Article:

Field, K. orcid.org/0000-0002-5196-2360, Carrillo, Y., Campbell, S.A. et al. (2 more authors) (2024) Innovation in plant and soil sciences to tackle critical global challenges. Plants People Planet, 6 (6). pp. 1153-1158. ISSN 2572-2611

https://doi.org/10.1002/ppp3.10520

Received: 8 April 2024 | Accepted: 12 April 2024
DOI: 10.1002/ppp3.10520

EDITORIAL

Plants People Planet PPP Open Access

Innovation in plant and soil sciences to tackle critical global challenges

1 | INTRODUCTION

The environmental consequences of anthropogenic climate change and other types of environmental degradation pose enormous challenges for the future of human societies (Dietz et al., 2020), requiring us to balance consumption with conservation and production with restoration to increase sustainability. Plants and soils are at the very centre of these challenges. As they are directly affected by climate change (Van der Putten et al., 2013), they can serve as key indicators of climate change (Hatfield et al., 2020; Higa et al., 2013; Morecroft & Keith, 2009). At the same time, they can offer opportunities to develop strategies that aim to mitigate and minimise environmental, biodiversity and societal impacts of climate change (Amelung et al., 2020; Lal, 2004; Silva & Lambers, 2021). Thus, plant and soil scientists now have unique opportunity and responsibility to draw on the latest research and innovations across disciplines to contribute towards global efforts in climate change mitigation, adaptation, conservation and ecological restoration.

The complexity of the current challenges requires a paradigm shift in how we use and manage our planet's plants and soils so that new approaches prioritise both productivity and sustainability to support the global population while minimising adverse impacts on the wider environment. To address these pressing challenges, it is now critical that researchers in plant and soil sciences come together to develop solutions to drive adaptation to changing conditions and mitigation of past and current damage.

2 | UNDERSTANDING THE FUTURE OF TERRESTRIAL CARBON SINKS

Terrestrial carbon sinks play a vital role in combating climate change by absorbing and storing carbon dioxide (Lal, 2004; Schulze, 2006). Understanding the future of these sinks is crucial for effective climate change adaptation and mitigation strategies. Both natural and managed ecosystems are potential carbon sinks, and so investigating their capacity to sequester carbon and mitigate greenhouse gas emissions is a focus of much ongoing research. One mode of investigating this is through deployment of Free-Air CO_2 Enrichment (FACE) experiments to study the effects of elevated carbon dioxide levels on vegetation (Ainsworth & Long, 2005; Norby & Zak, 2011), providing valuable insights into plant responses and ecosystem dynamics under future climate scenarios.

Technological advancements through Earth observation and climate modelling can help to predict the behaviour of terrestrial carbon sinks in response to a changing climate. Satellite imagery, LiDAR (Light Detection and Ranging) and advanced computational models can help monitor and precisely quantify changes in carbon stocks across varied ecosystems (Asner et al., 2010; Dalponte et al., 2019; Kulawardhana et al., 2014; Zhao et al., 2023). These remote sensing tools also help identify key drivers of carbon fluxes, such as land use change (Zhu et al., 2019), disturbance (Goward et al., 2008) and climate variability (Sun et al., 2019), helping to facilitate more accurate predictions of carbon sink dynamics in the future. Interdisciplinary efforts to advance our understanding of terrestrial carbon sinks and their role in the global carbon cycle are more essential than ever before. Collaboration across disciplines, including plant and soil sciences, climatology, ecology and remote sensing, will drive a more comprehensive assessment and understanding of carbon sequestration potential and ecosystem resilience. By integrating new knowledge, technologies and policy interventions, humanity may become able to harness the full potential of terrestrial carbon sinks, helping to mitigate climate change and build a more sustainable future (Zhao et al., 2023).

3 | PLANT- AND SOIL-BASED CLIMATE MITIGATION

Plant and soil sciences underpin new approaches to land management such as afforestation, reforestation and improved agricultural practices that help to sequester carbon dioxide and thereby reduce greenhouse gas emissions (Böttcher et al., 2012; Padilla et al., 2010). Afforestation involves the establishment of new forests on land that has not been forested in recent history (Doelman et al., 2020), while reforestation focuses on restoring forests on previously deforested or degraded land (Nave et al., 2019). Both approaches enhance carbon sequestration by increasing plant biomass, thereby capturing and storing atmospheric carbon dioxide through photosynthesis. However, recent research suggests that the climate benefits of such approaches may be overestimated (Weber et al., 2024), highlighting the need for more research in this area. Geoengineering approaches, such as application of rock dust to enhance the drawdown of atmospheric CO_2 through increased biological weathering, also hold promise in this area (Beerling et al., 2018) but again require more research at various scales to determine long-term efficacy and viability.

