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# The Role of Agroforestry system in reducing Farmers' Exposure to Climate Change

# El papel del sistema agroforestal en la reducción de la exposición de los agricultores al cambio climático

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## Abstract

Agroforestry plays a crucial role in climate change adaptation and increases resilience to its effects by promoting diverse land-use patterns, sustainable livelihoods and income streams, higher forest and agricultural output, and a reduction in production losses due to weather. Agroforestry had a significant role in reducing farmers' sensitivity to shock. Trees enable reduced susceptibility, greater farming system resilience, and residential protection from climate-related hazards. Subsistence farmers are among those who are most sensitive to current climatic fluctuation. Agroforestry systems offer several advantages to smallholder farmers who are vulnerable to the effects of climate change. These systems may be particularly crucial in rural, agriculturally based economies where there are few other viable sources of income. They can also boost output and financial stability while assisting systems in adjusting to increased climatic variability and mitigating greenhouse gas emissions through sequestration. Increased agricultural production, environmental sustainability, food security, income diversification, specific coping mechanisms, a higher standard of living, and soil and water conservation are some of the major advantages of agroforestry. Many agroforestry systems have the capacity to both lessen and respond to climatic uncertainty. Agroforestry systems, in general, voluntarily include both mitigation and adaptation techniques and provide disadvantaged farmers with a variety of options to guarantee food security while minimizing climate change.



## Resumen

La agrosilvicultura desempeña un papel crucial en la adaptación al cambio climático y aumenta la resiliencia a sus efectos promoviendo diversos patrones de uso de la tierra, medios de vida y fuentes de ingresos sostenibles, una mayor producción forestal y agrícola y una reducción de las pérdidas de producción debidas a las condiciones meteorológicas. La agrosilvicultura desempeñó un papel importante en la reducción de la sensibilidad de los agricultores a las perturbaciones. Los árboles permiten reducir la susceptibilidad, aumentar la resiliencia de los sistemas agrícolas y proteger las viviendas de los peligros relacionados con el clima. Los agricultores de subsistencia se encuentran entre los más sensibles a las fluctuaciones climáticas actuales. Los sistemas agroforestales ofrecen varias ventajas a los pequeños agricultores vulnerables a los efectos del cambio climático. Estos sistemas pueden ser especialmente cruciales en las economías rurales de base agrícola, donde hay pocas otras fuentes viables de ingresos. También pueden impulsar la producción y la estabilidad financiera, al tiempo que ayudan a los sistemas a adaptarse a una mayor variabilidad climática y a mitigar las emisiones de gases de efecto invernadero mediante el secuestro. El aumento de la producción agrícola, la sostenibilidad medioambiental, la seguridad alimentaria, la diversificación de los ingresos, los mecanismos específicos de supervivencia, un mayor nivel de vida y la conservación del suelo y el agua son algunas de las principales ventajas de la agrosilvicultura. Muchos sistemas agroforestales tienen la capacidad tanto de disminuir como de responder a la incertidumbre climática. Los sistemas agroforestales, en general, incluyen voluntariamente técnicas tanto de mitigación como de adaptación y ofrecen a los agricultores desfavorecidos diversas opciones para garantizar la seguridad alimentaria minimizando al mismo tiempo el cambio climático.

## Introduction

Climate unpredictability is a reality that presents difficulties for everyone. In some places, it is viewed as a change in weather patterns, while in others; it becomes a matter of survival[1]. This is particularly true in developing nations where the bulk of people rely on agriculture supported by rainfall for a living[2]. Despite the fact, that many people rely on agriculture for their livelihoods it is the one that is most vulnerable to the effects of climate change (CC)[3]. Due of this, communities that depend on it may be exposed to climate variability (CV). As that agriculture is rain-fed, one of the main solutions is to take agricultural or land-use measures that could lessen or accommodate the risks associated with CC[4].

Due to the substantial effects that CC is having on natural and human systems across all continents, food production is declining and there is an increase in food insecurity in many regions of the world[5]. Nelson[6] estimates that during the next 40 years, agricultural productivity could decrease by 10-20 %, which would have a severe effect on rural populations in developing and transitional nations[7]. Solutions are being developed to mitigate the expected effects of CC and the poor's vulnerability to it[2].

Agroforestry (AF) is frequently suggested as a solution to the problems of both food security and CC[8]. When there are two or more crop seasons in a row, AF practices like planting leguminous trees during the fallow period are used (improved fallow). AF can boost adaptability to CV, mitigate the consequences of extreme weather events like droughts or heavy rains, and improve wellbeing in many tropical regions by integrating short-and long-term trees with crops (distributed intercropping)[9]. AF contributes to slowing CC while this is happening by expanding and developing carbon sinks, which are regions where carbon dioxide from the atmosphere is absorbed and stored in things like biomass and soil[4].

