Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Regenerative Agriculture and Planetary Health: A Framework for Understanding Co- benefits Across Environmental, Human, and Animal Health

Alex Sadzewicz
Emory University
Thomas Clasen
tclasen@emory.edu
Emory University

Systematic Review

Keywords:

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10503432/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

Title: Regenerative Agriculture and Planetary Health: A Framework for Understanding Co-benefits Across Environmental, Human, and Animal Health

Authors: Alex Sadzewicz, MPH, JD and Thomas Clasen, JD, PhD

Institutional Address: Gangarosa Department of Environmental Health, Rollins School of Public Health, Emory University, 1615 Clifton Rd. NE, Atlanta, GA 30322 USA

Corresponding Author: Thomas Clasen, JD, PhD, tclasen@emory.edu

Regenerative Agriculture and Planetary Health: A Framework for Understanding Co-benefits Across Environmental, Human, and Animal Health

Alex Sadzewicz, MPH, JD and Thomas Clasen, JD, PhD
Gangarosa Department of Environmental Health
Rollins School of Public Health
Emory University
Atlanta, GA USA

Summary

Conventional industrial agriculture generates well-documented harms across multiple dimensions of planetary health, from greenhouse gas emissions and soil degradation to the contamination of waterways and harmful exposures in farmworker communities. Regenerative agriculture has attracted growing scientific and policy attention as a systems-level response, yet its full range of co-benefits remains incompletely mapped and unevenly evidenced. This paper synthesizes the peer-reviewed literature across five benefit categories: carbon sequestration, soil health, water quality, animal welfare, and reduction of human exposures to hazardous agricultural chemicals and biological agents. Evidence is strongest for carbon sequestration, which has generated mature market mechanisms, and for soil health, which is well characterized biophysically if rarely translated into economic value. Water quality improvements are directionally supported but lack systematic quantification. Animal welfare benefits of pasture-based regenerative systems are documented in the behavioral and veterinary literature but have not been integrated into planetary health research frameworks. Reduction in human chemical and biological exposures represents the least developed benefit category despite substantial evidence that conventional agriculture generates serious harms in farmworkers and adjacent communities. Viewed together, these co-benefits make a stronger case for regenerative transition than any single benefit category alone, and the planetary health framework provides the integrating lens through which that case can be most coherently made. Empirical research comparing health outcomes in communities adjacent to regenerative versus conventional farms, economic modeling of reduced agricultural chemical exposures, and integration of animal welfare metrics into planetary health assessments should be priorities for the field.

Introduction

The concept of planetary health provides an integrating framework for understanding the relationships between human civilization, food systems, and the ecological foundations on which both depend. Defined Las the achievement of the highest attainable standard of health, wellbeing, and equity worldwide through attention to the human and natural systems that define the safe environmental limits within which humanity can flourish,[1] planetary health demands that agriculture be evaluated not only for productive output but for its simultaneous effects on soil, water, biodiversity, climate, animal welfare, and human health.

Conventional industrial agriculture, characterized by large-scale monocultures, heavy reliance on synthetic fertilizers and pesticides, and intensive animal husbandry,[2,3,4] creates risks across each of

these domains. It degrades soil health, reduces biodiversity, pollutes waterways, contributes substantially to greenhouse gas emissions, and generates harmful exposures in farmworkers and surrounding communities. Regenerative agriculture has emerged as a systems-level alternative, though it resists a single authoritative definition.[5]

The scientific and policy literature has amassed considerable evidence on certain benefits of regenerative systems, particularly carbon sequestration and soil health, and economic frameworks for valuing these benefits are developing. The distribution of evidence is, however, highly uneven. Research on regenerative agriculture's health implications focuses mainly on nutrition, dietary diversity, and food security;[6-8,] the environmental public health dimension--the ways in which agricultural systems sequester carbon, improve soil health and water quality, and reduce harmful exposures in farmworkers and surrounding communities, remains largely unmapped. The welfare of animals raised within regenerative systems has received even less systematic attention.

