CLIMATE-SMART LIVESTOCK: INTEGRATING AGROFORESTRY PRACTICES IN PASTURE MANAGEMENT FOR ENHANCED ENVIRONMENTAL BENEFITS

Raluca-Aniela GHEORGHE-IRIMIA[1], Cosmin ŞONEA [1#], Paul-Rodian TĂPĂLOAGĂ[2*], Dana TĂPĂLOAGĂ [1*], Gigi-Cristinel ŞONEA[3]

1) University of Agronomical Sciences and Veterinary Medicine Bucharest, Faculty of Veterinary Medicine, Bucharest, Romania
2) University of Agronomical Sciences and Veterinary Medicine Bucharest, Faculty of Animal Productions Engineering and Management
3) Ministry of Agriculture and Rural Development - Romania

REVIEW

Abstract
This review article provides a comprehensive examination of climate-smart livestock practices, emphasizing their pivotal role in advancing sustainable agricultural development amidst escalating climate change challenges. Climate-smart livestock practices, characterized by their ability to enhance agricultural productivity, improve resource utilization efficiency, and bolster resilience to climate variability, offer a transformative approach to livestock farming. These practices not only aim to sustain agricultural output but also to mitigate the adverse environmental impacts traditionally associated with livestock farming, such as greenhouse gas emissions and biodiversity loss.
A significant focus of the article is on the integration of agroforestry within pasture management as a core climate-smart strategy. Agroforestry, the practice of integrating trees with crops and livestock within agricultural systems, is presented as a multifaceted solution that addresses the ecological drawbacks of conventional livestock farming. This sustainable approach contributes to enhanced biodiversity, soil conservation, and improved water management, establishing a harmonious balance between agricultural productivity and environmental stewardship.
The anticipated environmental benefits of adopting climate-smart livestock practices, particularly through agroforestry, are highlighted. These benefits include the sequestration of carbon, reduction in soil erosion, enhancement of soil fertility, and preservation of water resources. By delineating the potential for significant environmental improvements, the article underscores the necessity of adopting and scaling up climate-smart practices within livestock farming. The integration of these practices not only promises to transform the landscape of agriculture in the face of climate change but also to ensure food security, enhance the resilience of farming communities, and contributes to the global pursuit of sustainability.

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#Corresponding author: cosmin_sn@yahoo.com
*Coordinator

INTRODUCTION

The introduction of climate-smart livestock practices represents a significant evolution in agricultural methodologies, aimed at enhancing productivity, improving resource utilization efficiency, and increasing resilience to the impacts of climate change within livestock farming operations (Şonea et al., 2023). These practices are central to the advancement of sustainable agricultural development, offering strategic solutions to the complex challenges posed by global climate alterations. Defined by their ability to elevate agricultural output in a sustainable manner, optimize resource use, reduce climate variability vulnerability, and minimize greenhouse gas emissions, climate-smart livestock practices embody an innovative approach to agriculture (Aryal et al., 2018).

The importance of these practices extends beyond operational improvements, delivering substantial benefits to animal welfare, farm productivity, and environmental conservation (Dumitrescu et al., 2019). By integrating climate-smart agricultural techniques, such as agroforestry, enhanced livestock breeds, and mulching, farmers can not only boost food production but also adapt to changing climatic conditions and aid in mitigating the effects of climate change (Mwongera et al., 2017). These practices provide dual benefits by enhancing resilience and productivity at the farm level and contributing to broader environmental objectives through emission reduction and ecosystem service enhancement.

Future research in the realm of climate-smart livestock practices is expected to focus on the effective amalgamation of various climate-smart strategies to fortify farmers' resilience to climatic shifts (Chandra et al., 2017, Petrean et al., 2024). Investigating the specific ways through which agroforestry and other climate-smart approaches can improve livestock welfare and farm efficiency presents a crucial research avenue (Teklewold et al., 2017). Moreover, identifying the impediments to the adoption of these innovative practices and devising strategies to surmount such obstacles are essential for their widespread dissemination and application (Park, 2022).

The detrimental environmental impacts associated with conventional livestock farming and pasture management necessitate a reassessment of traditional agricultural practices. Standard methods frequently contribute to environmental issues such as deforestation, soil erosion, and high levels of greenhouse gas emissions, highlighting the critical need for sustainable alternatives.

