Biogeochemistry (2022) 161:47–58
https://doi.org/10.1007/s10533-022-00952-6

Soil science in the time of climate mitigation

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Received: 16 February 2022 / Accepted: 24 June 2022 / Published online: 26 July 2022

Abstract Soil and other Earth scientists who conduct research on C management found themselves, in the past decade within a swirl of efforts concerning climate mitigation, economic and business investments in carbon markets, and political aspirations. All these external pressures are issues with which soil science is largely unfamiliar. As a result, science has responded without deeply considering the landscape in which it finds itself, and some of the unanticipated challenges these issues present. Here, we suggest soil C scientists now consider and respond to these issues. The first order challenge is to transition from the concept of *technical* carbon sequestration potentials, made in the absence of social and policy contexts, to *societally achievable* sequestration estimates based on highly transdisciplinary teams of natural and social sciences and scientists. To achieve this will requires re-thinking national science funding programs, in which climate-relevant social science is under-funded. In addition, the science of soil C itself is in need of a priority shift. Presently, publications in soil C sequestration out-strip papers on soil feedbacks to climate change, and on how to adapt soil to climate change: two areas of research which may well be more societal important in the next few decades than sequestering C. Most seriously, given the urgent nature of our collective societal climate problem, our profession must not find itself a decade from now continuing the now 20-year-old narrative that soil C can potentially mitigate climate change and compensate for greenhouse gas emissions. We must consider the possibility that other options and expenditures of resources are more viable, and we must reframe our science's objectives to expand into the many other urgent needs that confront humanity.

Keywords Soil carbon sequestration · Natural climate solutions · Environmental social science · Climate change · Conflicts of interest

Responsible Editor: Jonathan Sanderman.

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Introduction

Soil science finds itself in uncharted terrain. In a span of just two decades, soil carbon science has become a tool relevant to global climate aspirations, international policy, political maneuvering, and potentially billions of dollars of public and private investments.

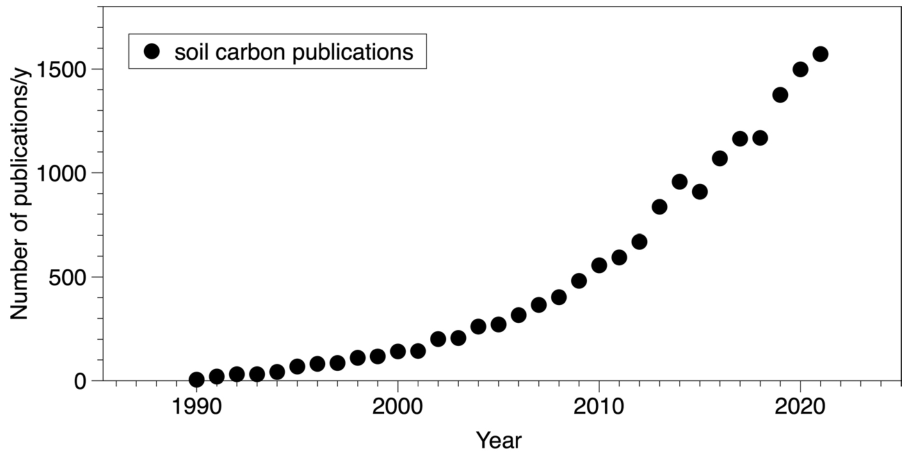

Fig. 1 A web of science search (TS = "soil carbon") of publications on the topic of soil carbon over time

This interest has in turn dramatically increased research funding directed toward soil carbon science and management, and catalyzed an unprecedented increase in research participation and publications (Fig. 1).

This recently acquired relevance within a maelstrom of differing objectives, aspirations, and monetary strategies has intersected with soil scientists who are generally unaccustomed to this level of interest and scrutiny. Given this unexpected landscape, it seems a critical time as a science to pause, deeply review, and question some issues if our science is to remain credible and continue as a source of reliable information for diverse stakeholders concerned with all aspects of our changing climate.