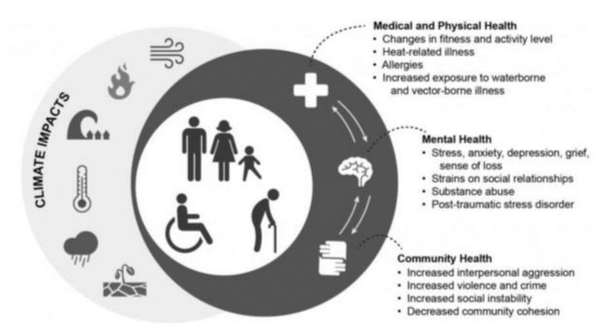
It is important to consider this from the farmers' perspective because local biophysical and socioeconomic factors greatly determine how much AF practices contribute to enhancing farmers' livelihoods[10]. Despite the worldwide advantage of regulating climate through carbon sequestration, smallholder farmers need to invest in innovative farming practices as well as bettering their livelihoods and changing their lives[11]. As a result, mitigation efforts at the level of smallholder farms must directly and concretely support farmers' livelihoods, for as by giving them access to food, fuel, or fodder, with mitigation working as a byproduct of the improved agricultural practice[12]. According to numerous studies, the only factors that are measured are AF essential role in boosting resilience to climate-related hazards or the amount of carbon storage in smallholder systems[13]. In light of this, the goal of this study was to examine how AF makes farmers less susceptible to CC.

## Development

*Vulnerability*. Is the measure of a system's susceptibility to or incapacity to handle the harsh environment brought on by CC, particularly its unpredictable nature and past extreme occurrences[14]. The degree of vulnerability of a system depends on its susceptibility to CV, the type, degree, and pace of climatic dissimilarity to which it is strongly exposed, as well as its capacity for survival. Resilience must be increased while exposure and sensitivity must be reduced in order to reduce a system's susceptibility to dangers associated with the climate[15].

Vulnerability is one of the traits of environmental and social processes, it is directly tied to the exposed system's susceptibility, sensitivity, and lack of resilience or capacity for adaptation to both extreme and nonextreme situations in the context of CV. It is described as being condition-specific and working in conjunction a dangerous event to increase risk[6,11]. Fundamental environmental components change continuity from the standpoint of CC, which in turn creates new danger situations for societies. For example, more severe and frequent occurrences may disseminate risk elements to new areas, showing core susceptibility. In fact, future vulnerability is already present in the current circumstances of the societies that may be exposed to future CV[16], as a result, underlying vulnerability factors will be exposed rather than necessarily created as new risks arise in previously unaffected areas[17].

**Figure 1 human well-being diagram[21]**

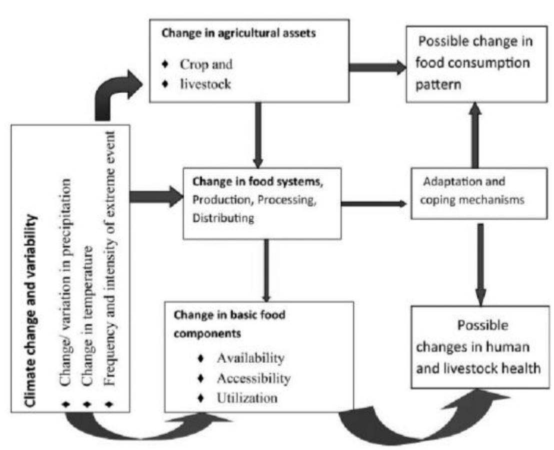



*Well-being*. According to a three-dimensional holistic view, human well-being is "a state of being with others, where human needs are met, where one can act meaningfully to pursue one's goals, and where one enjoys and appreciates a satisfactory quality of life"[18]. According to this theory, happiness includes relational and subjective well-being in addition to material or financial well-being[19]. In addition, a number of scholars distinguish between the factors that determine wellbeing and their constituents[20]. Examples of "determinants" are things that lead to or help make improvements in wellbeing while "constituents" are things like happiness, health, and positive interpersonal relationships[20]. A few determinants are the accessibility of capital, expertise, and clean water.

*Climate variability*. Due to CV, numerous regions of the world have experienced and will continue to suffer various effects. The annual variance in the climate above or below a long-term average value is known as CV[22], refers to climatic fluctuations that occur over seasons or years, as opposed to everyday circumstances, like when one rainy season is more intense or lengthy than others. The tropics have experienced less change in average surface temperatures and precipitation during the past century than the rest of the world[23].