This paper examines the full range of planetary health co-benefits that regenerative agriculture may offer. It begins by defining regenerative agriculture and inventories its principal claimed benefits. It then examines the state of evidence across those benefit categories, develops a conceptual model of agricultural exposure pathways, explores how specific regenerative practices could reduce harmful exposures, and identifies the research gaps that most constrain the field's ability to quantify and communicate its planetary health value.

Defining Regenerative Agriculture

Regenerative agriculture is perhaps best understood not as a fixed set of practices but as an orientation: farming in ways that actively restore rather than deplete the ecological systems on which agriculture depends. Multiple definitions coexist in the literature, each emphasizing different dimensions of this orientation.[5]

Process-based definitions focus on what farmers do: planting cover crops to protect and enrich soil between cash crop cycles; eliminating or reducing tillage to preserve soil structure and microbial communities; integrating livestock into crop systems to cycle nutrients naturally; and using agroforestry to embed trees into farming landscapes. Outcome-based definitions focus on what these practices accomplish: improved soil organic matter and microbial diversity, sequestration of atmospheric carbon, reduced erosion and nutrient runoff, enhanced habitat for pollinators and wildlife, and greater resilience to drought and climate variability.[5]

Early conceptual work by Harwood described the goals of regenerative systems as including the production of highly nutritious foods, integrated nutrient-flow systems, stable biological interactions, self-reliant nitrogen cycling, semi-closed systems that reduce dependence on external inputs, and animal agriculture that reduces hormone use.[9] The Intergovernmental Panel on Climate Change (IPCC) defines regenerative agriculture as sustainable land management practices focused on ecological functions that can be effective in building resilience of agro-ecosystems.[10]

Concrete examples of regenerative practices include cover cropping, no-till or reduced-till cultivation, rotational grazing, agroforestry, silvopasture, and organic certification, which prohibits synthetic pesticides and fertilizers and requires adherence to a national list of approved substances.[11] Not all regenerative farms are certified organic, and not all organic farms employ the

full suite of regenerative practices, but the overlap is substantial. This paper uses the IPCC framing as a broad umbrella that accommodates both process and outcome dimensions.

Principal Benefits of Regenerative Agriculture: What We Know and What We Do Not

The planetary health case for regenerative agriculture rests on five categories of benefit: climate mitigation through carbon sequestration; improved soil health and long-term agricultural productivity; water quality improvement; animal welfare; and reduced human exposure to hazardous chemical and biological agents. These categories differ sharply in the depth of supporting evidence and in the degree to which that evidence has been translated into economic or policy terms.

Carbon Sequestration: The Most Modeled and Monetized Benefit

The relationship between regenerative agricultural practices and soil carbon storage is the best characterized of the five benefit categories, and the only one to have generated mature market mechanisms for monetization. Regenerative practices, including cover cropping, no-till, agroforestry, and rotational grazing, increase soil organic matter, which sequesters atmospheric carbon dioxide.[12] The IPCC estimates that enhanced soil carbon practices could sequester up to 23 gigatons of CO_2 by 2050.[10]

Research has quantified sequestration outcomes across diverse regenerative practices and geographies, finding that cover cropping produces consistent near-term carbon gains while no-till effects grow larger over time as soil structure develops.[13] Carbon credit markets have translated these physical outcomes into economic value. Under voluntary carbon markets, farms earn credits for documented carbon sequestration, which can be sold to corporations seeking to offset emissions. Programs vary in methodology, rigor, and price, and the literature identifies significant concerns about permanence, additionality, and price volatility.[14,15] McKinsey analysis finds that only one-third of US farmers perceive a positive near-term return on investment from cover cropping alone, underscoring that current carbon credit prices may be insufficient to drive widespread adoption without complementary incentives.[16]

Soil Health: Quantified but Undermonetized

The soil health benefits of regenerative practices are well supported in the peer-reviewed literature. A systematic review of regenerative organic agriculture found that compared to conventional farming, regenerative systems increased soil organic carbon by 22%, soil total nitrogen by 28%, and soil microbial biomass carbon by 133%.[17] A meta-analysis of studies from India found that biochar application, farmyard manure, green manure, conservation tillage, and crop residue retention all produced consistent soil organic carbon gains.[18]

These improvements translate into tangible agricultural benefits: increased water retention and drought resilience, reduced erosion, improved nutrient cycling, and reduced reliance on synthetic inputs over time. Yet the economic value of these outcomes has rarely been captured systematically at a farm or landscape scale. Partial valuations exist, including reduced fertilizer

costs and improved yields under drought conditions,[19] but comprehensive economic models that quantify the full soil health dividend remain an important gap in the literature.