Reshaping the narrative

A rather un-helpful dichotomy has emerged in discussions around natural climate mitigation strategies (mitigation involving the use of natural systems and processes to sequester atmospheric CO_2). Many recent publications have explored the potential for large-scale climate solutions based both on back-of-the-envelope calculations or more complex modeling that have included large-scale reforestation (e.g., Bastin et al. 2019 although see Hermoso et al. 2021), enhanced rock weathering (e.g., Beerling et al. 2020), or altering management of managed land to increase soil carbon stocks (National Academies of Sciences, Engineering, and Medicine 2019). Interest in climate solutions has soared after two developments: the IPCC's 2018 special report on 1.5 °C, which indicated that nearly all scenarios for limiting warming to 1.5 °C with limited or no overshoot rely on significant amounts of carbon dioxide removal, and the rapid adoption of national and corporate net-zero targets, which imply that residual emissions from hard-to-transition sectors will be balanced by sinks—like soil carbon sequestration. From a business's standpoint, meeting these targets hinges upon making carbon removal work, and from a social perspective, climate solutions like soil carbon sequestration are preferred to unfamiliar industrial techniques such as direct air capture (Wolske et al. 2019; Sweet et al. 2021). There is, then, mounting pressure to calculate the potential of natural climate solutions and deliver on them. This pressure goes beyond the corporate space to national governments. Fourteen countries have included agricultural soil carbon sequestration in their Nationally Determined Contributions under the Paris Agreement (Weise et al. 2021). Several countries touch on soil carbon sequestration as an option in their long-term climate strategies, with a few nations such as Australia explicitly considering offsets from soil carbon to meet net-zero goals; nearly all countries mention some form of biosphere climate solutions.

For each of these proposed biosphere climate solutions, critics have been deeply skeptical of the claims based not only on fundamental scientific principles and observational data, but also on undeniable social, political and economic complexities that all human enterprise must navigate and that will most certainly modify the technical potentials.

The intense interest in—and in fact, need for—natural climate solutions risks ignoring or diverting

Table 1 Near-term researchable issues relevant to soil carbon science and its societal utility

Soil carbon issue	Possible activities
The science of soil carbon sequestration	• Conduct meta-analyses of soil carbon management literature: agricultural, forestry, and enhanced weathering to evaluate current knowledge and identify knowledge gaps
	• Open the hood of soil carbon sequestration models to determine if models reflect what we know and predict what we need
	• Test model predictions in different management and geographical settings
	• Arrive at reliable and cost-effective verification strategies
The role of climate change	• Embed climate feedbacks into all model and carbon purchasing scenarios
	• Increase research into feedbacks in management systems
Conflicts of interest	• Require journals to establish clear protocols for what constitutes COI in a diverse business, political, and social milieu
	• Engage universities to establish firewalls between academics and business and other outside interested actors
Social science and policy	• Request journals to discourage purely "technical potential" papers, and request social science-justifiable estimates as starting targets
	• Encourage funders to fund soil carbon research that is interdisciplinary (natural and social science) from the outset
Climate adaptation	• Separate and clarify ways soil can be adapted to climate change from climate mitigation strategies
	• Other ideas?
Community debate and flexibility	• Consider the possible scenario that climate mitigation with soils is not cost effective, due to verification costs
	• Assess carbon removal technologies according to a wide range of social and biophysical metrics
	• Consider reframing soil science role in climate adaptation and sustainability

Each of these bullet points are discussed in greater depth in the following sections, and are supplemented with suggested research questions that should be answered to improve the present science-society compact that is implicit in issues around soil C

attention from a broader view of our science that requires resolution to assure we adequately contend with the real issue: the mitigation and adaptation to climate change.

Soil C can indeed be managed and in cases increased in agricultural systems (Paustian et al. 2016). However, to achieve this at scale requires that a number of poorly addressed issues be considered and resolved. Table 1 is an attempt to outline issues in need of much deeper discussion in order to facilitate meaningful advances in soil science relevant to climate change.

First, we should generate an updated "state of the science" analysis of the impacts of differing management practices, in differing agronomic, forested, or managed biomes, to create a solid framework of what is presently known (and revise past and widely repeated earlier estimates accordingly) and to generate research questions to fill in critical knowledge gaps.

Second, soil carbon science must embed the best estimates of how changing climate and soil C feedbacks are impinging on efforts to sequester climatically significant amounts of carbon. Where there are knowledge gaps, and there are many, these must be identified.