According to Intergovernmental Panel on CC (IPCC), CC projections, the majority of the humid and sub-humid tropics may experience a rise in the frequency of droughts, floods, and extreme rainfall events, which typically indicates more precipitation variability. Developing nations that still heavily rely on rain-fed agriculture and other ecological resources will be particularly negatively impacted by CC[3]. Moreover, due to human activity, rural regions are now more vulnerable to drought[24]. As population growth in drought-prone areas results in unsustainable land and resource use, drought sensitivity increases.

**Figure 2 Diagram of climate variability[25]**



*Impact of climate change on farmers' well-being***.** Several researches show that adverse impact of CV on farmers' welfare[26,27]. Rainfall variability can result in either floods or droughts, depending on the kind of deviation from the long-term normal. The management of natural resources, water resources, settlements, infrastructure, and food security are impacted by variations in rainfall[28]. Farmers that depend on seasonal cues to plant their crops struggle because of the more unpredictable weather patterns[26]. Planting delays brought on by a decrease in rainfall have a big impact on agricultural output. Some crops are badly destroyed when rain hits early than planned. Farmers sometimes blame unpredictable rainfall that falls late in the growing season for crop illnesses like blight, which lowers their anticipated seasonal income[26].

Droughts have serious negative effects on the economy and society, especially in developing nations where a considerable amount of the national Gross Domestic Product (GDP) is derived from agricultural production. Three different types of consequences were discovered, including animal loss, decreased productivity, and higher production costs[29]. People's wellbeing is directly impacted by these losses, especially in rural communities where livestock is the main source of income. In addition, the demand for natural resources, particularly forests, rises during droughts as a result of increased charcoal production, agricultural development, logging, and forest grazing during dry seasons[23].

Floods are more frequent than droughts and changes in rainfall, and they have an immediate negative impact on people's quality of life[28]. Floods affect communities both instantly and subsequently. Loss of livestock and human life, increased disease risk, movement restrictions, higher commodity prices, contaminated water, trouble accessing cooking supplies, property destruction, and increased food insecurity are some of the immediate effects. Many lasting consequences of floods include decreased soil health, loss of infrastructure and houses, emigration, and lower value of agricultural land. Throughout the past century, damage associated with floods has also grown because to increased land use, loss of forest covers human encroachment on floodplains, and higher population concentrations in flood-prone areas[30].

*Agroforestry systems*. AF is the deliberate integration of woody vegetation (trees or shrubs) with agricultural and/or animal production systems in order to profit from the resulting ecological and economic interactions[31]. The Common Agricultural Policy (CAP) and other state programs have frequently sped up the transition to specialized forms of agriculture and forestry[32]. The need to balance productivity and environmental improvement may present a chance for an AF renaissance. When tree and crop systems are integrated, resources (such solar radiation or water) are captured more effectively than when they are separated, as is sometimes the case with AF[33]. Also, it has been discovered that AF can help with regulating ecosystem services, such as nitrogen cycling.

*Agroforestry and vulnerability*. Has been suggested as a workable strategy to help subsistence farmers lessen their vulnerability to CC[4]. Because 15 % of farms there have at least 30 % forest cover, Sub-Saharan Africa has a huge potential to absorb carbon and lower other agriculture-related greenhouse gases (GHG) emissions[34]. Crop diversification, long rotation techniques for soil conservation, home gardens, bordering plantings, perennial crops, hedgerow intercropping, living fences, enhanced fallows, or mixed stratum AF are some examples of AF systems. With the control of water flow processes and microclimate buffering, well-managed AF can significantly contribute to improving tolerance to confusing climatic fluctuation[34].

Due to their deep root systems, trees are thought to be less vulnerable to climate-related dangers like floods and droughts[35,36]. The qualities of the human-environment system, which consists of the human, social, physical, and natural capital, are what determine a system's sensitivity. AF contributes to the preservation and upkeep of natural resources by, for instance, reducing sources of pollution like dust, minimizing soil erosion, and establishing habitats for wildlife. It expedites adaptable responses to quick changes in ecological circumstances by simultaneously conserving or replenishing soil and water resources[34].

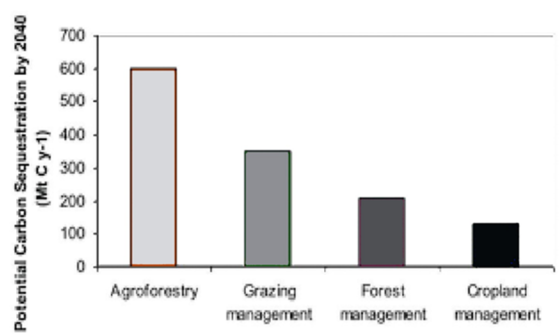
A key step in replacing energy sources and addressing the carbon balance issue is the development of sustainable AF methods[34]. The time and effort needed to obtain fuel wood is significantly reduced by the use of AF[9]. AF raises a family's total standard of living through increasing agricultural output, off-farm income, wealth, and the farm's environmental conditions. Another material resource employed on the farm for protection and to raise the value of the property is trees[37].