Water Quality: Biophysically Plausible, Economically Unquantified

Regenerative practices reduce agricultural pollution of waterways through multiple mechanisms. Cover crops and no-till reduce surface runoff and erosion, limiting the transport of sediment, synthetic fertilizers, and pesticides into streams, rivers, and groundwater.[20] Agroforestry systems enhance water infiltration and reduce nutrient losses through tree root networks.[21] Reduced synthetic fertilizer use lowers the risk of nitrate contamination of drinking water, which has been associated with increased cancer risk and adverse health outcomes in communities near conventional agricultural fields.[22-23]

The biophysical evidence for these effects is credible and growing. Comprehensive economic valuations, for example estimating the downstream water treatment cost savings or healthcare cost reductions that would follow from widespread adoption of regenerative practices, have not been developed. Water quality improvement remains a benefit that is qualitatively understood but quantitatively underspecified.

Reduction of Human Exposures: A Critical and Largely Unmapped Gap

The most underexplored planetary health benefit of regenerative agriculture is its capacity to reduce human exposure to the hazardous substances associated with conventional farming. This gap is notable because the evidence that conventional agriculture generates harmful exposures is substantial.

Communities near industrial food animal production facilities face elevated rates of respiratory illness, methicillin-resistant *Staphylococcus aureus* (MRSA), Q fever, and stress-related conditions.[24] Pesticide drift from conventional crop fields has been associated with adverse birth outcomes, increased cancer risk, cognitive impairments, neurological effects, and asthma in surrounding communities.[25-27] Synthetic fertilizer runoff contaminates groundwater with nitrates, increasing risk of certain cancers and causing methemoglobinemia in infants.[24,25] Pesticides and fertilizers bioaccumulate in body tissues, entering the food chain with potential for both acute and chronic health effects.[28]

Despite this evidence on the exposure side, the literature contains almost no studies comparing environmental health outcomes in communities adjacent to regenerative versus conventional farms. No economic model has estimated the public health cost savings that would accompany a transition to regenerative systems. This absence is striking given the magnitude of the harms documented in conventional agricultural settings and the conceptual plausibility of exposure reductions under regenerative management.

Animal Welfare: An Emerging Planetary Health Dimension

The welfare of animals raised within agricultural systems constitutes an underrecognized dimension of planetary health. Contemporary animal welfare science, formalized in frameworks such as the Five Domains Model,[29] evaluates welfare across nutritional, physical, health, behavioral, and mental domains. Regenerative systems, with their emphasis on pasture access,

rotational management, and species-appropriate environments, address several of these domains in ways that confined industrial systems structurally cannot.

Pasture-raised cattle and pigs have been shown to exhibit lower cortisol levels and reduced frequencies of stereotypic behavior compared to confinement-reared counterparts, consistent with lower chronic stress. Chickens in polyculture and silvopasture systems demonstrate significantly higher rates of foraging and dust bathing, behaviors widely used as proxy indicators of positive welfare states. Rotational grazing systems enable freedom of movement, expression of social behaviors, and access to diverse forage that supports nutritional welfare.

