Zero Carbon Analytics

Briefing · July 2024

Agroecological practices in climate change resilience

Key points:

- A number of meta-analyses, reviews and studies have compared the environmental and economic outcomes of agroecological practices compared to conventional agricultural practices.
- There is a strong empirical evidence base for agroecology-aligned practices in supporting climate change adaptation, mitigation and resilience.
- Benefits from agroecology practices include improved grain yields with fewer inputs, greater biodiversity, improved soil health and water security, and enhanced carbon sequestration.
- Agroecology practices also reduce the need for pesticides and fossil-fuel-intensive synthetic fertilisers, reducing environmental risks as well as economic and health burdens for farmers.
- Studies have also found that the concurrent application of more than one agroecological practice increases beneficial outcomes, with some finding that the positive outcomes increase with time.
- While a number of agroecological benefits have been identified, the impacts are highly context-specific. Approaches will need to be tailored to the conditions of the region, ecosystem or farm.

What the science tells us about the benefits of agroecological practices

Agroecology emphasises the use of natural processes and resources to create sustainable and resilient agricultural systems. It is a response to modern intensive agricultural systems that focus on maximising production, sometimes at the expense of ecological and environmental health. A number of common agricultural practices are aligned with agroecology. For example, planting legumes alongside other crops – a centuries-old practice that is still widely used today – can improve soil fertility and water infiltration into the soil, thereby enhancing the health of the soil ecosystem and ultimately leading to increased crop yields.

Critics question the ability of agroecology to meet food security needs in a world that is increasingly at risk of climate change-induced threats that place pressure on natural systems, humans and economies.[1] However, scientific support does exist for

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[1] David Zaruk, 'Is Agroecology a Solution or an Agenda?', *Outlook on Agriculture* 52, no. 3 (2023), https://doi.org/10.1177/00307270231191807.

agroecological practices in enhancing resilience through energy efficiency, ecosystem services, food security and economic outcomes.

Through assessing more than 30 meta-analyses, seven second-order meta-analyses, and several reviews and field trials, this article summarises some of the ways by which agroecology-aligned practices can contribute to climate change resilience.

Yield and economic benefits with fewer inputs and emissions

One of the core tenets of agroecology is to reduce reliance on external inputs, such as synthetic fertilisers, pesticides and herbicides, in favour of practices that support biodiversity and soil health. As synthetic fertilisers are energy-intensive to produce and are typically made using fossil fuels, limiting their use can help reduce greenhouse gas emissions from agriculture. Synthetic fertilisers also contribute to nitrous oxide emissions - a potent greenhouse gas with significant ozone-depleting potential - once applied to the soil, with one study estimating that two thirds of emissions from synthetic fertilisers occur once they have been applied to the field.[2] Fertiliser application in conventional agriculture is excessive - nitrogen and phosphorus inputs are 60% and 48% higher than what major crops can use to grow - marking a clear space for agroecology-aligned principles in reducing emissions.[3]

Excessive chemical fertiliser application does not necessarily improve yields. For example, larger quantities of nitrogen or phosphorus fertiliser application did not have a positive effect on grain crop yields in a meta-analysis of more than 70 smallholder farms based in sub-Saharan Africa.[4] Rather, a positive effect was only noted at the lowest phosphorus fertiliser application rates of 0–20 kg P ha–1 and 20–40 kg P ha–1, while increasing the amount of fertiliser had negative effects on yield. Other estimates suggest that nitrogen and phosphorus application could be reduced by up to 29% and 22%, respectively, while maintaining current yields of wheat, rice and maize.[5] Reduced fertiliser inputs in agroecological systems also alleviate a major economic expense for farmers.[6] However, it is important to note that in certain areas, such as those with historically low fertiliser input levels, input reduction may not be appropriate.[7]

Shifting cropland systems towards agroforestry systems – whereby trees or shrubs are planted alongside crops or livestock – is a viable solution to addressing the leaky nitrogen cycle - whereby excess nitrogen is leaked into the environment or atmosphere, leading to emissions and water pollution, biodiversity loss and habitat degradation.[8] The consistent use of cover crops – which are crops that are not planted for immediate harvesting but rather because they offer some ecosystem benefit – can help reduce emissions from

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[2] Yunhu Gao and André Cabrera Serrenho, 'Greenhouse Gas Emissions from Nitrogen Fertilizers Could Be Reduced by up to One-Fifth of Current Levels by 2050 with Combined Interventions', *Nature Food* 4 (2023): 170–78, https://doi.org/10.1038/s43016-023-00698-w.