*Agroforestry's results directly increase resilience*. Results like the realization of rights or an increase in wellbeing are important indicators of resilience[38]. Examining factors including food security, asset ownership, school attendance, nutrition, and other factors might help determine these results. The best asset insurance and plan for dealing with probable CC events is the presence of trees on the farm. AF is a direct source of food and fruit. Also, it offers a further source of income from the selling of lumber and firewood[37].

*Agroforestry's role in reducing climate vulnerability.* Enhancing the wellbeing of farmers due of its dual function in helping farmers adjust to these changes and combating CC through carbon sequestration, AF practices have recently attracted increased attention[4]. A possible method for assisting subsistence farmers reduce their vulnerability to CC is AF[3,4,39]. In agricultural systems, trees are employed consciously to boost farm output, diversify income streams, and provide environmental services[40].

One strategy to boost farm productivity is to intercrop nitrogen-fixing trees between rows of food crops. This method does this by providing crops with nutrient availability in limited amounts. In AF activities, tree products including fruit, wood, and fuel wood are also used and sold. Due to their deep root systems, trees are thought to be less vulnerable to climate-related shocks like floods and droughts[23]. Almost half of the demand for both residential and commercial wood is satisfied by AF. For example, they provide about 80 % of the necessary firewood, 70 % to 80 % of the necessary wood for plywood, 60 % of the necessary raw materials for paper pulp, and 9-11 % of the necessary green cattle feed[34].

**Figure 3 potential carbon sequestration**




*Carbon sequestration potentials of agroforestry*. Carbon is removed from the atmosphere via biological or physical processes and stored in a variety of carbon sinks such as vegetation, soils, and seas[33]. The biomass of above-and below-ground plants, as well as the relatively stable forms of organic and inorganic carbon in the soil profile, all contribute to the terrestrial ecosystem's ability to sequester carbon[41]. AF techniques could boost soil carbon reserves on arable areas, assisting farmers in implementing CC mitigation strategies and enhancing soil health[4,42,43]. According to the Kyoto Protocol, AF is an important future approach for reducing atmospheric $CO_2$. In order to raise soil and above-ground carbon stocks globally and lessen greenhouse gas emissions and the effects of CC, AF systems seem to be a potential agricultural management method the flow and long-term carbon storage in the terrestrial biosphere will be significantly impacted by a major expansion in the area covered by AF[44]. Because they consist of more than two species, like pasture, AF systems are far better at storing carbon than monoculture agricultural fields[4].

*Improve farmer livelihood*. When evaluating the benefits of AF to farmers' lives, which are influenced by local biophysical and socioeconomic factors, it is important to reflect their viewpoints[10]. The possibility of carbon sequestration to influence climate on a global scale is not a strong justification for farmers to use new farming practices[11]. As a result, smallholder farm mitigation operations are essential to generate direct benefits to farmers' livelihoods, such as providing food, fuel, or fodder, with mitigation being a co-benefit of higher agricultural output[12]. The ability of farmers to adjust their way of life to the effects of CC may be improved by AF. Trees play a significant role in preventing CC in addition to limiting exposure to threats associated to the climate[45].

Trees on farms significantly improve farmers' capacity to respond to the risks of CC through crop and income diversification, soil and water conservation, and efficient nutrient cycling[46]. By satisfying the requirements of millions of subsistence farmers for food, fuel, and revenue, AF products can significantly contribute to their economic growth as long as they are supported by effective cultivation, processing, and marketing practices.

*Production diversification*. AF generally boosts and diversifies agricultural productivity per area of trees, crops, and livestock, protects against negative impact of wind or water flow, and creates new products that increase the farming operation's financial flexibility and diversity[47]. Also, it can significantly minimize the effects of CC[4] AF systems, a conventional resource management adaptation, may present prospects for enhancing farmer adaptation to CC due to their direct provision of food, fodder, and firewood as well as minimizing the effects of CC[47]. The ability to diversify production, strengthen the resilience of subsistence farmers, and reduce production risk may be achievable as a result of the favorable correlations between AF and adaptation to CC.