Third, the scientific profession must assess the multiple roles that many scholars have taken, and create clear and community-based firewalls between science and business/advocacy. Specifically, affiliations, consultant fees, or investments in businesses or advocacy groups should be clearly acknowledged as competing and conflicting interests in publications.

Fourth, it is critical that any serious effort to propose potential adoption of practices, and potential environmental impacts, deeply embed both social science and natural science in these analyses; we know from past failures that natural science solutions can fail without attention to social and cultural barriers to best practices.

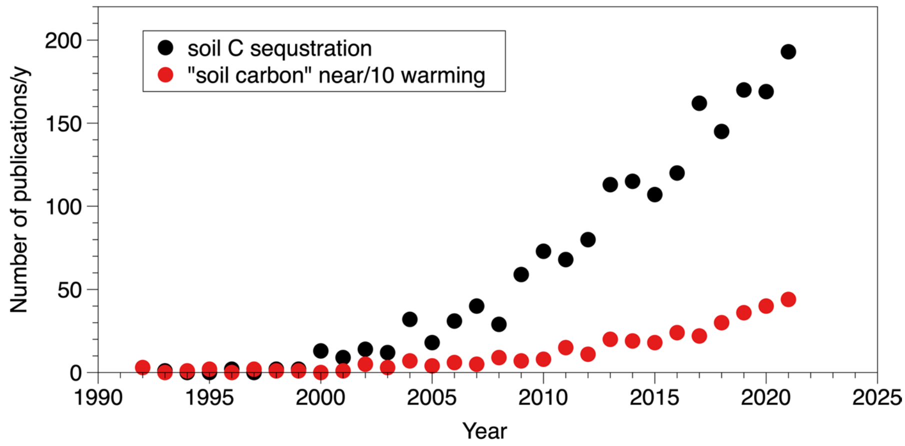

Fig. 2 A web of science search (TS = "soil carbon" near/10 warming = soil carbon with the word warming appearing within ten words; TS = "soil carbon sequestration" of publications in carbon sequestration vs. climate feedback effects over time)

Fifth, soil science should establish a stronger presence in climate adaptation. We need to better understand in which circumstances soil carbon sequestration can increase adaptive capacity (e.g. through increased soil permeability to deal with flooding, the potential for regional cooling due to increased moisture, or increased on-farm revenue streams), and if there are instances in which adoption of soil carbon practices may be maladaptive: e.g. if incentive programs fail, causing revenue losses or yield decreases (Droste et al. 2020; Buck et al. 2020).

Finally, soil scientists should create a stronger feedback loop with funding agencies, and not simply be content that funds are expended on soil research. Additionally, funding from private sources should be considered in these discussions. Scientists must be honest about where knowledge gaps and redundancy exists, and suggest where these funds are most critically needed. There have been efforts by soil scientists to reach funding agencies with scientific agendas (e.g., Jordan et al. 2001; Richter et al. 2011) but these conversations need to be brought into the funding agencies themselves to create critical funding pathways for applied, interdisciplinary, and focused research.

The issues surrounding soil carbon research

The science of soil carbon sequestration

The exponential explosion of papers focusing on soil C sequestration (Fig. 2) is suggestive that there is a need at this time for a global integration of the impacts of varying management practices, in differing locales, on soil C. The most recent such effort (Lessmann et al. 2021), while an advancement, focused on existing meta-studies and reviews. How does the burgeoning literature become integrated into a more holistic view? One example might be strategic compilation efforts, through an organization such as the National Center for Ecological Analysis and Synthesis, as a way to facilitate such a large team effort.

The result may be a way to reign in the *technical* scenarios that can then be addressed with the help of social scientists. Technical scenarios are incomplete first steps in developing climate mitigation strategies. Technical projections with a corresponding social analysis should become the new gold standard in all natural C mitigations efforts. Social scientists must be engaged in these processes from the beginning, which will encourage faster and more realistic *socially achievable* sequestration potentials, and timelines.

Some of the questions to be addressed in any new meta-analysis and in the key issues of Table 1 are listed in Table 2. For the science of soil C sequestration, the rates, potential limits, and residence times of soil C in managed soils are among first-order issues that might be addressed.

