su130843.