Within this context, agroforestry offers a viable solution, proposing an integrated model that combines trees, crops, and livestock into a unified agricultural ecosystem. This strategy not only addresses the ecological drawbacks of conventional farming methods but also provides numerous advantages, including improved biodiversity, soil preservation, and carbon sequestration capabilities.

Therefore, this review aims to systematically analyze the contribution of climate-smart livestock practices, particularly agroforestry, as sustainable solutions to the environmental challenges inherent in traditional livestock farming and pasture management. By examining the effectiveness, advantages, and future directions of these practices, this review seeks to enrich the discourse on sustainable agriculture and underscore the critical role of climate-smart strategies in achieving environmental equilibrium and ensuring food security amidst the ongoing challenges of climate change.

THE CONCEPT OF CLIMATE-SMART LIVESTOCK

Incorporating climate-smart practices into livestock management emerges as a pivotal strategy for bolstering agricultural sustainability amidst escalating climate change challenges. These methodologies endeavor to elevate livestock production efficiencies while concurrently attenuating environmental repercussions. The essence of climate-smart agriculture (CSA) encapsulates a trio of core objectives: augmenting productivity, amplifying resource utilization efficacy, and diminishing susceptibilities to climatic variations, notably within the domain of livestock management (Aryal et al., 2018). Such approaches are instrumental in not only fostering agricultural resilience but also in safeguarding environmental integrity.

Evidence underscores the criticality of adopting climate-smart agricultural practices (CSAPs) for sustainable agricultural enhancement (Aryal et al., 2018). Furthermore, research delineates livestock size as a critical factor influencing the adoption of CSAPs, accentuating the necessity to integrate livestock-centric considerations into these sustainable strategies (Belay et al., 2023).

Climate-smart livestock systems are meticulously engineered to improve animal welfare, boost production efficiency, and enhance farm profitability, all the while addressing the environmental quandaries and health issues pervading livestock farming (Park, 2022). These systems are aimed at alleviating animal stress, optimizing production metrics, and mitigating the environmental challenges intrinsic to livestock agriculture.

The fusion of climate-smart practices within livestock management frameworks has demonstrably fostered positive outcomes on farmers' nutritional security, thereby highlighting the intricate linkage between effective livestock management and food security paradigms (Yuya et al., 2022). Investigative efforts into the synergy between climate-smart livestock production methodologies and farmers' nutritional security have spotlighted the imperative for comprehensive strategies that concurrently tackle agricultural and nutritional hurdles (Shahbaz et al., 2022).

For smallholder farmers, the embracement of climate-smart livestock production tactics unveils avenues for bolstering climate resilience and enhancing livelihoods (Ayal & Mamo, 2023). The integration of such practices across livestock value chains presents a promising pathway for stakeholders to optimize yields, profitability, and sustainability, thereby cushioning the impacts of climatic perturbations (Thongoh et al., 2021).

AGROFORESTRY PRACTICES: AN OVERVIEW

Agroforestry practices encompass a spectrum of integrative land management approaches that synergistically combine trees, crops, and livestock within a unified agricultural framework. These practices serve as a cornerstone for sustainable pastoral management, offering a suite of ecological and economic benefits. Enhanced soil vitality, increased biological diversity, and augmented carbon sequestration capabilities stand out as prominent advantages derived from these practices (Tadesse, 2019). Predominantly, agroforestry configurations pertinent to pasture management encompass silvopastoral systems, alley cropping, and windbreaks (Herder et al., 2017).

Silvopasture, a distinguished form of agroforestry, orchestrates a harmonious coexistence of trees, forage, and livestock, facilitating an environment that provides essential shade and shelter for animals, while concurrently bolstering forage production (Buergler et al., 2005). Alley cropping, another agroforestry variant, entails the strategic alignment of tree rows interspersed with crops or pasturelands, aimed at fostering soil conservation and diversifying agricultural yield (Arage, 2021). Windbreaks, constituted by linear plantings of trees or shrubs, play a pivotal role in minimizing wind erosion, safeguarding livestock, and establishing microclimates conducive to pasture development (Herder et al., 2017).

The infusion of trees into pasture-based livestock systems through agroforestry not only amplifies biodiversity and ecosystem services but also fortifies livelihoods, underscoring the integral role of agroforestry in community and ecosystem support (Chizmar et al., 2020; Aryal et al., 2019). Such systems enhance soil organic carbon reserves, water quality, and nutrient cycling, showcasing the environmental stewardship of integrating arboreal elements into pastoral landscapes (Udawatta et al., 2010; Kibet et al., 2022). Specifically, silvopastoral practices have demonstrated their efficacy in augmenting forage production and botanical diversity, thereby elevating livestock productivity (Buergler et al., 2005).