Alternative agricultural practices such as agroforestry, conservation agriculture, and cover cropping offer additional opportunities for carbon sequestration in soils (Lal, 2015; Poeplau & Don, 2015; Shi et al., 2018). Agroforestry integrates trees and shrubs into agricultural landscapes, providing multiple benefits such as enhanced soil fertility, erosion control and biodiversity conservation while sequestering carbon in woody biomass and soil organic matter (Ramachandran Nair et al., 2009). Conservation agricultural techniques, including no-till and reduced tillage, help minimise soil disturbance and thereby reduce carbon loss, preserving soil structure and promoting carbon storage (Hobbs et al., 2008; Lal, 2015). Cover cropping that involves planting non-commercial crops during fallow periods can help further protect soil from erosion, improve nutrient cycling and increase organic carbon inputs (Dabney et al., 2001).

Together, these approaches offer promising avenues to effectively combat global warming and enhance carbon storage in soil. However, it is essential to be mindful of unintended consequences that may arise from these measures, such as disruptions to local biodiversity or other environmental issues (Torralba et al., 2016). By integrating scientific knowledge, technological innovations and holistic ecosystem management approaches, plant- and soil-based mitigation strategies have significant potential towards helping to address climate change while promoting environmental sustainability and resilience. Collaboration between researchers, policymakers, land managers and local communities is essential to design and implement mitigation measures that balance carbon sequestration goals with other ecological and socioeconomic objectives.

4 | CLIMATE-READY AGRICULTURE

Climate change is affecting almost all aspects of crop growth and productivity (Lesk et al., 2016), posing significant threats to food security against a backdrop of global population growth and rapid shifts in dietary patterns (Kastner et al., 2012) Soil erosion, salinisation and desertification are further reducing agricultural capacity (Mukhopadhyay et al., 2021; Rhodes, 2014), while intensive irrigation and poor water management are leading to water scarcity and depletion of groundwater resources (Balasubramanya et al., 2022). Development of new climate-resilient crop varieties and sustainable cropping strategies, through targeted breeding of climate-resilient traits, will be central in securing future food production. New land management techniques to improve soil health, such as no-till farming and cover cropping, are likely to play important roles in helping improve soil health and function, while simultaneously mitigating greenhouse gas emissions, increasing carbon storage and driving the selection of disease-suppressing soil microbiomes (Rolfe et al., 2019). Implementation of sustainable agricultural practices such as precision agriculture and regenerative approaches may bolster these efforts (Bohan et al., 2022; Chappell & LaValle, 2011).

In developing new approaches to improving agricultural productivity against the background of climate change, targets for innovation should centre on leveraging new developments in crop and soil sciences to improve crop productivity and stress tolerance. To improve the resilience of our crops to the environmental extremes associated with climate change, a better understanding is needed of how plants cope with variable and multifactorial stresses, which requires basic research on plant acclimation to abiotic stresses, stress memory and resistance to pests and diseases (Harris et al., 2023; Wilkinson et al., 2023). Technological innovation is also critical: apart from advances in precision breeding (i.e., CRISPR gene editing) that take advantage of the rapidly expanding availability of genomic data, remote sensing to monitor outbreaks of pests and diseases, precise irrigation, real-time soil moisture monitoring and engineering of beneficial soil microbial communities will maximise potential sustainability, efficiency and yield in regions prone to biotic or abiotic stresses.

Climate-ready agriculture should place a strong emphasis on soil health as a crucial component in building resilience to climate change. Regenerative and precision agricultural techniques and technologies and the use of 'biofertilizers', including inoculation with beneficial soil microbes (e.g., mycorrhizal fungi, nitrogen-fixing and/or other rhizospheric growth promoting bacteria), are among the innovations that target conserving and improving soil fertility, enhancing water retention and reducing greenhouse gas emissions (Rosenzweig & Hillel, 2000). Soil management practices are integral to biodiversity conservation and ecosystem health. Effective management of soil ecosystems bolsters against environmental degradation, including soil erosion, declining water quality and pollution from agriculture, thereby safeguarding the integrity of terrestrial and aquatic ecosystems.

5 | LAND MANAGEMENT AND EMERGING CONTAMINANTS

With the rapid proliferation of new chemicals and pollutants in the environment, understanding the behaviour and fate of these contaminants in soil ecosystems and their subsequent assimilation into plants is crucial so as to develop new strategies to mitigate their effects and safeguard the health of the environment and inhabitants. Phytoremediation, a process whereby plants are used to remove, degrade or immobilise pollutants, offers one such innovative solution but may require specific tailoring to different contamination scenarios, taking into account local environmental factors and potential land use (Weyens et al., 2009). Green remediation strategies not only offer cost-effective and sustainable alternatives to more traditional remediation methods but also have clear potential to contribute to the restoration of degraded landscapes.