The impact of climate change

Proposals of ways to sequester soil carbon must be made in the context of the changing climate. The negative correlation between mean annual temperature and soil C and N is one of the longest standing relationships in soil science (Jenny 1929). Yet, remarkably, significant debate exists on the rate and sign of

Table 2 First order questions to be addressed and clarified

Soil carbon issue	Questions
The science of soil carbon sequestration	• What are the realistic maximum rates of soil C sequestration in different management settings and in different soils/climates?
	• What are the residence times of C sequestration under agriculture and reforestation? Is this C readily released with return to conventional practices?
	• Is there a soil C saturation limit in agricultural and forestry settings that is inherently lower than the theoretical limit in the unmanaged soil?
	• Will social and cultural factors outweigh potential physical sequestration rates?
	• Are there nutrient costs to increased soil C in agricultural settings?
	• What is the role of a warming climate in affecting soil C sequestration potentials?
The role of climate change	• Rates of soil C feedbacks to warming in temperate managed systems?
	• Impacts of shifting agriculture (in response to climate) on soil C?
Conflicts of interest	• Is present policy and funding being impacted by varying conflicts of interest?
	• What are the impacts of non-financial conflicts of interests, such as the need to build a brand on social media, on soil research?
Social science and policy	• What factors influence farmers decision making, and their trusted sources of information?
	• What policy choices are most cost and climate effective (comparative analyses of key mitigation strategies)?
	• Is policy better crafted if mitigation and adaptation goals are dealt with separately?
	• What are the moral hazards of reliance on unproven or misleading strategies?
Climate adaptation	• What soil properties can be effectively managed for warmer, drier agriculture?
	• How will agricultural adaptation to a changing climate (irrigation, planting/harvest intensity, species choice) affect soil C pools?
	• How will shifting agriculture affect previously unmanaged soils?
Community debate and flexibility	• Is further science what is needed, or do we have enough information to determine the potential of managed soils to absorb more C?
	• What are the most effective strategies at our disposal to effectively use public resources to manage atmospheric CO_2?

transient soil responses to combined warming and CO_2 increases (Davidson and Janssens 2006). Few estimates of global soil C sequestration rates, even recent and critical re-analyses (Lessmann et al. 2021), include corresponding potential soil C losses due to soil warming.

This imbalance of focus is reflected in publication numbers. In Web of Science searches of "soil carbon sequestration" vs. "soil carbon" with the word "warming" located within ten words from soil C, with a factor of ten more papers per year were devoted to carbon sequestration (Fig. 2). The imbalance of effort in this is both puzzling and unsettling. Using the recent *technical* carbon sequestration rate of roughly 0.5 Gt C year^{-1}, for a 20 year potential duration (Lessmann et al. 2021), 10 Gt C *may* (if all social obstacles fall by the wayside) be captured in managed lands. In contrast, soil feedbacks to warming (including unmanaged lands) may be 10^2 Gt C by the early twenty-second century (Crowther et al. 2016). An underlying impediment in soil C feedback science is the small number of observational studies (time series observations of soils) vs modeling or climate manipulation studies (both lab and field). Model outputs are diverse, and many suggest soil C gains due to CO_2 fertilization effects (Lawrence et al. 2019). Models also suggest soil C gains with management of plant residues, without sufficient long-term studies of asymptotes of long-term soil C stability due to residue management. Improving and expanding the research in this area is a first order obligation for soil C science, as important to societal welfare, or more, than work on C sequestration.

Conflicts of interest

Interest in soil carbon as a climate mitigation strategy, and as a marketable product either directly or through a business sustainability strategy, has brought soil biogeoscientists into new areas of commercial activities. This is a new permeation of the tension between science and its commercialization. Consulting, third party advising for agribusiness and C neutrality programs, and creation of new soil C sequestration verification methods or technologies (e.g. rapid field soil C assessments and instruments) are all relatively new commercial activities that come with potential financial benefits. These may in some cases conflict, or lend a perception of conflict, with impartial science. This issue has recently been raised, but very poorly followed up on, in the earth sciences (Oreskes et al. 2015; Tollefson 2015).