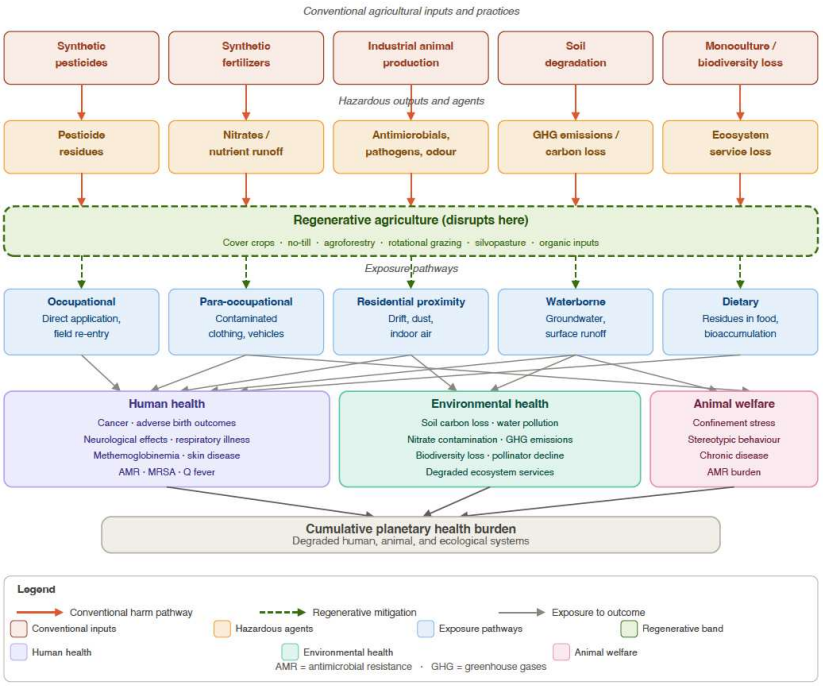
Regenerative systems may also reduce disease-related suffering. The diverse, nutrient-dense forage characteristic of well-managed regenerative pastures is associated with lower parasite burdens and reduced reliance on prophylactic antimicrobials, though outcomes are sensitive to management quality.[19] Silvopasture in particular has been associated with reductions in antibiotic use compared to industrialized meat production, with implications not only for animal welfare but for the community-level harms of antimicrobial resistance.[30-32]

Important limitations constrain the evidence base. Most studies are observational rather than controlled trials. Outdoor access introduces genuine welfare trade-offs, including predation risk and weather exposure, which must be weighed against the benefits of natural behavior expression.[33] And the welfare literature has not historically been integrated into planetary health or regenerative agriculture research frameworks, a gap that represents both a scholarly omission and a policy opportunity.

Conventional vs Regenerative Agricultural Exposure Pathways: A Conceptual Model

Agricultural exposures to hazardous substances reach human populations through several distinct pathways (Fig 1). Understanding these pathways is essential to reasoning about how changes in farming practice could reduce the burden of exposure.

Figure 1. Exposure pathways from conventional agricultural practices to planetary health outcomes, and the potential of regenerative agriculture to reduce them



Direct occupational exposure occurs among agricultural workers who apply pesticides and synthetic fertilizers and work in treated fields. This is the most intensively studied exposure pathway, though worker protections remain inadequate relative to documented risks.[34] Para-occupational exposure affects household members of agricultural workers, particularly children, through contaminated clothing, vehicles, and skin contact.[35]

Residential proximity to agricultural fields is associated with exposure through two additional routes: pesticide drift, in which airborne chemical particles travel from fields and deposit in residential dust and indoor air; and runoff, in which precipitation carries pesticide and fertilizer residues into surface water and groundwater used by nearby communities.[36,37] Dietary exposure occurs when pesticide residues on or in food are consumed.[38] Finally, communities near industrial food animal production facilities are exposed to occupational and ambient emissions of nitrates, antibiotic residues, heavy metals, and hormones through air and groundwater pathways.[35]

The intensity of exposure through each of these pathways is directly shaped by the quantity and type of chemicals applied in agricultural production. Conventional agriculture, with its dependence on synthetic inputs and its tendency to intensify that dependence as monocultures degrade soil fertility and increase pest pressure, creates a self-reinforcing cycle of escalating chemical use and exposure. Regenerative practices disrupt this cycle.[39]

Regenerative Practices and Their Potential to Reduce Exposures

Carbon Incentive Programs

Carbon incentive programs are relevant to exposure reduction insofar as the practices they incentivize overlap with reductions in agrochemical use. Many qualifying practices, including cover cropping, no-till, and agroforestry, also reduce synthetic input requirements.[40] Green finance mechanisms have been shown in modeling studies to have the potential to substantially reduce chemical fertilizer use.[41] The reduction of agrochemical use is associated with improved soil quality and carbon sequestration, creating a cycle in which economic incentives for carbon storage also produce human health co-benefits.[42] However, the literature on carbon programs focuses almost entirely on biophysical environmental impacts rather than human health outcomes. The exposure-reduction co-benefits of carbon programs have not been quantified, and no studies have estimated their public health value.