*Ecosystem protection*. Sustainable AF techniques have the potential to protect ecosystems and human livelihoods while providing the groundwork for long-term economic and social development[48]. In particular, under the current CC scenarios, AF systems support food security for farmers by supplying ecosystem services and diversifying agricultural yield[4,49]. Planting trees next to crops enhances soil fertility, prevents and controls erosion, reduces water logging, prevents the acidification and eutrophication of streams and rivers, increases local biodiversity, lessens the need for fuel from natural forests, and provides livestock with fodder, according to[4]. Also, it might strengthen the system's defenses against CC unfavorable effects.

*Addressing food security*. AF may be advantageous to farmers in a number of ways. By generating more commodities for sale or domestic consumption, it can frequently increase soil fertility and farm household resilience[50]. The most crucial technologies for guaranteeing food security are AF ones since they assist many people in escaping poverty and combating falling resource and agricultural production. For instance, the yields of crops on more degraded fields can be doubled or tripled when fertilizer trees are mixed with inorganic fertilizers. Furthermore, fodder trees can be utilized in smallholder zero-grazing systems to augment or replace commercial feeds, enhance kinds of temperate and tropical fruits that can be consumed to increase household income and nutrition, and grow swiftly into fast-growing timber and fuel[51].

## Conclusion

AF has the potential to significantly improve food security, CC resilience, and environmental resource conservation. As a result, households are significantly less likely to be shocked. AF is one of the best approaches to help children overcome their fear of danger and overcome food insecurity. AF is one of the most promising parts, particularly as it relates to rural, smallholder farmers who must adapt to more demanding climatological conditions such as longer droughts, more severe floods, and rainfall that more variable. It has been proposed as a feasible technique for reducing climate sensitivity while also generating resources and income from carbon, wood energy, enhanced soil fertility, improved local climate conditions, and ecosystem services.

A versatile, environmentally beneficial resource management strategy involves trees on farms. Farm trees are utilized to regulate, preserve, and produce. A landscape approach promotes collaboration between mitigation and adaptation, with carbon sequestration serving as a crucial technique for reducing CC. AF is one of the most promising elements, especially for rural, smallholder farmers who must adjust to more difficult climatological conditions such as longer droughts, more severe floods, and more erratic rainfall. It has been presented as a viable method for reducing climate sensitivity while also producing resources and income from carbon, wood energy, improved soil fertility, improved local climate conditions, and ecosystem services.

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## Conflicts of interest

Author declare no conflict interest on publishing paper.

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## Ethical considerations

I hereby declare that the review entitled “The Role of Agroforestry Lowering Farmers' Exposure to Climate Change **“**is our original work and has not been published any elsewhere and all sources of material used for this review have been correctly approved.

## Research limitations

The authors declare that there were no research limitations.

## Authors' contribution

*Mr. Wendu Kebede,* contribute during this review was prepared by adjusting and reviewing different journal articles and also making organizing and writing the review. *Mr. Zerfu Deresu,* contributed with the analysis of review and its interpretation.in additionally making grammatically correction and editing.

## Literature cited

1. Dazé A. Understanding vulnerability to climate change. insights from application of CARE's climate vulnerability and capacity analysis (CVCA) methodology [Internet]. Netherlands: Care Climate Change & Resilience; 2011 [cited April 12, 2023]. 34 p. Recovered from: https://careclimatechange.org/wp-content/uploads/2015/05/CARE_Understanding_Vulnerability.pdf
2. Morton JF. The impact of climate change on smallholder and subsistence agriculture. Proc Natl Acad Sci USA 2007;104(50):19680-5. DOI: https://doi.org/10.1073/pnas.0701855104
3. The World Bank. World development report 2008. Agriculture for development [Internet]. Washington DC: The International Bank for Reconstruction and Development; 2008 [cited May 2, 2023]. 386 p. Recovered from: https://www.givewell.org/files/DWDA%202009/Interventions/Agriculture/World%20Development%20Report%202008.pdf
4. Verchot LV, Van Noordwijk M, Kandji S, Tomich T, Ong C, Albrecht A, et al. Climate change: linking adaptation and mitigation through agroforestry. Mitig Adapt Strat Glob Change 2007;12(5):901-18. DOI: https://doi.org/10.1007/s11027-007-9105-6
5. Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, et al, editors. Climate Change 2014: Impacts, Adaptation, and Vulnerability [Internet]. New York: Cambridge University Press; 2014 [cited April 12, 2023]. 34 p. Recovered from: https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf
6. Nelson GC, Rosegrant MW, Koo J, Robertson R, Sulser T, Zhu T, et al. Climate change impact on agriculture and costs of adaptation [Internet]. Washington, D.C: International Food Policy Research Institute; 2009. 32 p. DOI: https://doi.org/10.2499/0896295354
7. Thompson J, Millstone E, Scoones I, Ely A, Marshall F, Shah E, et al. Agri-Food system dynamics: pathways to sustainability in an era of uncertainty [Internet]. Brighton: University of Sussex; 2007 [cited May 2, 2023]. 79 p. Recovered from: https://www.ids.ac.uk/download.php?file=files/agriculture.pdf
8. Reynolds M, Cairns J, Stirling C, Low J, Campos H, Wassmann R. Stress tolerant varieties to counter climate change. In: Dinesh D, Campbell B, Bonilla-Findji O, Richards M, editors. 10 best bet innovations for adaptation in agriculture: A supplement to the UNFCCC NAP Technical Guidelines. CCAFS Working Paper no. 215. [Internet]. Wageningen: The Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS); 2017. p. 1-68. Recovered from: https://www4.unfccc.int/sites/NAPC/Documents%20NAP/Supplements/CGIAR%20Supplement.pdf
9. Thorlakson T, Neufeldt H. Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. Agric Food Secur 2012;1:15. DOI: https://doi.org/10.1186/2048-7010-1-15
10. Smith-Dumont E, Bonhomme S, Pagella TF. Structured stakeholder engagement leads to development of more diverse and inclusive agroforestry options. Exp Agric 2019;55(Suppl 1):252-74. DOI: https://doi.org/10.1017/s0014479716000788
11. Bryan E, Ringler C, Okoba B, Koo J, Herrero M, Sivestri S. Can agriculture support climate change