Agroforestry's capacity to contribute significantly to climate change mitigation through carbon sequestration further accentuates its environmental value (Lorenz & Lal, 2014). These systems are adept at reducing fire hazards, enhancing carbon storage, moderating microclimates, and curtailing soil erosion and nutrient depletion, offering a sustainable alternative to traditional agriculture (Moreno et al., 2017).

Moreover, the ecosystem services rendered by agroforestry practices—such as soil erosion control, microclimate optimization for yield improvement, economic diversification, and water quality preservation—are invaluable for the sustenance of livestock production and welfare (Bentrup et al., 2019). The deliberate amalgamation of trees with crops and/or livestock in agroforestry systems engenders a multitude of economic and ecological benefits over conventional farming approaches (Dupraz et al., 2019). These systems are instrumental in averting environmental degradation, boosting agricultural productivity, enhancing carbon sequestration, and supporting robust soil and ecosystem health, thereby ensuring stable incomes and accruing multifaceted benefits to human welfare (Castle et al., 2022).

In essence, agroforestry systems are pivotal in biodiversity conservation, soil enrichment, and the preservation of clean air and water resources, all of which are critical for the sustainability of livestock management practices (Atreya et al., 2021). They optimize a wealth of eco-physical, economic, and social advantages for farmers, local communities, and the broader society, showcasing their indispensable role in combating land degradation, improving soil health, and bolstering ecosystem resilience (Tomar et al., 2021).

INTEGRATING AGROFORESTRY WITH PASTURE MANAGEMENT

The strategic integration of agroforestry within livestock farming necessitates comprehensive planning and a nuanced understanding of various determinants to ensure efficacy. Scholarly contributions delineate a myriad of methodologies for the incorporation of agroforestry practices into livestock enterprises, with a pronounced emphasis on the significance of engaging farmers and diversifying agricultural operations as essential factors for the effective implementation of agroforestry.

Foremost in the scholarly narrative on the implementation of agroforestry is the acknowledgment of the pivotal role of farmers and their perceptions. Jose (2009) underscores the necessity of aligning agroforestry initiatives

with the viewpoints of farmers to guarantee the success of such endeavors, advocating for the inclusion of farmers in the decision-making and planning stages as a fundamental strategy for the enduring integration of agroforestry practices in livestock farms. This participatory model not only promotes adoption but also assures the sustainability of agroforestry systems.

Additionally, the diversification of agricultural activities through the lens of agroforestry is highlighted as a critical adaptation strategy in the context of climate change. Fadina & Barjolle (2018) emphasize the integration of crop-livestock diversification along with agroforestry as vital for enhancing resilience against the uncertainties and extremities of climate change. Such integrative measures serve as safeguards, bolstering the adaptive capacity of agricultural systems.

The elevation of farmers' awareness and capacity building emerges as critical for the successful deployment of agroforestry practices. Rois-Díaz et al. (2017) emphasize the imperative to augment farmers' understanding of the comprehensive benefits of agroforestry, advocating for the deployment of extension services and training programs as effective channels for imparting knowledge on the merits of agroforestry in livestock settings.

Furthermore, the facilitation of policy support and the establishment of regulatory environments conducive to agroforestry are identified as crucial facilitators. Camilli et al. (2017) highlight the importance of policy mechanisms that encourage the adoption of agroforestry, spotlighting the role of stakeholders in advancing policy measures that are supportive of agroforestry's integration. Initiatives by governments that offer incentives and technical support are instrumental in embedding agroforestry practices into livestock farming systems.

The amalgamation of agroforestry with pasture management presents significant prospects for enhancing livestock welfare and overall farm productivity. Thorlakson & Neufeldt (2012) posit that agroforestry practices can lead to an increase in farm productivity and incomes, thereby improving farmer well-being. Introducing trees into pasture ecosystems not only benefits livestock welfare through the provision of essential amenities such as shade and shelter but also enriches animal health and comfort through diverse forage options.

Evidence suggests that agroforestry systems, owing to their resource complementarity, achieve higher agricultural productivity than monoculture systems, with trees procuring resources beneficial for both crops and livestock (Smith et al., 2012). This approach to diversification engenders a resilient and productive agricultural ecosystem that supports livestock welfare and enhances farm efficiency.