Agroforestry

Agroforestry offers some of the most mechanistically clear pathways to exposure reduction. It reduces demand for chemical inputs through two primary mechanisms: improvement of nitrogen cycling (tree-associated nitrogen-fixing bacteria reduce the need for synthetic fertilizer) and disruption of pest life cycles through biological and structural diversity.[42] With lower agrochemical use, the volume of substances available to enter exposure pathways is reduced at the source.

Agroforestry also reduces the transport of chemicals once applied. Tree root systems enhance water infiltration and reduce surface runoff, limiting the movement of pesticide and nutrient residues into waterways.[21-23] Windbreaks formed by trees reduce pesticide drift, as does the microclimate stabilization that agroforestry systems create by reducing temperature inversions.[43] Taken together, agroforestry appears to reduce both the production of agricultural hazards and their capacity to reach human populations, a dual benefit that is mechanistically compelling but empirically under-characterized in human health terms.[42]

Silvopasture

Silvopasture extends the agroforestry framework to animal production. In addition to the exposure-reduction mechanisms described above, silvopasture systems have been associated with reductions in antibiotic use and improvements in animal welfare and productivity compared to industrialized meat production.[27-29] Because antibiotic residues in industrial animal agriculture contribute to antimicrobial resistance and to community exposure through air and water pathways,[31] reduced antibiotic use in silvopasture systems has plausible human health implications that have not yet been quantified. Silvopasture thus represents a convergence point for animal welfare and human health co-benefits, two benefit categories that have rarely been analyzed together.

Organic and Prohibited Substances Frameworks

While not all regenerative agriculture is certified organic, organic farming represents the most rigorously regulated form of regenerative production and provides the clearest evidence of exposure reduction through agrochemical substitution. A comparative analysis found that 55% of conventional agricultural pesticide active substances carried health or environmental hazard statements, compared to only 3% of organic pesticides; 16% of conventional pesticides included warnings about carcinogenicity, teratogenicity, or acute lethality, compared to none of their organic counterparts; and 94% of conventional pesticides had established health-based guidance values for dietary and non-dietary exposures, compared to 7% of organic pesticides.[43] These

figures imply that the shift from conventional to organic production could substantially reduce occupational and community exposure to the most hazardous agricultural chemicals.

Organic certification is a high bar that many small-scale farmers cannot meet. Regenerative practices that fall short of full organic certification can nonetheless meaningfully reduce agrochemical use and the exposures it generates. A 2024 analysis found that reducing chemical inputs in agriculture requires a systems-level change rather than incremental adjustments, and that regenerative management frameworks are among the most promising vehicles for achieving that change.[44]

Discussion

Viewed through a planetary health lens, the case for regenerative agriculture is stronger than any single benefit category suggests. Carbon sequestration, soil health, water quality, animal welfare, and reduction of human chemical exposures are not independent claims: they are linked manifestations of a systemic shift away from the extractive logic of conventional industrial agriculture. The planetary health framework, precisely because it asks how human health and natural system integrity can be secured together, is the appropriate analytic context for a form of farming that pursues those objectives simultaneously.

The evidence base, however, is unevenly developed. At the top of the hierarchy sits carbon sequestration, well modeled, increasingly monetized through carbon markets, and supported by robust physical evidence across diverse agroecological contexts. Below it is soil health, quantified in the peer-reviewed literature in biophysical terms but rarely translated into comprehensive economic value estimates. Below that is water quality improvement, biophysically plausible and directionally supported but lacking systematic economic quantification. Animal welfare and reduction of human chemical exposures occupy the lower rungs: least modeled, least monetized, and in some ways most consequential for the living beings who inhabit agricultural landscapes.