[3] Paul C. West et al., 'Leverage Points for Improving Global Food Security and the Environment', *Science* 345, no. 6194 (2014): 326, https://doi.org/10.1126/science.1246067.

[4] Marc Corbeels et al., 'Limits of Conservation Agriculture to Overcome Low Crop Yields in Sub-Saharan Africa', *Nature Food* 1, no. 7 (2020): 449, https://doi.org/10.1038/s43016-020-0114-x.

[5] West et al., 'Leverage Points for Improving Global Food Security and the Environment', 326.

[6] David Weisberger, Virginia Nichols, and Matt Liebman, 'Does Diversifying Crop Rotations Suppress Weeds? A Meta-Analysis', ed. Upendra M. Sainju, *PLOS ONE* 14, no. 7 (2019): e0219847, https://doi.org/10.1371/journal.pone.0219847.

[7] Gatien N Falconnier et al., 'The Input Reduction Principle of Agroecology Is Wrong When It Comes to Mineral Fertilizer Use in Sub-Saharan Africa', *Outlook on Agriculture* 52, no. 3 (2023): 311–26, https://doi.org/10.1177/00307270231199795.

[8] Ahmed S. Elrys et al., 'Expanding Agroforestry Can Increase Nitrate Retention and Mitigate the Global Impact of a Leaky Nitrogen Cycle in Croplands', *Nature Food* 4, no. 1 (2022): 109–21, https://doi.org/10.1038/s43016-022-00657-x.

fertilisers by adding more nitrogen to the soil and reducing nitrate leaching. This limits the need for nitrogen application, with some analyses finding that cover cropping reduces nitrate leaching by up to 69% compared to fields left to fallow.[9,10]

Multiple studies confirm that agroecological practices can improve crop yields with fewer inputs compared to conventional farming practices.[11] This is increasingly important as the effects of human-caused climate change, such as reduced rainfall, are anticipated to lower agricultural yields, thereby threatening food security. For example, a global systematic review of legume rotation - whereby staple crops are rotated with legumes - found a 20% increase in crop yields (rice, wheat and maize) on average compared to non-legume cropping systems.[12] In China, a long-term field experiment on the effects of intercropping – the simultaneous cultivation of two or more crops on one field – on grain yields found that yields were on average 22% higher than in comparable monoculture systems.[13] A review on the economic performance of agroecology in Europe found that agroecological farming generates incomes that exceed those of conventional agriculture, provides more employment per hectare, uses less fossil fuels and enhances biodiversity and landscapes.[14]

A key finding of several of these studies is that the adoption of multiple agroecological practices maximises yield benefits over a single practice, and that these yield benefits tend to increase with time and are more stable year-to-year than in comparable conventional farming systems.

Improved ecosystem services, offering multiple benefits

Human-caused climate change is significantly impacting the provision of ecosystem services, defined as the benefits that humans derive from nature.[15] For example, changes in precipitation can lead to water scarcity, with knock-on effects for food production, or can lead to biodiversity loss, which would reduce the provision of various ecosystem services important for resilience. Studies show that farms with higher biodiversity show greater

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[9] Richard Waite and Alex Rudee, '6 Ways the US Can Curb Climate Change and Grow More Food', World Resources Institute, August 20, 2020, https://www.wri.org/insights/6-ways-us-can-curb-climate-change-and-grow-more-food.

[10] Amin Nouri et al., 'When Do Cover Crops Reduce Nitrate Leaching? A Global Meta-analysis', *Global Change Biology* 28, no. 15 (2022): 4736–49, https://doi.org/10.1111/gcb.16269.

[11] Sieglinde S. Snapp et al., 'Biodiversity Can Support a Greener Revolution in Africa', *Proceedings of the National Academy of Sciences* 107, no. 48 (2010): 20840–45, https://doi.org/10.1073/pnas.1007199107; Gudeta Sileshi et al., 'Meta-Analysis of Maize Yield Response to Woody and Herbaceous Legumes in Sub-Saharan Africa', *Plant and Soil* 307, no. 1–2 (2008): 1–19, https://doi.org/10.1007/s11104-008-9547-y; Marc Corbeels et al., 'Limits of Conservation Agriculture to Overcome Low Crop Yields in Sub-Saharan Africa', *Nature Food* 1, no. 7 (2020): 447–54, https://doi.org/10.1038/s43016-020-0114-x; Shem Kuyah et al., 'Agroforestry Delivers a Win-Win Solution for Ecosystem Services in Sub-Saharan Africa. A Meta-Analysis', *Agronomy for Sustainable Development* 39, no. 5 (2019): 47, https://doi.org/10.1007/s13593-019-0589-8; Georges F. Félix et al., 'Enhancing Agroecosystem Productivity with Woody Perennials in Semi-Arid West Africa. A Meta-Analysis', *Agronomy for Sustainable Development* 38, no. 6 (2018): 57, https://doi.org/10.1007/s13593-018-0533-3.