New research into potential land and waste management strategies have potential to develop new approaches that help to minimise the introduction and spread of emerging contaminants. By promoting effective soil management, including the techniques inherent in regenerative approaches to agriculture (Meidl et al., 2024; Sallach et al., 2021; Urra et al., 2019), the risks of soil contamination and leaching of contaminants into groundwater could be mitigated. Prioritisation of biodiversity maintenance could play a crucial role in buffering against the impacts of emerging contaminants and maintaining or enhancing critical ecosystem services (Dawson et al., 2011). Plant biodiversity is key in water purification with riparian zones and wetlands serving as natural water filtration systems. By maintaining plant and microbial diversity in these systems, their capacity for filtering out emerging contaminants is maximised with beneficial impacts on water quality (David et al., 2023).

Importantly, biodiverse environments are important culturally and recreationally, providing spaces for recreation, tourism and well-being. By prioritising the conservation of biodiversity, these values are preserved, fostering societal interest and enthusiasm for protecting the natural world (McGinlay et al., 2018). Only by improving our understanding of the complex interplay between emerging contaminants, soils and plants alongside collaboration across disciplines and stakeholders will it be possible for the development of effective mitigation strategies against environmental pollution and promotion of wider ecosystem health and functionality.

6 | URBANISATION

Green spaces, such as parks, gardens and urban forests, enhance well-being in urban environments (Lee & Maheswaran, 2011; Schebella et al., 2019). These spaces not only provide aesthetic appeal to towns and cities but also serve as vital components of urban ecosystems, supporting biodiversity (Aronson et al., 2017) and mitigating the urban heat island effect (Edmondson et al., 2016). By leveraging new understanding in selecting and cultivating species that can thrive in urban conditions, there is great potential to exploit urban greenspaces to enhance these benefits as well as improve air quality in towns and cities (Hewitt et al., 2020; Venter et al., 2024).

Urban horticulture represents another important area where innovation in plant and soil sciences will have future impact, particularly in promoting sustainable food production in limited spaces and fostering community engagement (Edmondson, Cunningham, et al., 2020; Edmondson, Childs, et al., 2020). Through innovative farming techniques such as vertical gardening, rooftop farming and community gardens, urban agriculture can contribute significantly to food security, environmental sustainability and social cohesion (Edmondson, Cunningham, et al., 2020). Cultivating urban forests and green corridors within towns and cities not only enhance biodiversity but also provide numerous ecosystem services, including carbon sequestration, stormwater management and temperature regulation (Sanesi et al., 2011; Schlaepfer et al., 2020). Development and adoption of innovative soil management techniques for urban areas are likely to play a key role in mitigating issues like soil erosion and urban runoff in rapidly developing urban landscapes. By implementing soil conservation practices such as green infrastructure and permeable paving, urban planners can minimise soil degradation in these areas, improving water quality and enhancing resilience of urban ecosystems to climate change impacts (Minixhofer & Stangl, 2021; Teixeira da Silva et al., 2018). There is potential in revitalising brownfield sites and degraded urban landscapes, transforming them into vibrant and sustainable environments that could contribute to broader ecosystem services thereby generating socioeconomic benefits (Hou et al., 2023). By integrating the latest knowledge developments and emerging technologies with planning and design, urban environments will be uniquely able to harness the potential of plant soil-based solutions to build resilient and sustainable environments in the future.

7 | BALANCING BIODIVERSITY GAIN

Plants and soils are the foundation of terrestrial food webs and support a rich diversity of consumers and higher trophic levels. Many of these (e.g., herbivorous and saprophagous insects) play critical roles in nutrient cycling and other ecosystem services, while some pose significant challenges to agriculture and forestry. Terrestrial ecological communities are threatened globally due to the effects of climate change, agricultural practices and land use change (Wagner et al., 2021), and thus, plant- and soil-based innovations for carbon dynamics or crop improvement need to explicitly consider how these efforts will impact biodiversity under climate change. In some cases, techniques such as precision pesticide application and use of genetically modified crop varieties can have significant benefits for non-target organisms (Klümper & Qaim, 2014). New landscape-scale ecological intensification approaches that aim to reduce external inputs by selectively enhancing key biodiversity in agroecosystems (e.g., pollinators and pest control) may also help balance biodiversity conservation with sustainable food production (Kleijn et al., 2019). However such approaches require additional research on their feasibility and acceptability, and significant questions remain about whether enhancement of agroecosystem diversity can sufficiently compensate for loss of natural habitats (Bateman & Balmford, 2023).