Moreover, agroforestry interventions are associated with positive impacts on agricultural productivity, ecosystem services, and human welfare, especially in contexts of low- and middle-income countries (Castle et al., 2021). These practices are conducive to improved soil health, augmented biodiversity, and enhanced ecosystem services, laying the groundwork for superior livestock management and productivity.

In addition, the integration of agroforestry with pasture management positively influences soil quality, carbon sequestration, and environmental sustainability (Paudel et al., 2011). Agroforestry practices bolster soil microbial biomass, fertility, and carbon content, essential elements for sustaining healthy pastures and supporting livestock welfare. This comprehensive approach illuminates the multi-dimensional benefits of incorporating agroforestry within livestock farming systems, offering a sustainable avenue towards enhancing agricultural resilience and productivity.

CHALLENGES AND FUTURE DIRECTIONS

The integration of agroforestry with livestock farming, while promising, encounters several formidable challenges that necessitate strategic solutions for its successful adoption. The scholarly discourse sheds light on an array of obstacles that may impede the seamless incorporation of agroforestry practices into livestock operations.

A critical barrier identified within the literature pertains to the elevated initial costs associated with the establishment of agroforestry systems. Farmers frequently face socio-economic constraints, a limited understanding of the benefit-cost ratio of agroforestry practices, and a dearth of comprehensive knowledge regarding agroforestry's multifaceted benefits (Atreya et al., 2021). Mitigating these financial hurdles and equipping farmers with cost-effective strategies for agroforestry deployment are essential steps toward fostering widespread adoption.

Additionally, the ambiguity in policy support, the inadequacy of extension services, and unclear administrative demarcations emerge as significant impediments (Atreya et al., 2021). The absence of coherent policy frameworks and robust institutional backing can significantly curtail the adoption of agroforestry in livestock farming contexts. Amplifying policy support, bolstering extension services, and establishing definitive guidelines are pivotal measures to navigate these institutional challenges.

Another notable challenge encompasses the insufficiency of scientific knowledge, expertise, and technological solutions tailored to the complex management demands of agroforestry systems (Atreya et al., 2021). There is a pressing need for farmer-centric training and capacity-building initiatives to adeptly manage the intricacies of integrated crop-tree-livestock systems. Providing accessible information, technical assistance, and comprehensive training programs can empower farmers to adeptly navigate agroforestry practices.

Moreover, the limited access to markets and marketing information for agroforestry products presents another hurdle (Atreya et al., 2021). The challenges associated with market access can undermine the economic sustainability of agroforestry systems. Cultivating market linkages, instituting market incentives, and furnishing marketing support are crucial strategies to address these economic constraints.

Looking ahead, the trajectory of research and development in climate-smart livestock and agroforestry practices harbors significant implications for advancing sustainable agricultural systems in a changing climate. The literature underscores emerging trends and potential avenues for future inquiry.

One evolving trend highlights the significance of adopting a multifaceted suite of climate-smart practices to enhance farmers' resilience to climatic perturbations. Investigations into the synergistic impacts of integrating agricultural water management, improved crop varieties, and fertilization strategies underscore their collective benefits on farm income and climate resilience, especially in regions such as the Nile Basin of Ethiopia (Teklewold et al., 2017). Future research could delve into the cumulative effects of diverse climate-smart practices on livestock systems.

Furthermore, the promotion of climate-smart agricultural practices, crop diversification, and agroforestry as strategies to counteract climate change effects has gained traction. Such approaches have proven effective in bolstering resilience within farming systems, as evidenced in the mid-hill regions of Western Nepal (Adhikari, 2018). Future studies may explore the specific contributions of agroforestry practices to climate resilience in livestock farming.

The potential of agroforestry as a sustainable carbon sequestration practice under varying climate scenarios has also garnered attention. Addressing financial, technical, and institutional challenges is critical for optimizing agroforestry's role in climate mitigation (Abbas et al., 2017). Future inquiries could focus on developing innovative financing models and policy interventions to enhance agroforestry adoption in livestock operations.

Lastly, the climate-smart agriculture (CSA) paradigm has emerged as a holistic framework to concurrently address food security, adaptation, and mitigation. The importance of CSA practices in navigating the challenges of climate change and agricultural productivity has been emphasized (Neufeldt et al., 2013). Future research endeavors could investigate the scalability and applicability of CSA practices across various livestock farming scenarios, paving the way for more resilient and sustainable agricultural landscapes.