Oreskes et al. (2015) point out several biases that are relevant to this issue. Most important, there is a documented bias for research outcomes that are favorable to the funding source, when compared to similar studies funded by other sources (Lundh et al. 2012; Seehusen and Koren 2013). As Oreskes et al. (2015) point out this bias is likely in most cases *unconscious*. But by noting funding sources and other potential COIs, both the author—and the readers—share in a joint transparency, and acknowledgement of human nature, that should only be helpful to our science. This need for transparency is made even clearer by another human tendency. As Oreskes et al. (2015) note, scientists (like consumers) are subject to a "third person effect", one where the scientist (or consumer) feels that other scientists (consumers) are more susceptible to bias due to funding sources or other pressures than the scientist her/himself is (Steinman et al. 2001). This prejudice (that others are biased, and that we are far less likely to be so) is in itself a strong argument for declarations of conflicts of many types.

A related issue is probably the widely encountered case (with respect to soil C) of studies funded by government grants, but where some of the scientists also have consulting, investment, or other financial ties to entities dependent on the growth of soil C sequestration activities. This is likely why there are few disclosures of conflicts in the present literature. We suggest here that these outside activities constitute conflicts that should be reported during publication, for they can subtly (and unconsciously) affect outcomes in ways similar to direct funding. We thus encourage the science community, and the editorial staff of journals, to deeply consider these connections and develop community-wide standards for how they should be acknowledged.

What remedies or actions are worth considering to contend with the blending of science with business/power/branding? While nearly all journals have competing interest statements, these appear to seldom be rigorously enforced or checked by editors.[1] Thus, it may be prudent that the soil and Earth science communities—through their respective professional societies—arrive at new and highly publicized community standards, and that these new standards be distributed to all the major journals which serve as outlets for peer reviewed papers. Oreskes et al. (2015) suggest that these then be used by journals to develop appropriate sanctions for those who fail to disclose connections.

While COI issues are potentially serious, there is also a need for a pragmatic and rational view of our emerging science. Some of our best scientists are, as is to be expected, vigorously sought out for business consulting, the creation of startups, and for political consultation. These activities may indeed complicate an individual's perceptions and biases, but they also do not necessarily disqualify their scientific integrity and insights. But we are humans, with a potential ability to ignore or discard information (unconsciously) that conflicts with ideas we value. Transparency and reporting of our array of connections need not be viewed, *prima facie*, as a red flag or a weakness, but rather as a standard of scientific and personal integrity.

[1] A cursory—and admittedly incomplete—review of papers in Biogeochemistry, Science, Nature, Soil Science Society of America Journal in the past 3 years reveals no reported conflicts of interest, by university professors, in soil carbon management related topics, a result that cannot be true given the pace of evolution of business relations the field. This may be simply due to a poor definition or articulation of what COI means, or an assumption that a submission from a university address is adequate separation of interests.

Social science and policy

We are in the midst of an era of papers published in highly visible science journals that articulate “technical potentials” of carbon sequestration, or even road maps to carbon neutrality of row crop farming (Northrup et al. 2021), in the absence of any political or social feasibility analyses. Journal editorial staffs must deeply consider the value, and the inadequacy, of these “half-way” analyses. Given the urgency of the climate problem, and the time sensitive nature of its remedies, spreadsheet projections made in a vacuum devoid of the human complexities that must be breeched to enact them is simply insufficient. For example, the recent National Academies of Sciences, Engineering, and Medicine (2019) report on “Negative Emissions Technologies and Reliable Sequestration: A Research Agenda”, was constituted entirely by scientists and engineers, though one member had a PhD in marine chemistry and was presently an energy and environmental law professor. No policy experts, or other social scientists, were engaged in a report on activities that clearly hinges on societal acceptance and support. How a “research agenda” can be proposed, devoid of the need of understanding the framework for social acceptance, is baffling for such a high level effort by the USA’s premier science institution. But in fact, this is but one example of a trend of keeping social sciences on a separate track from assessment of carbon dioxide removal (Dowell et al. 2020) and marginalizing and constraining social sciences within carbon removal research (Markusson et al. 2020).