The biodiversity directly associated with plants is likely to drive strong feedbacks with numerous ecosystem-scale processes, but these feedbacks remain an area requiring considerable further research. Consumption of plant material by insect herbivores can have substantial impacts on ecosystem function (Couture et al., 2015), and climate-dependent range expansion of outbreaking herbivores is expected to play a significant role in carbon capture and storage (Kurz et al., 2008). Some of the strongest drivers of nutrient fluxes across the above-belowground interface may involve consumers (Bardgett & Wardle, 2003), but these complex interactions, and their consequences for natural and managed ecosystems, remain poorly understood. Similarly, in highly modified agricultural or urban ecosystems, innovations to improve sustainability may require new approaches to landscape modification, such as the distribution of field-scale pest management strategies (Larsen et al., 2024). These strategies can have far-reaching feedbacks by impacting pollinator populations and leading to pollen limitation (Woodcock et al., 2016), and innovations to improve crop pollination may soon be needed to offset pollinator decline.

8 | CONCLUSIONS

Against this background we are delighted to announce a forthcoming Special Issue of *Plants, People, Planet*, to bring together an exciting collection of innovative and exciting new research, reviews, reports and opinion pieces exploring the latest innovations in plant and soil sciences and their contributions to addressing the climate and ecological crises. We welcome suggestions for potential articles covering all aspects of plant and soil research in the context of global change and associated challenges. We welcome articles within (but not limited to) the following broad themes:

- Future of terrestrial carbon sinks
- Climate mitigation strategies
- Climate-ready agriculture and crops
- Soil health
- Biodiversity conservation and ecosystem management
- Urbanisation
- Land management and emerging contaminants.

KEYWORDS
adaptation, climate change, global challenges, mitigation, plant science, soil science, sustainability

AUTHOR CONTRIBUTIONS
All authors contributed to conceptualising the manuscript. Katie J. Field led the writing and produced the first draft of the manuscript, Yolima Carrillo, Stuart A. Campbell, Jurriaan Ton and Adam Frew contributed to drafting, editing and finalising the paper. All authors approved the final draft.

ACKNOWLEDGEMENTS
We gratefully acknowledge a BBSRC International Partnering Award (BB/X018962/1) for supporting collaborative research activities between researchers in Plants, Photosynthesis and Soil at the University of Sheffield and at the Hawkesbury Institute for the Environment at Western Sydney University.

CONFLICT OF INTEREST STATEMENT
Authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT
Data sharing is not applicable to this article as no new data were created or analyzed in this study.

Katie J. Field[1]
Yolima Carrillo[2]
Stuart A. Campbell[1]
Jurriaan Ton[1]
Adam Frew[2]

[1]*Plants, Photosynthesis and Soil, School of Biosciences, University of Sheffield, Western Bank, Sheffield, UK*
[2]*Hawkesbury Institute for the Environment, Western Sydney University, Penrith, New South Wales, Australia*

Correspondence
Katie J. Field, Plants, Photosynthesis and Soil, School of Biosciences, University of Sheffield, Western Bank, Sheffield S10 2TN, UK.
Email: k.j.field@sheffield.ac.uk
Adam Frew, Hawkesbury Institute for the Environment, Western Sydney University, Penrith, New South Wales 2751 Australia.
Email: a.frew@westernsydney.edu.au

ORCID
Katie J. Field https://orcid.org/0000-0002-5196-2360
Yolima Carrillo https://orcid.org/0000-0002-8726-4601
Stuart A. Campbell https://orcid.org/0000-0001-7357-8143
Jurriaan Ton https://orcid.org/0000-0002-8512-2802
Adam Frew https://orcid.org/0000-0001-9859-2419

REFERENCES
Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. *New Phytologist*, *165*(2), 351–372. https://doi.org/10.1111/j.1469-8137.2004.01224.x

Amelung, W., Bossio, D., de Vries, W., Kögel-Knabner, I., Lehmann, J., Amundson, R., Bol, R., Collins, C., Lal, R., Leifeld, J. J. N. C., & Minasny, B. (2020). Towards a global-scale soil climate mitigation strategy. *Nature Communications*, *11*(1), 5427. https://doi.org/10.1038/s41467-020-18887-7

Aronson, M. F., Lepczyk, C. A., Evans, K. L., Goddard, M. A., Lerman, S. B., MacIvor, J. S., Nilon, C. H., & Vargo, T. (2017). Biodiversity in the city: Key challenges for urban green space management. *Frontiers in Ecology and the Environment*, *15*(4), 189–196. https://doi.org/10.1002/fee.1480

Asner, G. P., Powell, G. V., Mascaro, J., Knapp, D. E., Clark, J. K., Jacobson, J., Kennedy-Bowdoin, T., Balaji, A., Paez-Acosta, G., Victoria, E., & Secada, L. (2010). High-resolution forest carbon stocks and emissions in the Amazon. *Proceedings of the National Academy of Sciences*, *107*(38), 16738–16742. https://doi.org/10.1073/pnas.1004875107