CONCLUSIONS

In conclusion, this mini-review has elucidated the pivotal role of agroforestry in transforming livestock farming into a more sustainable, productive, and environmentally friendly practice. The integration of trees, crops, and livestock within a unified agricultural framework presents a multifaceted approach to addressing the pressing challenges of climate change, biodiversity loss, and soil degradation. Key points discussed include the significant benefits of agroforestry practices such as enhanced soil health, improved biodiversity, increased carbon sequestration, and bolstered resilience against climatic variabilities. The challenges in adopting agroforestry, including socioeconomic barriers, policy constraints, and the need for technical knowledge, underscore the necessity for targeted interventions to facilitate widespread adoption.

The incorporation of agroforestry practices within pasture management is not merely an agricultural innovation but a requisite for environmental sustainability in livestock farming. By enhancing ecosystem services,

reducing greenhouse gas emissions, and promoting a more efficient use of natural resources, agroforestry stands at the forefront of sustainable agricultural practices. Its role in mitigating the impacts of climate change, while simultaneously supporting livelihoods and improving farm productivity, cannot be overstated.

Therefore, a concerted call to action is directed towards researchers, policymakers, and practitioners.

The journey towards sustainable livestock farming is complex and multifaceted, requiring the collaboration of all stakeholders involved. By embracing agroforestry, we can embark on a path that not only ensures the viability of agricultural livelihoods but also guards the health of our planet for future generations.

REFERENCES

Abbas, F., Hammad, H., Fahad, S., Cerdà, A., Rizwan, M., Farhad, W., … & Bakhat, H. 2017. Agroforestry: a sustainable environmental practice for carbon sequestration under the climate change scenarios—a review. Environmental Science and Pollution Research, 24(12), 11177-11191. https://doi.org/10.1007/s11356-017-8687-0

Adhikari, S. 2018. Drought impact and adaptation strategies in the mid-hill farming system of western Nepal. Environments, 5(9), 101. https://doi.org/10.3390/environments5090101

Arage, A. 2021. Assessment of farmer's perception and adoption of agroforestry practices: the case of Assosa district, western Ethiopia. American Journal of Applied Scientific Research, 7(2), 15. https://doi.org/10.11648/j.ajasr.20210702.11

Aryal, J., Jat, M., Sapkota, T., Khatri-Chhetri, A., Kassie, M., Rahut, D., … & Maharjan, S. 2018. Adoption of multiple climate-smart agricultural practices in the Gangetic Plains of Bihar, India. International Journal of Climate Change Strategies and Management, 10(3), 407-427. https://doi.org/10.1108/ijccsm-02-2017-0025

Aryal, J., Rahut, D., Maharjan, S., & Erenstein, O. 2018. Factors affecting the adoption of multiple climate-smart agricultural practices in the Indo-Gangetic Plains of India. Natural Resources Forum, 42(3), 141-158. https://doi.org/10.1111/1477-8947.12152

Aryal, K., Thapa, P., & Lamichhane, D. 2019. Revisiting agroforestry for building climate resilient communities: a case of package-based integrated agroforestry practices in Nepal. Emerging Science Journal, 3(5), 303-311. https://doi.org/10.28991/esj-2019-01193

Atreya, K., Subedi, B., Ghimire, P., Khanal, S., Charmakar, S., & Adhikari, R. 2021. Agroforestry for mountain development: prospects, challenges and ways forward in Nepal. Archives of Agriculture and Environmental Science, 6(1), 87-99. https://doi.org/10.26832/24566632.2021.0601012

Ayal, D. & Mamo, B. 2023. Smallholder farmers' adoption of climate-smart livestock production: practices, status, and determinants in Hidebu Abote Woreda, central Ethiopia. https://doi.org/10.21203/rs.3.rs-2587412/v1

Belay, A., Kebede, W., & Golla, S. 2023. Determinants of climate-smart agricultural practices in smallholder plots: evidence from Wadla district, northeast Ethiopia. International Journal of Climate Change Strategies and Management, 15(5), 619-637. https://doi.org/10.1108/ijccsm-06-2022-0071

Bentrup, G., Hopwood, J., Adamson, N., & Vaughan, M. 2019. Temperate agroforestry systems and insect pollinators: a review. Forests, 10(11), 981. https://doi.org/10.3390/f10110981

Blaga Petrean, A., Daina, S., Borzan, M., Macri, A. M., Bogdan, L., Lazar, E. A., & Popescu, S. 2024. Pasture Access Effects on the Welfare of Dairy Cows Housed in Free-Stall Barns. Agriculture, 14(2), 179.