Social sciences—policy, psychology, economics, rural sociology, and more—should be embedded in soil C and climate research at the outset of experimental design and proposal writing. Outworn ideas that a scientific “information deficit” (Suldovsky 2017) exists among policy makers, or the idea that the role of science is to deliver technical solutions to a “loading dock” for policy specialists (Cash et al. 2006; Rogga 2020) to pick up and haul to some sort of policy enactment, must be jettisoned. Natural and social scientists must step into each other’s terrain, and create new intellectual partnerships. Major natural science symposia on climate mitigation that have no social science participants should be considered a thing of the past (Amundson 2020). These symposia should also be crafted with social scientists in the development stages, in order to assure broad participation and effective engagement. Scientific societies, largely in the natural sciences, should consider waiving registration fees and devise other incentives to draw relevant social science, and create a cross-disciplinary community of interaction.

Climate adaptation

The related issue of the climate change challenge is adaptation. While there is a sense that focusing on adaptation is an acknowledgement of failure to mitigate, it is probably one of the most societally impactful areas of research involving our changing climate (e.g. Renwick et al. 2021). Raynor (2010) argues this is the avenue to bring real, immediate, and visible impacts to communities. The revision of zoning laws, investments in local infrastructure and design, urban forest planning and management are examples of local adaptive activities with direct impacts.

Despite this need, the allure of mitigation appears to dominate the soil science literature (Fig. 3). A search of “soil” AND “climate adaptation” shows almost no activity until about 2010, and today the output is about an order of magnitude less than papers focused on “soil carbon sequestration”. An alternative search (“soil” AND “climate change adaptation”) provides more citations, but still less than C sequestration. Managing soil for climate adaptation (or any other specific goal, such as reduced erosion) is not just C management, or one of its ancillary “wins”. Collaborating with agronomists, forest scientists, and others to develop ways of easing the stresses of climate change is an under-investigated area in agriculture and soil science, but one rich in opportunity.

Community debate about priorities

Practicing scientists are well aware of the ebb and flow of research support and its scarcity, but often lack a holistic overview. Thus, a recent review of the history of current climate research funding, and the fractions of this pool directed to natural vs. social sciences, is an important starting point (Overland and Sovacool 2020). One important finding is that research on climate change amounted to only 2–5% of all research funding between 1990 and 2018, though in absolute terms it still is a significant $40 billion USD. However, the key finding was

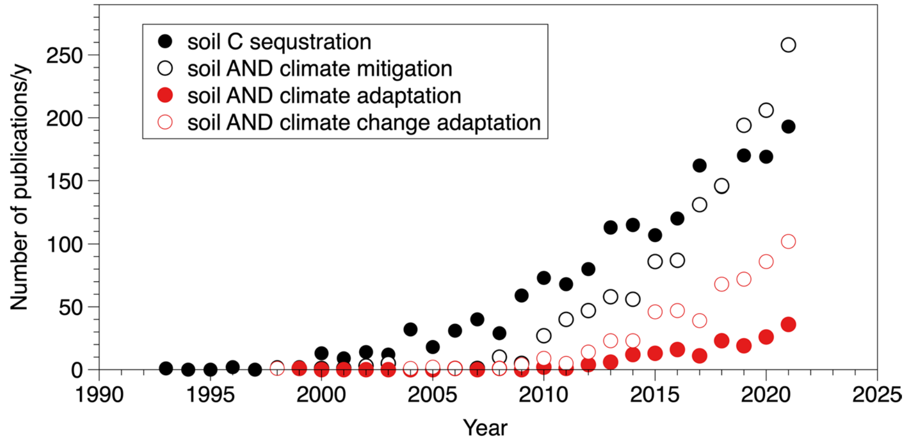

Fig. 3 A comparison of the number of Web of Science publications in "soil carbon sequestration" and soil AND "climate adaptation" since 1990