adaptation, greenhouse gas mitigation and rural livelihoods? insights from Kenya. Climatic Change 2013;118(2):151-65. DOI: https://doi.org/10.1007/s10584-012-0640-0

12. Ogle SM, Olander L, Wollenberg L, Rosenstock T, Tubiello F, Paustian K, et al. Reducing greenhouse gas emissions and adapting agricultural management for climate change in developing countries: providing the basis for action. Glob Chang Biol 2014;20(1):1-6. DOI: https://doi.org/10.1111/gcb.12361

13. Henry M, Tittonell P, Manlay RJ, Bernoux M, Albrecht A, Vanlauwe B. Biodiversity, carbon stocks and sequestration potential in aboveground biomass in smallholder farming systems of western Kenya. Agric Ecosyst Environ 2009;129(1-3):238-52. DOI: https://doi.org/10.1016/j.agee.2008.09.006

14. Parry ML, Canziani OF, Palutikof J, van der Linden P, Hanson C, editors. Climate Change 2007: Impacts, Adaptation and Vulnerability [Internet]. New York: Cambridge University Press; 2007 [cited April 12, 2023]. 987 p. Recovered from: https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

15. Nguyen Q, Hoang MH, Öborn I, van Noordwijk M. Multipurpose agroforestry as a climate change resiliency option for farmers: an example of local adaptación in Vietnam. Climatic Change 2013;117(1-2):241-57. DOI: https://doi.org/10.1007/s10584-012-0550-1

16. Copestake J. Wellbeing in international development: What’s new? J Int Dev 2008;20(5):577-97. DOI: https://doi.org/10.1002/jid.143

17. Sumner A, Mallett R. Snakes and ladders, buffers and passports: rethinking poverty, vulnerability and wellbeing [Internet]. Brasilia, DF: International Policy Centre for Inclusive Growth; 2011 [cited May 2, 2023]. 1 p. Recovered from: https://ipcig.org/publication/26765?language_content_entity=en

18. Costanza R, Fisher B, Ali S, Beer C, Bond L, Boumans R, et al. Quality of life: an approach integrating opportunities, human needs, and subjective well-being. Ecol Econ 2007;61(2-3):267-76. DOI: https://doi.org/10.1016/j.ecolecon.2006.02.023

19. Hess JJ, McDowell JZ, Luber G. Integrating climate change adaptation into public health practice: using adaptive management to increase adaptive capacity and build resilience. Environ Health Perspect 2012;120(2):171-99. DOI: https://doi.org/10.1289/ehp.1103515

20. Naish S, Dale P, Mackenzie JS, McBride J, Mengersen K, Tong S. Climate change and dengue: a critical and systematic review of quantitative modelling approaches. BMC Infect Dis 2014;14:167. DOI: https://doi.org/10.1186/1471-2334-14-167

21. Shiferaw B, Tesfaye K, Kassie M, Abate T, Prasanna BM, Menkir A. Managing vulnerability to drought and enhancing livelihood resilience in sub-Saharan Africa: Technological, institutional and policy options. Weather Clim Extrem 2014;3:67-79. DOI: https://doi.org/10.1016/j.wace.2014.04.004

22. Cannon T. Vulnerability analysis, livelihoods and disasters. In: Ammann WJ, Dannenmann S, Vulliet L, editors. RISK21 - Coping with Risks due to Natural Hazards in the 21st Century. London: Taylor & Francis Group; 2006. p. 41-9. DOI: https://doi.org/10.1201/9780203963562.ch4