Buergler, A., Fike, J., Burger, J., Feldhake, C., McKenna, J., & Teutsch, C. 2005. Botanical composition and forage production in an emulated silvopasture. Agronomy Journal, 97(4), 1141-1147. https://doi.org/10.2134/agronj2004.0308

Camilli, F., Pisanelli, A., Seddaiu, G., Franca, A., Bondesan, V., Rosati, A., … & Burgess, P. 2017. How local stakeholders perceive agroforestry systems: an Italian perspective. Agroforestry Systems, 92(4), 849-862. https://doi.org/10.1007/s10457-017-0127-0

Castle, S., Miller, D., Merten, N., Ordonez, P., & Baylis, K. 2022. Evidence for the impacts of agroforestry on ecosystem services and human well-being in high-income countries: a systematic map. Environmental Evidence, 11(1). https://doi.org/10.1186/s13750-022-00260-4

Castle, S., Miller, D., Ordoñez, P., Baylis, K., & Hughes, K. 2021. The impacts of agroforestry interventions on agricultural productivity, ecosystem services, and human well-being in low- and middle-income countries: a systematic review. Campbell Systematic Reviews, 17(2). https://doi.org/10.1002/cl2.1167

Chandra, A., McNamara, K., & Dargusch, P. 2017. Climate-smart agriculture: perspectives and framings. Climate Policy, 18(4), 526-541. https://doi.org/10.1080/14693062.2017.1316968

Chizmar, S., Castillo, M., Pizarro, D., Vásquez, H., Bernal, W., Rivera, R., … & Cubbage, F. 2020. A discounted cash flow and capital budgeting analysis of silvopastoral systems in the Amazonas region of Peru. Land, 9(10), 353. https://doi.org/10.3390/land9100353

Dupraz, C., Wolz, K., Lecomte, I., Talbot, G., Vincent, G., Mulia, R., … & Noordwijk, M. 2019. Hi-safe: a 3D agroforestry model for integrating dynamic tree–crop interactions. Sustainability, 11(8), 2293. https://doi.org/10.3390/su11082293

Dumitrescu, V., Borlea, F., Tîrziu, E., Hotea, I., Ilie, M., & Colibar, O. (2019). Researches regarding the feeding of the Black Goat (Rupicapra rupicapra). Lucrari Stiintifice - Universitatea de Stiinte Agricole a Banatului Timisoara, Medicina Veterinara, 52(3), 45-48

Fadina, A. & Barjolle, D. 2018. Farmers' adaptation strategies to climate change and their implications in the Zou Department of South Benin. Environments, 5(1), 15. https://doi.org/10.3390/environments5010015

Herder, M., Moreno, G., Mosquera-Losada, M., Palma, J., Sidiropoulou, A., Santiago-Freijanes, J., … & Burgess, P. 2017. Current extent and stratification of agroforestry in the European Union. Agriculture Ecosystems & Environment, 241, 121-132. https://doi.org/10.1016/j.agee.2017.03.005

Jose, S. 2009. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforestry Systems, 76(1), 1-10. https://doi.org/10.1007/s10457-009-9229-7

Kibet, E., Musafiri, C., Kiboi, M., Macharia, J., Ng'etich, O., Kosgei, D., … & Ngetich, F. 2022. Soil organic carbon stocks under different land utilization types in Western Kenya. Sustainability, 14(14), 8267. https://doi.org/10.3390/su14148267

Lorenz, K. & Lal, R. 2014. Soil organic carbon sequestration in agroforestry systems. A review. Agronomy for Sustainable Development, 34(2), 443-454. https://doi.org/10.1007/s13593-014-0212-y

Moreno, G., Aviron, S., Berg, S., Crous-Duran, J., Franca, A., Jalón, S., … & Burgess, P. 2017. Agroforestry systems of high nature and cultural value in Europe: provision of commercial goods and other ecosystem services. Agroforestry Systems, 92(4), 877-891. https://doi.org/10.1007/s10457-017-0126-1