[12] Jie Zhao et al., 'Global Systematic Review with Meta-Analysis Reveals Yield Advantage of Legume-Based Rotations and Its Drivers', *Nature Communications* 13, no. 1 (2022): 4926, https://doi.org/10.1038/s41467-022-32464-0.

[13] Xiao-Fei Li et al., 'Long-Term Increased Grain Yield and Soil Fertility from Intercropping', *Nature Sustainability* 4, no. 11 (2021): 943–50, https://doi.org/10.1038/s41893-021-00767-7.

[14] Jan Douwe van der Ploeg et al., 'The Economic Potential of Agroecology: Empirical Evidence from Europe', *Journal of Rural Studies* 71 (2019): 46–61, https://doi.org/10.1016/j.jrurstud.2019.09.003.

[15] Yadvinder Malhi et al., 'Climate Change and Ecosystems: Threats, Opportunities and Solutions', *Philosophical Transactions of the Royal Society B: Biological Sciences* 375, no. 1794 (2020): 20190104, https://doi.org/10.1098/rstb.2019.0104.

resilience to climate disasters.[16] A number of studies from across the world have found that agroecological practices improve ecosystem services such as pollination, pest control, erosion, soil fertility and water management compared to conventional systems, and also enhance biodiversity.[17,18,19,20] A third of the negative effects of landscape simplification - such as reduced provision of services and decreased crop production - were found to be due to decreased pollinator richness, emphasising the importance of practices that support pollinator diversity.[21]

While conventional farming practices, such as intensive cultivation and pesticide use, are some of the biggest contributors to pollinator decline globally, agroecological practices increase the abundance and density of beneficial insects, reduce the abundance and density of insect pests, increase pollinator diversity, and reduce weed density and the abundance of parasitic and non-parasitic weeds.[22,23,24,25] With pollination services globally valued at around USD 1 trillion, an abrupt pollinator collapse could cost around 1-2% of global GDP in the short term.[26]

Diversified farming systems, which are aligned with agroecology in that they incorporate different species or varieties rather than relying on single crops or species, in both high- and low-income countries are more profitable for farmers than conventional monoculture systems even when increased labour costs are considered, thereby dispelling myths that increased labour costs offset the benefits of diversification.[27] In addition, diversification enhances biodiversity, pollination, pest control, nutrient cycling, soil fertility, and water regulation without compromising crop yields.[28] Estimates for rice suggest that

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[16] Stacy M. Philpott et al., 'A Multi-Scale Assessment of Hurricane Impacts on Agricultural Landscapes Based on Land Use and Topographic Features', *Agriculture, Ecosystems & Environment* 128, no. 1–2 (2008): 12–20, https://doi.org/10.1016/j.agee.2008.04.016; Eric Holt-Giménez, 'Measuring Farmers' Agroecological Resistance after Hurricane Mitch in Nicaragua: A Case Study in Participatory, Sustainable Land Management Impact Monitoring', *Agriculture, Ecosystems & Environment* 93, no. 1–3 (2002): 87–105, https://doi.org/10.1016/S0167-8809(02)00006-3.

[17] Felipe Cozim-Melges et al., 'Farming Practices to Enhance Biodiversity across Biomes: A Systematic Review', *npj Biodiversity* 3, no. 1 (2024): 1, https://doi.org/10.1038/s44185-023-00034-2.

[18] Mario Torralba et al., 'Do European Agroforestry Systems Enhance Biodiversity and Ecosystem Services? A Meta-Analysis', *Agriculture, Ecosystems & Environment* 230 (2016): 150–61, https://doi.org/10.1016/j.agee.2016.06.002.

[19] Sara Palomo-Campesino, José A. González, and Marina García-Llorente, 'Exploring the Connections between Agroecological Practices and Ecosystem Services: A Systematic Literature Review', *Sustainability* 10, no. 12 (2018): 4339, https://doi.org/10.3390/su10124339.