Balasubramanya, S., Brozović, N., Fishman, R., Lele, S., & Wang, J. (2022). Managing irrigation under increasing water scarcity. *Agricultural Economics*, *53*(6), 976–984. https://doi.org/10.1111/agec.12748

Bardgett, R. D., & Wardle, D. A. (2003). Herbivore-mediated linkages between aboveground and belowground communities. *Ecology*, *84*(9), 2258–2268. https://doi.org/10.1890/02-0274

Bateman, I., & Balmford, A. (2023). Current conservation policies risk accelerating biodiversity loss. *Nature*, *618*(7966), 671–674. https://doi.org/10.1038/d41586-023-01979-x

Beerling, D. J., Leake, J. R., Long, S. P., Scholes, J. D., Ton, J., Nelson, P. N., Bird, M., Kantzas, E., Taylor, L. L., Sarkar, B., & Kelland, M. (2018). Farming with crops and rocks to address global climate, food and soil security. *Nature Plants*, *4*(3), 138–147. https://doi.org/10.1038/s41477-018-0108-y

Bohan, D. A., Richter, A., Bane, M., Therond, O., & Pocock, M. J. (2022). Farmer-led agroecology for biodiversity with climate change. *Trends in Ecology & Evolution*, *37*(11), 927–930. https://doi.org/10.1016/j.tree.2022.07.006

Böttcher, H., Freibauer, A., Scholz, Y., Gitz, V., Ciais, P., Mund, M., Wutzler, T., & Schulze, E. D. (2012). Setting priorities for land management to mitigate climate change. *Carbon Balance and Management*, *7*, 5. https://doi.org/10.1186/1750-0680-7-5

Chappell, M. J., & LaValle, L. A. (2011). Food security and biodiversity: Can we have both? An agroecological analysis. *Agriculture and HumanV*, *28*, 3–26. https://doi.org/10.1007/s10460-009-9251-4

Couture, J. J., Meehan, T. D., Kruger, E. L., & Lindroth, R. L. (2015). Insect herbivory alters impact of atmospheric change on northern temperate forests. *Nature Plants*, *1*(3), 15016. https://doi.org/10.1038/nplants.2015.16

Dabney, S. M., Delgado, J. A., & Reeves, D. W. (2001). Using winter cover crops to improve soil and water quality. *Communications in Soil Science and Plant Analysis*, *32*(7–8), 1221–1250. https://doi.org/10.1081/CSS-100104110

Dalponte, M., Jucker, T., Liu, S., Frizzera, L., & Gianelle, D. (2019). Characterizing forest carbon dynamics using multi-temporal lidar data. *Remote Sensing of Environment*, *224*, 412–420. https://doi.org/10.1016/j.rse.2019.02.018

David, G., Rana, M. S., Saxena, S., Sharma, S., Pant, D., & Prajapati, S. K. (2023). A review on design, operation, and maintenance of constructed wetlands for removal of nutrients and emerging contaminants. *International Journal of Environmental Science and Technology*, *20*(8), 9249–9270. https://doi.org/10.1007/s13762-022-04442-y

Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C., & Mace, G. M. (2011). Beyond predictions: Biodiversity conservation in a changing climate. *Science*, *332*(6025), 53–58. https://doi.org/10.1126/science.1200303

Dietz, T., Shwom, R. L., & Whitley, C. T. (2020). Climate change and society. *Annual Review of Sociology*, *46*, 135–158. https://doi.org/10.1146/annurev-soc-121919-054614

Doelman, J. C., Stehfest, E., van Vuuren, D. P., Tabeau, A., Hof, A. F., Braakhekke, M. C., Gernaat, D. E., van den Berg, M., van Zeist, W. J., Daioglou, V., & van Meijl, H. (2020). Afforestation for climate change mitigation: Potentials, risks and trade-offs. *Global Change Biology*, *26*(3), 1576–1591. https://doi.org/10.1111/gcb.14887

Edmondson, J. L., Childs, D. Z., Dobson, M. C., Gaston, K. J., Warren, P. H., & Leake, J. R. (2020). Feeding a city–Leicester as a case study of the importance of allotments for horticultural production in the UK. *Science of the Total Environment*, *705*, 135930. https://doi.org/10.1016/j.scitotenv.2019.135930

Edmondson, J. L., Cunningham, H., Densley Tingley, D. O., Dobson, M. C., Grafius, D. R., Leake, J. R., McHugh, N., Nickles, J., Phoenix, G. K., Ryan, A. J., & Stovin, V. (2020). The hidden potential of urban horticulture. *Nature Food*, *1*(3), 155–159. https://doi.org/10.1038/s43016-020-0045-6

Edmondson, J. L., Stott, I., Davies, Z. G., Gaston, K. J., & Leake, J. R. (2016). Soil surface temperatures reveal moderation of the urban heat island effect by trees and shrubs. *Scientific Reports*, *6*(1), 33708. https://doi.org/10.1038/srep33708