The asymmetry in this evidence base is partly a function of the difficulty of measurement and partly a function of research priorities. Carbon sequestration has attracted investment because it maps onto financial instruments. Soil health is increasingly measured because precision agriculture creates commercial incentives to do so. Animal welfare and community health have attracted less investment because their benefits are diffuse, difficult to attribute, and historically treated as externalities rather than co-benefits.

Closing these gaps requires specific empirical work. Studies comparing exposure biomarkers in workers and communities near regenerative versus conventional farms would provide the foundational evidence that the environmental health case currently lacks. Welfare assessments using standardized instruments such as the Five Domains Model,[26] applied systematically across regenerative and conventional systems, would make the animal welfare case legible to policymakers and funders. Economic analyses estimating the healthcare cost savings associated with reduced agricultural chemical exposures would strengthen the overall economic argument for regenerative transition.

The present moment is propitious for this work. The Planetary Health Alliance, the growing body of One Health policy frameworks, and increasing federal investment in research on cumulative chemical exposures all create institutional contexts in which the full planetary health case for

regenerative agriculture could gain traction. Conventional agriculture's global physicochemical deregulation has been identified as a first-order systemic risk to planetary health.[45] The systematic synthesis of the co-benefits analyzed here suggest the planetary health opportunities presented by transitioning to regenerative agriculture. At the same time, there are important research gaps that warrant additional empirical science to ground this synthesis.

Regenerative agriculture will not, by itself, resolve the planetary health crisis generated by industrial food systems. It is a systems-level approach that requires systems-level evidence. Developing that evidence base, across all five benefit categories and with explicit attention to the co-benefits that have historically been most neglected, should be a priority for the field.

Declarations

Contributors. AS and TC conceived, researched and wrote the paper.

Declaration of interests. None declared.

Data sharing. This is a review and perspective piece; no new data were generated or analyzed.

References

1. Whitmee S, Haines A, Beyrer C, et al. Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. Lancet. 2015;386(10007):1973–2028.

2. Knorr D, Watkins TR. Alterations in Food Production. New York: Van Nostrand Reinhold; 1984.

3. Beus CE, Dunlap RE. Conventional versus alternative agriculture: the paradigmatic roots of the debate. Rural Sociology. 1990;55(4):590–616.

4. Sumberg J, Giller K. What is "conventional" agriculture? Global Food Security. 2022;32:100617.

5. Newton P, Civita N, Frankel-Goldwater L, Bartel K and Johns C (2020) what is regenerative agriculture? a review of scholar and practitioner definitions based on processes and outcomes. Front. Sustain. Food Syst. 4:577723.

6. English, A. (2025). *Can Regenerative Agriculture support food security and diet goals?* The Food Foundation. https://foodfoundation.org.uk/sites/default/files/2025-11/Diets%20and%20Regenerative%20Agriculture.pdf

7. Rosier CL, Knecht A, Steinmetz JS, Weckle A, Bloedorn K, Meyer E. From soil to health: advancing regenerative agriculture for improved food quality and nutrition security. Front Nutr. 2025 Oct 17;12:1638507.

8. Ramkumar D, Marty A, Ramkumar J, Rosencranz H, Vedantham R, Goldman M, Meyer E, Steinmetz J, Weckle A, Bloedorn K, Rosier C. Food for thought: Making the case for food produced via regenerative agriculture in the battle against non-communicable chronic diseases (NCDs). One Health. 2024 Apr 20;18:100734.

9. Harwood RR. International Overview on Regenerative Agriculture. Emmaus, PA: Rodale Press; 1983.

10. IPCC. Climate Change and Land. Geneva: Intergovernmental Panel on Climate Change; 2019.

11. USDA. National Organic Program. Agricultural Marketing Service. https://www.ams.usda.gov/about-ams/programs-offices/national-organic-program. Accessed 2026.

12. Abebaw, S. E., E. M.Yeshiwas, and T. G.Feleke. 2025. A systematic review on the role of agroforestry practices in climate change mitigation and adaptation. Climate Resilience and Sustainability 4, no. 2: 4, e70018. https://doi.org/10.1002/cli2.70018

13. Brummitt CD, et al. Solutions and insights for agricultural monitoring, reporting, and verification (MRV) from three consecutive issuances of soil carbon credits. Journal of Environmental Management. 2024;369:122284.

