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EDITORIAL

Climate solutions: the next phase of understanding and implementation

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More than five decades ago, the first generation of climate models skillfully predicted the levels of global warming we see today (Hausfather et al. 2019). More than ten years ago, the scientific community reached a consensus regarding the human drivers of global climate change (Cook et al. 2013). Today, the principal task at hand is to move from describing the problem to devising tangible solutions, a task that is more easily said than done.

Natural climate solutions have been proposed as a pathway for regaining climate stability through the removal of atmospheric carbon dioxide from the atmosphere. In particular, atmospheric carbon capture through land conservation and sustainable management has received increasing attention. However, natural carbon capture is slow and low compared to the rates of fossil fuel emission (Baldocchi and Penuelas 2019). Moreover, different land-use sectors compete for limiting resources and incentives within and across key regions, which often results in divergent goals and potential for climate change mitigation and adaptation (Silva and Lambers 2021). Plant and soil scientists are well positioned to assess and improve the technical potential of land-based atmospheric carbon capture, but assessments of potential are limited with respect to what may be realizable under social and ecological constraints.

The most recent global report on climate change mitigation (IPCC 2022) points to three areas of exceptional potential: (*i*) sustainable agriculture, which could sequester 4.1 $PgCO_2$ eq yr^{-1}; (*ii*) ecosystem restoration (i.e., protection and sustainable management of forests, savannas, and grasslands), which could sequester 7.3 $PgCO_2$ eq yr^{-1}; (*iii*) enhanced silicate weathering, which could sequester 1 to 100 $PgCO_2$ eq yr^{-1}. A synergistic approach that combines innovations in each of those areas can accelerate carbon capture by improving decision-making at the zone of friction between short-term self-interested gains of individuals and longer-term shared community goals (Silva 2022). But we have yet to address the disconnect between climate change mitigation and adaptation policies in terms of estimating what can be realistically and justly achieved under future scenarios. In other words, there is a critical and widening gap between basic science and applications in this field, a gap that must be bridged toward the next phase of understanding and implementation of scalable climate solutions.

In this special issue, we introduce a generalizable framework for *Enhanced Natural Climate Solutions (NCS+)*, defined as activities that can be coordinated to increase carbon drawdown and permanence on

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land while improving livelihoods and the just provision of natural resources in vulnerable communities and ecosystems (Silva et al. 2022). The framework builds on interdisciplinary research into the mechanisms of plant and soil carbon capture, and related socioecological interactions, to inform top-down incentives and bottom-up adoption. Specifically, we suggest a multi-tiered approach for the prioritization of projects that would advance NCS+ in partnership with communities and industries across heterogenous landscapes. As concrete examples of feasibility, this special issue also brings case studies of new and *"rediscovered"* NCS+ technologies used from the tropics to boreal regions. Select examples include incentivized conservation of forests through voluntary carbon markets (Bomfim et al. 2022); restoration of soil and biomass carbon stocks in native and non-native coastal ecosystems (Zhang et al. 2022); ecological modeling of climate mitigation and adaptation policies for the sustainable management of timber production in aridifying regions (Giebink et al. 2022); assessments of risk and benefits of traditional pyrogenic carbon production and application in developing nations (Aquije et al. 2021); studies of soil structure and function of root mycorrhizal communities in ecological transitions (Ghotsa Mekontchou et al. 2022); and a meta-analysis of organic matter accumulation and decomposition at different soil depths in response to management (Gaudel et al. 2021).

The studies selected for this special issue represent but a few examples of the emerging scientific literature in this field. Taken together, they offer insights into how NCS+ might improve atmospheric carbon capture through conservation of natural ecosystems and interventions in human-engineered systems, where carbon sequestration and adaptation to climate-induced hazards might be synergized. The scientific community can provide rigor to NCS+ and related policies, although scientists must also maintain objectivity and avoid conflicts of interests with emerging and evolving markets (Davidson 2022). In this context, new investments in integrative plant and soil research are as warranted as they are urgent, and hold significant potential for improving understanding as well as implementation of climate change mitigation and adaptation efforts at regional to global scales.

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