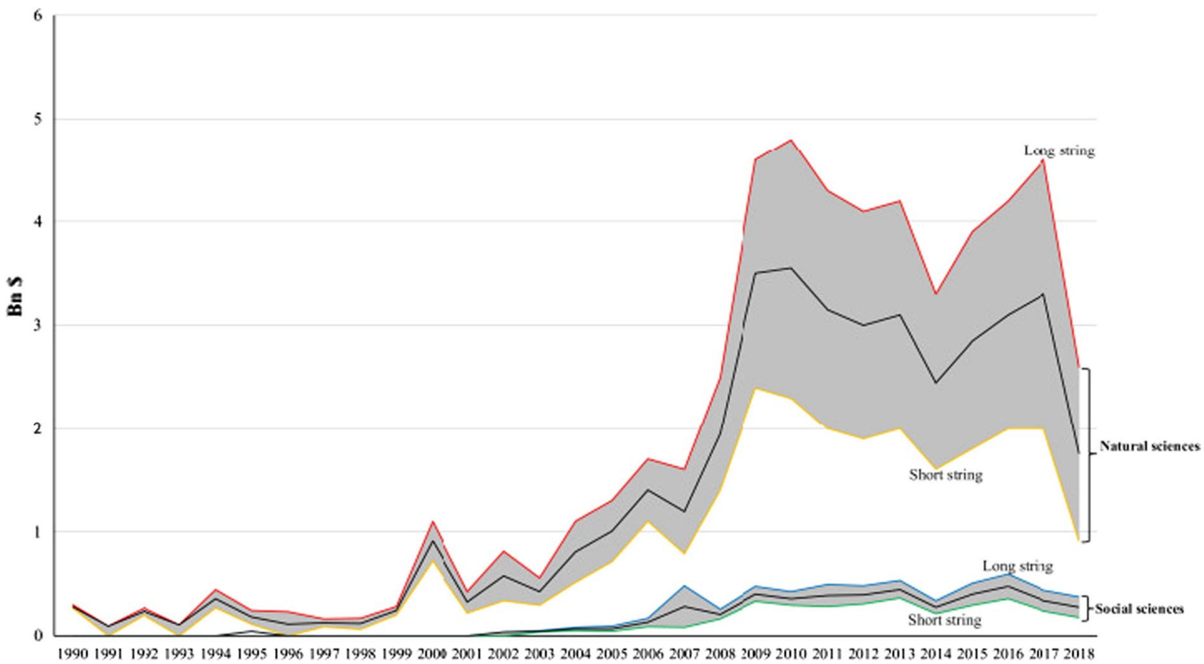

Fig. 4 Funding (in billions of USD) for climate research in the natural and technical sciences versus the social sciences and humanities. The gray areas represent ranges of estimates derived from differing search terms. From Overland and Sovacool (2020)

the fact that most funding goes to natural science, with only about 5% devoted to the social sciences (Fig. 4). This imbalance exists despite the fact that the solution to climate change is both a social and technological problem, with political, communication, and cultural barriers to implementing natural science-based strategies.

To remedy this situation, the authors propose some steps to improve the impact of science on the climate challenge:

- *Make funding commensurate with and focused on the magnitude of the problem*

Climate change mitigation is a social and cultural problem, as well as one involving natural sciences. The funding in the (appropriate) sciences therefore should be commensurate with the scale of the problem. How do we, as natural scientists who receive the bulk of the current funding stream, articulate this to funding agencies also commonly led by individuals with similar natural science backgrounds? It is true that natural science facilities and instrumentation are indeed expensive. But, in a world where resources are limited, should we argue for monetary re-allocations from natural science to areas of research that may be more critical, yet are lacking in resources? And as scientists, we might engage in self-reflection and argue for more practical and solution-based science funding. Or more boldly, as recently suggested (Glavovic et al. 2021) do scientists declare a moratorium on further climate related research until a fundamental change is made in the science-policy interface? The issue that this concept attempts to highlight is the large gap between climate science knowledge and societal concern for the issues and an implementation of appropriate responses. It highlights that scientists should not remain content with further research funding that results in more data that is, as in the past, unacted upon. Should science engage in a paradigm change (Lubchenco 1998), and demand stronger government, industry, and consumer responses?

- *Coordinate efforts and increase transparency of expenditures*

  Both internally and globally, there is overlap and redundancy of research in some areas, and glaring gaps in others, due to the present lack of a structure to coordinate and provide a transparent framework of funded projects across the globe. Developing ways to easily observe and monitor these efforts could help agencies, and individual scientists, better allocate new streams of funding to address gaps or weaknesses in our knowledge.