Goward, S. N., Masek, J. G., Cohen, W., Moisen, G., Collatz, G. J., Healey, S., Houghton, R. A., Huang, C., Kennedy, R., Law, B., & Powell, S. (2008). Forest disturbance and North American carbon flux. *Eos, Transactions American Geophysical Union*, *89*(11), 105–106. https://doi.org/10.1029/2008EO110001

Harris, C. J., Amtmann, A., & Ton, J. (2023). Epigenetic processes in plant stress priming: Open questions and new approaches. *Current Opinion in Plant Biology*, *75*, 102432. https://doi.org/10.1016/j.pbi.2023.102432

Hatfield, J. L., Antle, J., Garrett, K. A., Izaurralde, R. C., Mader, T., Marshall, E., Nearing, M., Philip Robertson, G., & Ziska, L. (2020). Indicators of climate change in agricultural systems. *Climatic Change*, *163*, 1719–1732. https://doi.org/10.1007/s10584-018-2222-2

Hewitt, C. N., Ashworth, K., & MacKenzie, A. R. (2020). Using green infrastructure to improve urban air quality (GI4AQ). *Ambio*, *49*(1), 62–73. https://doi.org/10.1007/s13280-019-01164-3

Higa, M., Nakao, K., Tsuyama, I., Nakazono, E., Yasuda, M., Matsui, T., & Tanaka, N. (2013). Indicator plant species selection for monitoring the impact of climate change based on prediction uncertainty. *Ecological Indicators*, *29*, 307–315. https://doi.org/10.1016/j.ecolind.2013.01.010

Hobbs, P. R., Sayre, K., & Gupta, R. (2008). The role of conservation agriculture in sustainable agriculture. *Philosophical Transactions of the Royal Society, B: Biological Sciences*, *363*(1491), 543–555. https://doi.org/10.1098/rstb.2007.2169

Hou, D., Al-Tabbaa, A., O'Connor, D., Hu, Q., Zhu, Y. G., Wang, L., Kirkwood, N., Ok, Y. S., Tsang, D. C., Bolan, N. S., & Rinklebe, J. (2023). Sustainable remediation and redevelopment of brownfield sites. *Nature Reviews Earth and Environment*, *4*(4), 271–286. https://doi.org/10.1038/s43017-023-00404-1

Kastner, T., Rivas, M. J. I., Koch, W., & Nonhebel, S. (2012). Global changes in diets and the consequences for land requirements for food. *Proceedings of the National Academy of Sciences*, *109*(18), 6868–6872. https://doi.org/10.1073/pnas.1117054109

Kleijn, D., Bommarco, R., Fijen, T. P., Garibaldi, L. A., Potts, S. G., & Van Der Putten, W. H. (2019). Ecological intensification: Bridging the gap between science and practice. *Trends in Ecology & Evolution*, *34*(2), 154–166. https://doi.org/10.1016/j.tree.2018.11.002

Klümper, W., & Qaim, M. (2014). A meta-analysis of the impacts of genetically modified crops. *PLoS ONE*, *9*(11), e111629. https://doi.org/10.1371/journal.pone.0111629

Kulawardhana, R. W., Popescu, S. C., & Feagin, R. A. (2014). Fusion of lidar and multispectral data to quantify salt marsh carbon stocks. *Remote Sensing of Environment*, *154*, 345–357. https://doi.org/10.1016/j.rse.2013.10.036

Kurz, W. A., Dymond, C. C., Stinson, G., Rampley, G. J., Neilson, E. T., Carroll, A. L., Ebata, T., & Safranyik, L. (2008). Mountain pine beetle and forest carbon feedback to climate change. *Nature*, *452*(7190), 987–990. https://doi.org/10.1038/nature06777

Lal, R. (2004). Soil carbon sequestration to mitigate climate change. *Geoderma*, *123*(1–2), 1–22. https://doi.org/10.1016/j.geoderma.2004.01.032

Lal, R. (2015). Restoring soil quality to mitigate soil degradation. *Sustainability*, *7*(5), 5875–5895. https://doi.org/10.3390/su7055875

Larsen, A. E., Noack, F., & Powers, L. C. (2024). Spillover effects of organic agriculture on pesticide use on nearby fields. *Science*, *383*(6689), p.eadf2572.