Mwongera, C., Shikuku, K., Twyman, J., Läderach, P., Ampaire, E., Van Asten, P., … & Winowiecki, L. 2017. Climate smart agriculture rapid appraisal (csa-ra): a tool for prioritizing context-specific climate smart agriculture technologies. Agricultural Systems, 151, 192-203. https://doi.org/10.1016/j.agsy.2016.05.009

Neufeldt, H., Jahn, M., Campbell, B., Beddington, J., DeClerck, F., Pinto, A., … & Zougmoré, R. 2013. Beyond climate-smart agriculture: toward safe operating spaces for global food systems. Agriculture & Food Security, 2(1). https://doi.org/10.1186/2048-7010-2-12

Park, S. 2022. Application strategy for sustainable livestock production with farm animal algorithms in response to climate change up to 2050: a review. Czech Journal of Animal Science, 67(11), 425-441. https://doi.org/10.17221/172/2022-cjas

Paudel, B., Udawatta, R., Kremer, R., & Anderson, S. 2011. Soil quality indicator responses to row crop, grazed pasture, and agroforestry buffer management. Agroforestry Systems, 84(2), 311-323. https://doi.org/10.1007/s10457-011-9454-8

Rois-Díaz, M., Lovrić, N., Lovrić, M., Ferreiro-Domínguez, N., Mosquera-Losada, M., Herder, M., … & Burgess, P. 2017. Farmers' reasoning behind the uptake of agroforestry practices: evidence from multiple case-studies across Europe. Agroforestry Systems, 92(4), 811-828. https://doi.org/10.1007/s10457-017-0139-9

Shahbaz, P., Abbas, A., Aziz, B., Alotaibi, B., & Traoré, A. 2022. Nexus between climate-smart livestock production practices and farmers' nutritional security in Pakistan: exploring level, linkages, and determinants. International Journal of Environmental Research and Public Health, 19(9), 5340. https://doi.org/10.3390/ijerph19095340

Smith, J., Pearce, B., & Wolfe, M. 2012. Reconciling productivity with protection of the environment: is temperate agroforestry the answer?. Renewable Agriculture and Food Systems, 28(1), 80-92. https://doi.org/10.1017/s1742170511000585

Șonea, C., Gheorghe-Irimia, R. A., Tăpăloagă, D., & Tăpăloagă, P. R. 2023. Nutrition and animal agriculture in the 21st century: A review of future prospects. Annals of the University of Craiova - Agriculture Montanology Cadastre Series, 53(1), 303-312.

Tadesse, S. 2019. Views and attitudes of local farmers towards planting, growing and managing trees in agroforestry system in Basona Worena district, Ethiopia. J Agri Sci Food Res, 10(1). https://doi.org/10.35248/2593-9173.19.10.258

Teklewold, H., Mekonnen, A., Köhlin, G., & Falco, S. 2017. Does adoption of multiple climate-smart practices improve farmers' climate resilience? Empirical evidence from the Nile basin of Ethiopia. Climate Change Economics, 08(01), 1750001. https://doi.org/10.1142/s2010007817500014

Thongoh, M., Mutembei, H., Mburu, J., & Kathambi, B. 2021. An assessment of barriers to MSMEs' adoption of CSA in livestock red meat value chain, Kajiado County, Kenya. American Journal of Climate Change, 10(03), 237-262. https://doi.org/10.4236/ajcc.2021.103011

Thorlakson, T. & Neufeldt, H. 2012. Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. Agriculture & Food Security, 1(1). https://doi.org/10.1186/2048-7010-1-15

Tomar, J., Ahmed, A., Bhat, J., Kaushal, R., Shukla, G., & Kumar, R. 2021. Potential and opportunities of agroforestry practices in combating land degradation. https://doi.org/10.5772/intechopen.97843

Udawatta, R., Garrett, H., & Kallenbach, R. 2010. Agroforestry and grass buffer effects on water quality in grazed pastures. Agroforestry Systems, 79(1), 81-87. https://doi.org/10.1007/s10457-010-9288-9

Yuya, B., Mohammed, J., & Ketema, M. 2022. An evaluation of nutritional security impacts of climate-smart adaptation practices among smallholder farmers of eastern Oromia, Ethiopia. Turkish Journal of Agriculture - Food Science and Technology, 10(12), 2377-2388. https://doi.org/10.24925/turjaf.v10i12.2377-2388.5241