23. Durán Zuazo VH, Rodríguez Pleguezuelo CR. Soil-erosion and runoff prevention by plant covers. A review. Agron Sustain Dev 2008;28(1):65-86. DOI: https://doi.org/10.1051/agro:2007062

24. Hepworth N, Goulden M. Climate change in Uganda: Understanding the implications and appraising the response [Internet]. Edinburgh: LTS International; 2008 [cited April 12, 2023]. 48 p. Recovered from: https://lib.icimod.org/record/13768
25. Gou X, Zhang F, Deng Y, Ettl GJ, Yang M, Gao L, et al. Patterns and dynamics of tree-line response to climate change in the eastern Qilian Mountains, northwestern China. Dendrochronologia 2012;30(2):121-6. DOI: https://doi.org/10.1016/j.dendro.2011.05.002
26. Ngoma H, Lupiya P, Kabisa M, Hartley F. Impacts of climate change on agriculture and household welfare in Zambia: an economy-wide analysis. Climatic Change 2021;167(3-4):55. DOI: https://doi.org/10.1007/s10584-021-03168-z
27. Mosquera-Losada MR, McAdam JH, Romero-Franco R, Santiago-Freijanes JJ, Rigueiro-Rodróguez A. Definitions and components of agroforestry practices in Europe. In: Rigueiro-Rodróguez A, McAdam J, Mosquera-Losada MR, editor. Agroforestry in Europe. Current Status and Future Prospects. Dordrecht: Springer, Dordrecht; 2009. p. 3-19. DOI: https://doi.org/10.1007/978-1-4020-8272-6_1
28. van Zanten BT, Verburg PH, Espinosa M, Gomez-y-Paloma S, Galimberti G, Kantelhardt J. European agricultural landscapes, common agricultural policy and ecosystem services: a review. Agron Sustain Dev 2014;34:309-25. DOI: https://doi.org/10.1007/s13593-013-0183-4
29. Jose S. Agroforestry for ecosystem services and environmental benefits: an overview. Agroforest Syst 2009;76(1):1-10. DOI: https://doi.org/10.1007/s10457-009-9229-7
30. Mbow C, Smith P, Skole D, Duguma L, Bustamante M. Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. Curr Opin Environ Sustain 2014;6:8-14. DOI: https://doi.org/10.1016/j.cosust.2013.09.002
31. Smith J. Agroforestry: reconciling production with protection of the environment a synopsis of research literature [Internet]. Cirencester: The Organic Research Centre; 2010 [cited May 2, 2023]. 24 p. Recovered from: https://orgprints.org/18172/1/Agroforestry_synopsis.pdf
32. Pandey R, Meena D, Aretano R, Satapathy S, Semeraro T, Gupta AK, et al. Socio-ecological vulnerability of smallholders due to climate change in mountains: Agroforestry as an adaptation measure. Change Adap Socio-Ecol Syst 2015;2(1):26-41. DOI: https://doi.org/10.1515/cass-2015-0003
33. Chavan SB, Uthappa AR, Sridhar KB, Keerthika A, Handa AK, Newaj R, et al. Trees for life: Creating sustainable livelihood in Bundelkhand region of central India. Curr Sci 2016;111(6):994-1002. DOI: https://doi.org/10.18520/cs/v111/i6/994-1002
34. Fuller R, Lain J. Measuring resilience: lessons learned from measuring resilience in Oxfam's large-N effectiveness reviews [Internet]. Oxford: Oxfam GB; 2015. [cited May 2, 2023]. 21 p.m. Recovered from: https://policy-practice.oxfam.org/resources/measuring-resilience-lessons-learned-from-measuring-resilience-in-oxfams-large-583601/
35. Challinor A, Wheeler T, Garforth C, Craufurd P, Kassam A. Assessing the vulnerability of comida crop systems in Africa to clima change. Climatic Change 2007;83:381-99. DOI: https://doi.org/10.1007/s10584-007-9249-0
36. Garrity D. Science-based agroforestry and the achievement of the Millennium Development Goals. In: Garriy D, Okono A, Grayton M, Parrott

S, editors. World Agroforestry into the future [Internet]. Nairobi: World Agroforestry Centre; 2006. p. 3-8. Recovered from: https://www.worldagroforestry.org/publication/world-agroforestry-future

37. Dhyani SK, Ram A, Newaj R, Handa AK, Dev I. Agroforestry for carbono sequestration in tropical India. In: Ghosh PK, Mahanta SK, Mandal D, Ramakrishnan S, editors. Carbon Management in Tropical and Sub-Tropical Terrestrial Systems. Singapore: Springer Singapore; 2020. p. 313-31. DOI: https://doi.org/10.1007/978-981-13-9628-1_19