14. Cariappa AAG, et al. Evaluating the potential and eligibility of conservation agriculture practices for carbon credits. Scientific Reports. 2024;14:9193.

15. Reddy S, et al. Carbon credit markets and conservation agriculture: standardization and stability. 2025.

16. McKinsey & Company. Revitalizing Fields and Balance Sheets Through Regenerative Farming. McKinsey Agriculture Practice; 2023.

17. Greta Colombi, Enrico Martani, Dario Fornara, Regenerative organic agriculture and soil ecosystem service delivery: A literature review, Ecosystem Services, Volume 73, 2025, 101721

18. Patil, M., Perumal, C., Choudhari, P. *et al.* Differential impacts of regenerative agriculture practices on soil organic carbon: a meta-analysis of studies from India. *Sci Rep* **15**, 33470 (2025). https://doi.org/10.1038/s41598-025-12149-6

19. Moyer, J., Smith, A., Rui, Y., Hayden, J. (2020). Regenerative agriculture and the soil carbon solution [white paper]. (https://rodaleinstitute.org/wp-content/uploads/Rodale-Soil-Carbon-White-Paper_v11-compressed.pdf)

20. Pavlidis, G., Tsihrintzis, V.A. Dnvironmental benefits and control of pollution to surface water and groundwater by agroforestry systems: a review. *Water Resource Manage* **32**, 1–29 (2018). https://doi.org/10.1007/s11269-017-1805-4

21. Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., & Wang, M.-Q. (2021). Heavy metals and pesticides toxicity in agricultural soil and plants: ecological risks and human health implications. *Toxics*, *9*(3), 42. https://doi.org/10.3390/toxics9030042

22. Alam, S.M.K., Li, P. & Fida, M. Groundwater nitrate pollution due to excessive use of n-fertilizers in rural areas of bangladesh: pollution status, health risk, source contribution, and future impacts. *Expo Health* **16**, 159–182 (2024). https://doi.org/10.1007/s12403-023-00545-0

23. Picetti R, Deeney M, Pastorino S, Miller MR, Shah A, Leon DA, Dangour AD, Green R. Nitrate and nitrite contamination in drinking water and cancer risk: A systematic review

with meta-analysis. Environ Res. 2022 Jul;210:112988. doi: 10.1016/j.envres.2022.112988

24. Casey JA, Kim BF, Larsen J, Price LB, Nachman KE. Industrial Food Animal Production and Community Health. Curr Environ Health Rep. 2015 Sep;2(3):259-71. doi: 10.1007/s40572-015-0061-0

25. Chen KC, Lee SF, Lin SW, Xie JS, Chang YH, Yiin LM, Hsieh CJ. Associations between residential proximity to agricultural land use as pesticides exposure and birth outcomes. Environ Sci Pollut Res Int. 2023 Mar;30(12):33253-33263. doi: 10.1007/s11356-022-24571-8.

26. Wei Zhou, Mengmeng Li, Varenyam Achal, A comprehensive review on environmental and human health impacts of chemical pesticide usage, Emerging Contaminants, Volume 11, Issue 1, 2025, 100410

27. Dereumeaux C, Fillol C, Quenel P, Denys S. Pesticide exposures for residents living close to agricultural lands: A review. Environ Int. 2020 Jan;134:105210. doi: 10.1016/j.envint.2019.105210.

28. Beyuo, J., Sackey, L.N.A., Yeboah, C. *et al.* The implications of pesticide residue in food crops on human health: a critical review. *Discov Agric* **2**, 123 (2024). https://doi.org/10.1007/s44279-024-00141-z

29. Mellor DJ. operational details of the five domains model and its key applications to the assessment and management of animal welfare. Animals (Basel). 2017 Aug 9;7(8):60. doi: 10.3390/ani7080060.