[20] Matthew W. Jordon et al., 'Implications of Temperate Agroforestry on Sheep and Cattle Productivity, Environmental Impacts and Enterprise Economics. A Systematic Evidence Map', *Forests* 11, no. 12 (2020): 1321, https://doi.org/10.3390/f11121321.

[21] Matteo Dainese et al., 'A Global Synthesis Reveals Biodiversity-Mediated Benefits for Crop Production', *SCIENCE ADVANCES*, 2019, 4.

[22] Joseph Millard et al., 'Global Effects of Land-Use Intensity on Local Pollinator Biodiversity', *Nature Communications* 12, no. 1 (2021): 2902, https://doi.org/10.1038/s41467-021-23228-3.

[23] Charlie C. Nicholson et al., 'Pesticide Use Negatively Affects Bumble Bees across European Landscapes', *Nature* 628, no. 8007 (2024): 355–58, https://doi.org/10.1038/s41586-023-06773-3.

[24] Anjaharinony A.N.A. Rakotomalala, Anoush M. Ficiciyan, and Teja Tscharntke, 'Intercropping Enhances Beneficial Arthropods and Controls Pests: A Systematic Review and Meta-Analysis', *Agriculture, Ecosystems & Environment* 356 (2023): 108617, https://doi.org/10.1016/j.agee.2023.108617.

[25] Lorena Pumariño et al., 'Effects of Agroforestry on Pest, Disease and Weed Control: A Meta-Analysis', *Basic and Applied Ecology* 16, no. 7 (2015): 573–82, https://doi.org/10.1016/j.baae.2015.08.006.

[26] Christian Lippert, Arndt Feuerbacher, and Manuel Narjes, 'Revisiting the Economic Valuation of Agricultural Losses Due to Large-Scale Changes in Pollinator Populations', *Ecological Economics* 180 (2021): 106860, https://doi.org/10.1016/j.ecolecon.2020.106860.

[27] Andrea C. Sánchez et al., 'Financial Profitability of Diversified Farming Systems: A Global Meta-Analysis', *Ecological Economics* 201 (2022): 107595, https://doi.org/10.1016/j.ecolecon.2022.107595.

[28] Giovanni Tamburini et al., 'Agricultural Diversification Promotes Multiple Ecosystem Services without Compromising Yield', *Science Advances* 6, no. 45 (2020): eaba1715, https://doi.org/10.1126/sciadv.aba1715.

diversification can increase biodiversity by 40%, improve economic performance, such as incomes and profits, by 26% and reduce crop damage by 31% in global production.[29]

Diversification practices deliver multiple benefits relating to ecosystem services without compromising yield, highlighting that mainstream, high-yielding agricultural systems can benefit from diversification practices and that these practices can help bolster future sustainable food production.[30]

Agroecological practices can also significantly decrease soil erosion - the most important indicator of land degradation - in temperate, tropical and mediterranean-type soils.[31] A systematic evidence map of temperate agroforestry on sheep and cattle productivity, environmental impacts and economics found that temperate agroforestry offers benefits compared to pasture without trees through sequestering carbon, reducing soil erosion, and improving water quantity and quality regulation.[32] There is also some evidence, albeit limited, that agroecological practices can improve livestock productivity.[33,34]

Enhanced food security and health

As food systems are highly vulnerable to climate risks, improving resilience to these risks is important for ensuring food security. There is empirical evidence for agroecological practices such as livestock integration, intercropping, crop diversification, organic manure application and agroforestry in improving food security and resilience.[35] A 2024 review found that livestock diversification, soil conservation and non-crop diversification - practices not recognised as traditional crop production, such as the planting of hedgerows - improved food security in an assessment of 2,655 farms, and that a combination of these practices yielded greater improvements than they achieved singularly.[36] A number of studies on the potential for agroecology to improve food security and nutrition have found that the number of agroecological practices implemented on a farm was positively associated with better food security and nutrition outcomes.

The demand for protein is projected to increase in the future, placing further demands on land and resources. Animal protein is an important source of nutrition, meaning a balance will need to be stuck between nutritional and environmental needs.[37] A review on whether agroecology can help meet protein requirements for 2050 estimated that using an agroecological model where livestock are fed only on pasture, waste or by-products – and

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[29] Xueqing He et al., 'Agricultural Diversification Promotes Sustainable and Resilient Global Rice Production', *Nature Food* 4, no. 9 (2023): 788–96, https://doi.org/10.1038/s43016-023-00836-4.