38. Luedeling E, Sileshi G, Beedy T, Dietz J. Carbon sequestration potential of agroforestry systems in Africa. In: Kumar B, Nair PKR, editors. Carbon Sequestration Potential of Agroforestry Systems. Dordrecht: Springer Dordrecht: 2011. p. 61-83. https://doi.org/10.1007/978-94-007-1630-8_4

39. Srinivasarao C, Sharma KL, Kundu S. Potential soil carbon sequestration in different land use and management systems in Peninsular India. In: Ghosh PK, Mahanta SK, Mandal D, Mandal B, Ramakrishnan S, editors. Carbon Management in Tropical and Sub-Tropical Terrestrial Systems. Singapore: Springer, Singapore; 2020. DOI: https://doi.org/10.1007/978-981-13-9628-1_1

40. DeZoysa M, Inoue M. Climate change impacts, agroforestry adaptation and policy environment in Sri Lanka. Open J For 2014;4(5):439-56. DOI: https://doi.org/10.4236/ojf.2014.45049

41. Maathai W. Agroforestry, climate change and habitat protection. In: Nair PKR, Garrity D, editors. Agroforestry - The Future of Global Land Use. Dordrecht: Springer Dordrecht. p. 3-6. DOI: https://doi.org/10.1007/978-94-007-4676-3_1

42. Lasco R, Pulhin F. Agroforestry for climate change adaptation and mitigation. An academic presentation for the College of Forestry and Natural Resources (CFNR), University of the Philippines Los Banos (UPLB), Los Banos, Laguna, Philippines; 2009.

43. Molua EL. The economics of tropical agroforestry systems: the case of agroforestry farms in Cameroon. For Policy Econ 2005;7(2):199-211. DOI: https://doi.org/10.1016/S1389-9341(03)00032-7

44. Wreford A, Moran D, Adger N. Climate change and agriculture impacts, adaptation and mitigation [Internet]. Paris: OECD publishing; 2010 [cited 22 May 2023]. 139 p. Retrieved from: https://www.oecd.org/greengrowth/climate-change-and-agriculture-9789264086876-en.htm

45. Mangala PZ, Makoto I. Climate change and agroforestry management in Sri Lanka: Adverse impacts, adaptation strategies, and policy implications. Department of Agricultural Economics, University of Ruhuna, Matara, Sri Lanka and Department of Global Agricultural Sciences, The University of Tokyo, Tokyo, Japan; 2014.

46. Thangata PH, Hilderbrand PE. Carbon stock and sequestration potential of agroforestry systems in smallholder agroecosystems of sub-Saharan Africa: Mechanisms for 'reducing emissions from deforestation and forest degradation '(REDD+). Agric Ecosyst'. Agric Ecosyst Environ 2012;158: 172-83. DOI: https://doi.org/10.1016/j.agee.2012.06.007

47. Mulugeta G. Evergreen agriculture: agroforestry for food security and climate change resilience. J Nat Sci Res 2014;4(11):80-90.

48. Hall NM, Kaya B, Dick J, Skiba U, Niang A, Tabo R. Effect of improved fallow on crop productivity, soil fertility and climate-forcing gas emissions in semi-arid conditions. Biol Fertil Soils 2006;42 (3):224-30. DOI: https://doi.org/10.1007/s00374-005-0019-8

49. McAdam JH, McEvoy PM. The Potential for silvopastoralism to enhance biodiversity on grassland farms in Ireland. In: Rigueiro-Rodróguez A, McAdam J, Mosquera-Losada MR, editors. Agroforestry in Europe. Current Status and Future Prospects. Dordrecht: Springer, Dordrecht: 2009. p. 343-56. DOI: https://doi.org/10.1007/978-1-4020-8272-6_17
50. Palm CA, Woomer PL, Alegre J, Arevalo L, Castilla C, Cordeiro DG, et al. Carbon sequestration and trace gas emissions in slash-and-burn and alternative land-uses in the humid tropics [Internet]. Nairobi: ASB Climate Change Working Group; 2000 [cited May 2, 2023]. 34 p. Recovered from: https://www.asb.cgiar.org/PDFwebdocs/climatechangephaseIIreport.pdf
51. Schoeneberger MM, Bentrup G, Patel-Weynand T, editors. Agroforestry: enhancing resiliency in U.S. agricultural landscapes under changing conditions [Internet]. Washington (DC): U.S. Department of Agriculture; 2017 [cited May 2, 2023]. Gen Tech Report WO-96. DOI: https://doi.org/10.2737/WOGTR96