30. Jose, S., Dollinger, J. Silvopasture: a sustainable livestock production system. *Agroforest Syst* **93**, 1–9 (2019). https://doi.org/10.1007/s10457-019-00366-8

31. Tambong, Jenard. (2025). Bibliometric analysis of silvopasture systems: integrating trees, livestock, and crops. International Journal of Research and Review. 10.52403/ijrr.20250115.

32. Joshi, P., Chakraborty, A., Sandhu, S. *et al.* Environmental, social and governance impacts of beef production systems: an integrated literature review. *J. Ind. Ecol.* **30**, 135–150 (2026). https://doi.org/10.1007/s44498-026-00011-5

33. Fraser, D., Weary, D. M., Pajor, E. A., & Milligan, B. N. (1997). A scientific conception of animal welfare that reflects ethical concerns. Animal welfare, 6, 187-205.

34. Deziel NC, Friesen MC, Hoppin JA, Hines CJ, Thomas K, Freeman LE. A review of nonoccupational pathways for pesticide exposure in women living in agricultural areas. Environ Health Perspect. 2015 Jun;123(6):515-24. doi: 10.1289/ehp.1408273.

35. Gomes M, Ralph TJ, Humphries MS, Graves BP, Kobayashi T, Gore DB. Waterborne contaminants in high intensity agriculture and plant production: A review of on-site and downstream impacts. Sci Total Environ. 2025 Jan 1;958:178084. doi: 10.1016/j.scitotenv.2024.178084.

36. Ahmad MF, Ahmad FA, Alsayegh AA, Zeyaullah M, AlShahrani AM, Muzammil K, Saati AA, Wahab S, Elbendary EY, Kambal N, Abdelrahman MH, Hussain S. Pesticides impacts on human health and the environment with their mechanisms of action and

possible countermeasures. Heliyon. 2024 Apr 4;10(7):e29128. doi: 10.1016/j.heliyon.2024.e29128.

38. Sandoval-Insausti, H., Chiu, Y. H., Wang, Y. X., Hart, J. E., Bhupathiraju, S. N., Mínguez-Alarcón, L., et al. (2022). Intake of fruits and vegetables according to pesticide residue status in relation to all-cause and disease-specific mortality: Results from three prospective cohort studies. *Environment International*, *159*, 107024. https://doi.org/10.1016/j.envint.2021.107024

39. Kumar, N. Anil, Priyanka Jattan, Wankhede Dinesh Digambar, Rashmi Mohapatra, Kamlesh Kumar Yadav, Charu Sharma, and Sagar Chaudhary. 2025. A review of soil organic carbon dynamics under regenerative agricultural practices. *International Journal of Plant & Soil Science* 37 (9):142-53. https://doi.org/10.9734/ijpss/2025/v37i95693.

40. Amitava Rakshit, Manoj Parihar, Vijay Singh Meena, Purushothaman Abhilash, Prakash Kumar Jha, Deepranjan Sarkar (eds). 2024 ISBN CRC Press. Regenerative Agriculture Translating Science to Action.

41. Lili Guo & Shuang Zhao & Yuting Song & Mengqian Tang & Houjian Li, 2022. Green finance, chemical fertilizer use and carbon emissions from agricultural production, Agriculture, 12(3), pages 1-18,

42. Elrys, A.S., Uwiragiye, Y., Zhang, Y. *et al.* Expanding agroforestry can increase nitrate retention and mitigate the global impact of a leaky nitrogen cycle in croplands. *Nat Food* **4**, 109–121 (2023). https://doi.org/10.1038/s43016-022-00657-

43. Burtscher-Schaden H, Durstberger T, Zaller JG. Toxicological comparison of pesticide active substances approved for conventional vs. organic agriculture in Europe. Toxics. 2022 Dec 2;10(12):753.

44. Brunelle, T., Chakir, R., Carpentier, A. *et al.* Reducing chemical inputs in agriculture requires a system change. *Commun Earth Environ* **5**, 369 (2024). https://doi.org/10.1038/s43247-024-01533-1

45. Velazquez JA, Negrutiu I. Agriculture and global physicochemical deregulation: planetary boundaries that challenge planetary health. Lancet Planet Health. 2019 Jan;3(1):e10-e11.