Lee, A. C., & Maheswaran, R. (2011). The health benefits of urban green spaces: A review of the evidence. *Journal of Public Health*, *33*(2), 212–222. https://doi.org/10.1093/pubmed/fdq068

Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature*, *529*(7584), 84–87. https://doi.org/10.1038/nature16467

McGinlay, J., Parsons, D. J., Morris, J., Graves, A., Hubatova, M., Bradbury, R. B., & Bullock, J. M. (2018). Leisure activities and social factors influence the generation of cultural ecosystem service benefits. *Ecosystem Services*, *31*, 468–480. https://doi.org/10.1016/j.ecoser.2018.03.019

Meidl, P., Lehmann, A., Bi, M., Breitenreiter, C., Benkrama, J., Li, E., Riedo, J., & Rillig, M. C. (2024). Combined application of up to ten pesticides decreases key soil processes. *Environmental Science and Pollution Research*, *31*(8), 11995–12004. https://doi.org/10.1007/s11356-024-31836-x

Minixhofer, P., & Stangl, R. (2021). Green infrastructures and the consideration of their soil-related ecosystem services in urban areas—A systematic literature review. *Sustainability*, *13*(6), 3322. https://doi.org/10.3390/su13063322

Morecroft, M. D., & Keith, S. A. (2009). Plant ecology as an indicator of climate and global change. In *Climate change* (pp. 297–305). Elsevier. https://doi.org/10.1016/B978-0-444-53301-2.00016-6

Mukhopadhyay, R., Sarkar, B., Jat, H. S., Sharma, P. C., & Bolan, N. S. (2021). Soil salinity under climate change: Challenges for sustainable agriculture and food security. *Journal of Environmental Management*, *280*, 111736. https://doi.org/10.1016/j.jenvman.2020.111736

Nave, L. E., Walters, B. F., Hofmeister, K. L., Perry, C. H., Mishra, U., Domke, G. M., & Swanston, C. W. (2019). The role of reforestation in carbon sequestration. *New Forests*, *50*(1), 115–137. https://doi.org/10.1007/s11056-018-9655-3

Norby, R. J., & Zak, D. R. (2011). Ecological lessons from free-air CO2 enrichment (FACE) experiments. *Annual Review of Ecology, Evolution, and Systematics*, *42*, 181–203. https://doi.org/10.1146/annurev-ecolsys-102209-144647

Padilla, F. M., Vidal, B., Sánchez, J., & Pugnaire, F. I. (2010). Land-use changes and carbon sequestration through the twentieth century in a Mediterranean mountain ecosystem: Implications for land management. *Journal of Environmental Management*, *91*(12), 2688–2695. https://doi.org/10.1016/j.jenvman.2010.07.031

Poeplau, C., & Don, A. (2015). Carbon sequestration in agricultural soils via cultivation of cover crops—A meta-analysis. *Agriculture, Ecosystems & Environment*, *200*, 33–41. https://doi.org/10.1016/j.agee.2014.10.024

Ramachandran Nair, P. K., Mohan Kumar, B., & Nair, V. D. (2009). Agroforestry as a strategy for carbon sequestration. *Journal of Plant Nutrition and Soil Science*, *172*(1), 10–23. https://doi.org/10.1002/jpln.200800030

Rhodes, C. J. (2014). Soil erosion, climate change and global food security: Challenges and strategies. *Science Progress*, *97*(2), 97–153. https://doi.org/10.3184/003685014X13994567941465

Rolfe, S. A., Griffiths, J., & Ton, J. (2019). Crying out for help with root exudates: Adaptive mechanisms by which stressed plants assemble health-promoting soil microbiomes. *Current Opinion in Microbiology*, *49*, 73–82. https://doi.org/10.1016/j.mib.2019.10.003

Rosenzweig, C., & Hillel, D. (2000). Soils and global climate change: Challenges and opportunities. *Soil Science*, *165*(1), 47–56. https://doi.org/10.1097/00010694-200001000-00007

Sallach, J. B., Thirkell, T. J., Field, K. J., & Carter, L. J. (2021). The emerging threat of human-use antifungals in sustainable and circular agriculture schemes. *Plants, People, Planet*, *3*(6), 685–693. https://doi.org/10.1002/ppp3.10222

Sanesi, G., Gallis, C., & Kasperidus, H. D. (2011). *Urban forests and their ecosystem services in relation to human health* (pp. 23–40). Forests.

Schebella, M. F., Weber, D., Schultz, L., & Weinstein, P. (2019). The well-being benefits associated with perceived and measured biodiversity in Australian urban green spaces. *Sustainability*, *11*(3), 802. https://doi.org/10.3390/su11030802

Schlaepfer, M. A., Guinaudeau, B. P., Martin, P., & Wyler, N. (2020). Quantifying the contributions of native and non-native trees to a city's biodiversity and ecosystem services. *Urban Forestry & Urban Greening*, *56*, 126861. https://doi.org/10.1016/j.ufug.2020.126861

Schulze, E. D. (2006). Biological control of the terrestrial carbon sink. *Biogeosciences*, *3*(2), 147–166. https://doi.org/10.5194/bg-3-147-2006