[30] Tamburini et al., 'Agricultural Diversification Promotes Multiple Ecosystem Services without Compromising Yield', 4.

[31] Mbezele Junior Yannick Ngaba et al., 'Meta-Analysis Unveils Differential Effects of Agroforestry on Soil Properties in Different Zonobiomes', *Plant and Soil* 496, no. 1–2 (2024): 589–607, https://doi.org/10.1007/s11104-023-06385-w.

[32] Jordon et al., 'Implications of Temperate Agroforestry on Sheep and Cattle Productivity, Environmental Impacts and Enterprise Economics. A Systematic Evidence Map'.

[33] Paulo César De Faccio Carvalho et al., 'Land-Use Intensification Trends in the Rio De La Plata Region of South America: Toward Specialization or Recoupling Crop and Livestock Production', *Frontiers of Agricultural Science and Engineering* 8, no. 1 (2021): 97, https://doi.org/10.15302/J-FASE-2020380.

[34] Jordon et al., 'Implications of Temperate Agroforestry on Sheep and Cattle Productivity, Environmental Impacts and Enterprise Economics. A Systematic Evidence Map'.

[35] Gilbert Dagunga et al., 'Agroecology and Resilience of Smallholder Food Security: A Systematic Review', *Frontiers in Sustainable Food Systems* 7 (2023): 1267630, https://doi.org/10.3389/fsufs.2023.1267630.

[36] Laura Vang Rasmussen et al., 'Joint Environmental and Social Benefits from Diversified Agriculture', *Science* 384, no. 6691 (2024): 87–93, https://doi.org/10.1126/science.adj1914.

[37] Maeve Henchion et al., 'Future Protein Supply and Demand: Strategies and Factors Influencing a Sustainable Equilibrium', *Foods* 6, no. 7 (2017): 53, https://doi.org/10.3390/foods6070053.

never fed on human-edible crops – can achieve a global diet within a limitation of 11–23 grams of protein per day from animal products.[38]

The adoption of agroecological principles can help alleviate disease costs associated with pesticide exposure. Pesticides have been linked to diabetes, reproductive disorders, neurological dysfunction, cancer and respiratory disorders in farmers.[39] A meta-analysis found a link between mental illnesses such as depression and pesticide exposure in farmers, with affected farmers experiencing financial difficulties and poor health.[40] For the general public, the annual health and disease costs of exposure to organophosphate pesticides in 2010 were estimated at USD 121 billion in Europe and USD 42 billion in the US.[41] Exposure to pesticides in Europe in 2003 was estimated to cause an average burden of lifetime lost per person of 2.6 hours and up to 45.3 days, and average costs per person over lifetime of EUR 12 and up to EUR 5,142 .[42] In addition, as pollinators are directly responsible for up to 40% of the world's micronutrient supply, including essential micronutrients such as vitamin A, pollinator collapse could result in 1.42 million additional deaths per year from non-communicable and malnutrition-related diseases, and 27 million lost disability-adjusted life-years annually at the global scale.[43]

Sequestration in plants and soil can help meet Nationally Determined Contributions

Estimates suggest that agroforestry can sequester 0.12 to 0.31 gigatons of carbon (Gt C) per year, making it comparable to other nature-based solutions such as reforestation (0.27 Gt C per year) and reduced deforestation (0.49 Gt C per year).[44] Agroforestry has also been identified as a key intervention for achieving Nationally Determined Contributions (NDCs). A 2023 review looked at the extent to which agroforestry is represented in current NDCs in 22 developing countries and found that more than 80% of countries that experienced deforestation between 2000 and 2015 could meet their unconditional NDC targets by converting 25% of deforested lands to agroforestry.[45] Integrating agroecological practices into countries'

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[38] Georgia Forsyth Sijpestijn, Alexander Wezel, and Sghaier Chriki, 'Can Agroecology Help in Meeting Our 2050 Protein Requirements?', *Livestock Science* 256 (2022): 104822, https://doi.org/10.1016/j.livsci.2022.104822.

[39] Lata Rani et al., 'An Extensive Review on the Consequences of Chemical Pesticides on Human Health and Environment', *Journal of Cleaner Production* 283 (2021): 124657, https://doi.org/10.1016/j.jclepro.2020.124657.

[40] Mariane Magalhães Zanchi, Katiuska Marins, and Ariane Zamoner, 'Could Pesticide Exposure Be Implicated in the High Incidence Rates of Depression, Anxiety and Suicide in Farmers? A Systematic Review', *Environmental Pollution* 331 (2023): 121888, https://doi.org/10.1016/j.envpol.2023.121888.