- *More rigorous and appropriate social science*
  It is argued here and elsewhere (Grundmann 2016) that an increased social science footprint is needed to result in climate remediation, an effort made in deep collaboration with the natural science underpinnings. However, as both Overland and Sovacool (2020) and Watts (2017) suggest, not all social science approaches are particularly relevant, and there is a need for an advancement of solution-based social science research. Watts (2017) in particular, argues that social science, like the natural sciences, is partially siloed into subdisciplines, with research and papers driven toward the development of new theory as an end in itself. The result is an "incoherency problem", one of numerous theoretical descriptions and explanations for a given problem, many of risk being mutually exclusive and in conflict. Watts (2017) suggests, among other remedies, that segments of the social sciences strive for empirical replication of theoretical predictions, integration and consolidation of theory, a focus on solution-based applied outcomes, and engagement in multi-disciplinary teams that push both the solutions to given problems, but also strive to advance the underlying social science that works on these issues. The emphasis on solution-based science may strike some social scientists the wrong way, given existing critiques of "climate solutionism"—i.e., assuming that solutions will naturally flow from objective facts put on the table (Hulme 2020)—but being solution-oriented does not mean that politics and values have to be masked. There are ways to doing social science that is practical, rigorous, and outcome-oriented while still addressing politics and power relations.

  Stated differently, the "right" natural and social scientists must be brought together. These teams must share some common goals and aspirations for tangible solutions and practical outcomes. An example is the current Nation Science Foundation Convergence Accelerator. Presently, it is likely that there are few participants in either the natural or social sciences who can identify a significant number of scholars in the other field with whom they might most effectively partner with. Facilitating the identification and encouragement of these participants might be the work of societal symposia (such as the American Geophysical Union meetings) or by other organizations such as the National Academies of Sciences, Engineering, and Medicine.

Multi-pronged solution-based soil science

The present research landscape of soil C as a climate mitigation strategy is characterized by an enormous imbalance in the participation of the natural vs the social sciences, a focus on sequestration science vs. soil climate feedback science, a gap in adaptation science, and a powerful forward momentum driven by advocates, social media, business, and scientific careerists invested in the problem. There is at the present time, after more than 30 years of science on this topic, no evidence that soil C sequestration has yet had a measurable impact on atmospheric CO_2 levels, or even that proposed practices will matter globally. As a climate mitigation strategy, we might ask is it now a Sisyphean endeavor, and will soil science still be suggesting this as a "potential mitigation strategy" in yet future decades? We suggest that this trap might be avoided by addressing the issues discussed here, and in this special issue of *Biogeochemistry*.

It is *en vogue* to view soil C sequestration as a "win–win" or "no regrets", exercise (Handelsman 2021). Even if climate meaningful C sequestration fails, then it is argued at least there will be improvements to soil health, reduced soil erosion, or positive impacts on other soil features. While possibly true, does this "one approach fits all" strategy drive or secure the best outcomes in the non-climate issues, and could funds be better spent and strategized to focus specifically on soil erosion reduction (for example)? Policy experts have questioned this one size fits all strategy. Raynor (2010) wrote "instead of loading more and more issues on the climate policy agenda, we should be unloading as much as possible onto other immediate policy priorities which can be pursued at national and subnational levels."

Soil science in the time of climate change has an enormous opportunity, and responsibility, to identify and unpack key issues, and create manageable avenues of inter-disciplinary effort—in multiple strategic areas. One of these is, indeed, an exploration of mitigation strategies and its socio-economic viability. However, as soil science wrestles with mitigation, a major pressing need and opportunity is adaptation. Both natural and agricultural biomes are already under climatic stresses that will change the long-established geographic patterns of landuse and biotic diversity.

We conclude by suggesting that soil science diversify its climate and sustainability portfolio, with corresponding changes in our research activities and output in societally relevant research. We should push for a more equitable distribution of funding to address these issues, essentially placing our bets in a broader set of activities than the present focus on soil C and its sequestration. Any gains that can be made in sequestering C will be welcome, but this should not cloud the breadth of the challenges ahead.

Acknowledgements This paper, and the special issue of which it is a part, resulted from the participation and enlivening discussion by many in the 2021 AGU symposium "Challenges and Opportunities of Managing Soil Carbon as a Natural Climate Solution."

Funding Amundson received support from the University of California Agricultural Experiment Station and the Betty and Isaac Barshad Chair in Soil Science.

Data availability There is no data generated for this paper.

Declarations

Conflict of interest All authors declare they have no conflicts of interest.

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