Shi, L., Feng, W., Xu, J., & Kuzyakov, Y. (2018). Agroforestry systems: Meta-analysis of soil carbon stocks, sequestration processes, and future potentials. *Land Degradation & Development*, *29*(11), 3886–3897. https://doi.org/10.1002/ldr.3136

Silva, L. C. R., & Lambers, H. (2021). Soil-plant-atmosphere interactions: Structure, function, and predictive scaling for climate change mitigation. *Plant and Soil*, *461*(1–2), 5–27. https://doi.org/10.1007/s11104-020-04427-1

Sun, Z., Wang, X., Zhang, X., Tani, H., Guo, E., Yin, S., & Zhang, T. (2019). Evaluating and comparing remote sensing terrestrial GPP models for their response to climate variability and CO2 trends. *Science of the Total Environment*, *668*, 696–713. https://doi.org/10.1016/j.scitotenv.2019.03.025

Teixeira da Silva, R., Fleskens, L., van Delden, H., & van der Ploeg, M. (2018). Incorporating soil ecosystem services into urban planning: Status, challenges and opportunities. *Landscape Ecology*, *33*, 1087–1102. https://doi.org/10.1007/s10980-018-0652-x

Torralba, M., Fagerholm, N., Burgess, P. J., Moreno, G., & Plieninger, T. (2016). Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. *Agriculture, Ecosystems & Environment*, *230*, 150–161. https://doi.org/10.1016/j.agee.2016.06.002

Urra, J., Alkorta, I., & Garbisu, C. (2019). Potential benefits and risks for soil health derived from the use of organic amendments in agriculture. *Agronomy*, *9*(9), 542. https://doi.org/10.3390/agronomy9090542

Van der Putten, W. H., Bardgett, R. D., Bever, J. D., Bezemer, T. M., Casper, B. B., Fukami, T., Kardol, P., Klironomos, J. N., Kulmatiski, A., Schweitzer, J. A., & Suding, K. N. (2013). Plant–soil feedbacks: The past, the present and future challenges. *Journal of Ecology*, *101*(2), 265–276. https://doi.org/10.1111/1365-2745.12054

Venter, Z. S., Hassani, A., Stange, E., Schneider, P., & Castell, N. (2024). Reassessing the role of urban green space in air pollution control. *Proceedings of the National Academy of Sciences*, *121*(6), e2306200121. https://doi.org/10.1073/pnas.2306200121

Wagner, D. L., Grames, E. M., Forister, M. L., Berenbaum, M. R., & Stopak, D. (2021). Insect decline in the Anthropocene: Death by a thousand cuts. *Proceedings of the National Academy of Sciences*, *118*(2), e2023989118. https://doi.org/10.1073/pnas.2023989118

Weber, J., King, J. A., Abraham, N. L., Grosvenor, D. P., Smith, C. J., Shin, Y. M., Lawrence, P., Roe, S., Beerling, D. J., & Martin, M. V. (2024). Chemistry-albedo feedbacks offset up to a third of forestation's CO2 removal benefits. *Science*, *383*(6685), 860–864. https://doi.org/10.1126/science.adg6196

Weyens, N., van der Lelie, D., Taghavi, S., & Vangronsveld, J. (2009). Phytoremediation: Plant–endophyte partnerships take the challenge. *Current Opinion in Biotechnology*, *20*(2), 248–254. https://doi.org/10.1016/j.copbio.2009.02.012

Wilkinson, S. W., Magerøy, M. H., López Sánchez, A., Smith, L. M., Furci, L., Cotton, T. E. A., Krokene, P., & Ton, J. (2019). Surviving in a hostile world: Plant strategies to resist pests and diseases. *Annual Review of Phytopathology*, *57*(1), 505–529. https://doi.org/10.1146/annurev-phyto-082718-095959

Woodcock, B. A., Isaac, N. J., Bullock, J. M., Roy, D. B., Garthwaite, D. G., Crowe, A., & Pywell, R. F. (2016). Impacts of neonicotinoid use on long-term population changes in wild bees in England. *Nature Communications*, *7*(1), 12459. https://doi.org/10.1038/ncomms12459

Zhao, S., Liu, M., Tao, M., Zhou, W., Lu, X., Xiong, Y., Li, F., & Wang, Q. (2023). The role of satellite remote sensing in mitigating and adapting to global climate change. *Science of the Total Environment*, *904*, 166820. https://doi.org/10.1016/j.scitotenv.2023.166820

Zhu, E., Deng, J., Zhou, M., Gan, M., Jiang, R., Wang, K., & Shahtahmassebi, A. (2019). Carbon emissions induced by land-use and land-cover change from 1970 to 2010 in Zhejiang, China. *Science of the Total Environment*, *646*, 930–939. https://doi.org/10.1016/j.scitotenv.2018.07.317