[41] Teresa M Attina et al., 'Exposure to Endocrine-Disrupting Chemicals in the USA: A Population-Based Disease Burden and Cost Analysis', *The Lancet Diabetes & Endocrinology* 4, no. 12 (2016): 996–1003, https://doi.org/10.1016/S2213-8587(16)30275-3.

[42] Peter Fantke, Rainer Friedrich, and Olivier Jolliet, 'Health Impact and Damage Cost Assessment of Pesticides in Europe', *Environment International* 49 (2012): 9–17, https://doi.org/10.1016/j.envint.2012.08.001.

[43] Matthew R Smith et al., 'Effects of Decreases of Animal Pollinators on Human Nutrition and Global Health: A Modelling Analysis', *The Lancet* 386, no. 10007 (2015): 1964–72, https://doi.org/10.1016/S0140-6736(15)61085-6.

[44] Drew E. Terasaki Hart et al., 'Priority Science Can Accelerate Agroforestry as a Natural Climate Solution', *Nature Climate Change* 13, no. 11 (2023): 1179, https://doi.org/10.1038/s41558-023-01810-5.

[45] Jagdish Chander Dagar, Sharda Rani Gupta, and Gudeta Weldesemayat Sileshi, eds., *Agroforestry for Sustainable Intensification of Agriculture in Asia and Africa*, Sustainability Sciences in Asia and Africa (Singapore: Springer Nature Singapore, 2023), https://doi.org/10.1007/978-981-19-4602-8.

National Biodiversity Strategies and Action Plans (NBSAPs) can also help fulfill Global Biodiversity Framework (GBF) commitments by encouraging the use of sustainable practices that protect biodiversity, build climate resilience and enhance food security.[46]

A literature review on soil carbon sequestration in the context of climate change found that agroecological practices such as the incorporation of organic matter into the soil, crop rotation and the use of cover crops can improve soil carbon sequestration.[47] One analysis suggests that increasing the soil organic carbon pool of degraded croplands using agroecological practices has the potential to increase yields of wheat by 20-40 kg per hectare, maize yields by 10-20 kg per hectare and cowpea yields by 0.5-1 kg per hectare.[48] The analysis also suggests that this approach can offset fossil fuel emissions by 0.4-1.2 Gt C per year, which is as much as 3% of current global fossil fuel emissions. Other estimates suggest that improved cropland management using agroecological principles could mitigate around 1.4–2.3 Gt carbon dioxide equivalent per year (CO2eq/year), while improved grazing management could mitigate 1.4–1.8 Gt CO2eq/year.[49]

The potential for sequestration will be highly context-specific, and the possible reversal of sequestration benefits remains an important limiting factor, especially for soil carbon.[50] Carbon sequestered in the soil can be retained for as long as agroecological practices are maintained and with minimal disturbance to the soil, thereby helping to address issues around the permanence of the sequestered carbon.[51] The consistent application of sustainable management practices is important for realising the mitigation benefits of soil and plant carbon sequestration.[52]

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[46] 'FAOLEX Database', Food and Agriculture Organization of the United Nations, 2023.

[47] Cristina I. Dias Rodrigues, Luís Miguel Brito, and Leonel J. R. Nunes, 'Soil Carbon Sequestration in the Context of Climate Change Mitigation: A Review', *Soil Systems* 7, no. 3 (2023): 64, https://doi.org/10.3390/soilsystems7030064.

[48] R. Lal, 'Soil Carbon Sequestration Impacts on Global Climate Change and Food Security', *Science* 304, no. 5677 (2004): 1623–27, https://doi.org/10.1126/science.1097396.

[49] Pete Smith et al., 'Which Practices Co-deliver Food Security, Climate Change Mitigation and Adaptation, and Combat Land Degradation and Desertification?', *Global Change Biology* 26, no. 3 (2020): 1532–75, https://doi.org/10.1111/gcb.14878.

[50] Cécile M. Godde et al., 'Soil Carbon Sequestration in Grazing Systems: Managing Expectations', *Climatic Change* 161, no. 3 (2020): 385–91, https://doi.org/10.1007/s10584-020-02673-x.

[51] Lal, 'Soil Carbon Sequestration Impacts on Global Climate Change and Food Security'.

[52] Rodrigues, Brito, and Nunes, 'Soil Carbon Sequestration in the Context of Climate Change Mitigation'.