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OPINION

Interactive effects of global change drivers as determinants of the link between soil biodiversity and ecosystem functioning

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Abstract

Biodiversity, both aboveground and belowground, is negatively affected by global changes such as drought or warming. This loss of biodiversity impacts Earth's ecosystems, as there is a positive relationship between biodiversity and ecosystem functioning (BEF). Even though soils host a large fraction of biodiversity that underlies major ecosystem functions, studies exploring the relationship between soil biodiversity and ecosystem functioning (sBEF) as influenced by global change drivers (GCDs) remain scarce. Here we highlight the need to decipher sBEF relationships under the effect of interactive GCDs that are intimately connected in a changing world. We first state that sBEF relationships depend on the type of function (e.g., C cycling or decomposition) and biodiversity facet (e.g., abundance, species richness, or biomass) considered. Then, we shed light on the impact of single and interactive GCDs on soil biodiversity and sBEF and show that results from scarce studies studying interactive effects range from antagonistic to additive to synergistic when two individual GCDs cooccur. This indicates the need for studies quantitatively accounting for the impacts of interactive GCDs on sBEF relationships. Finally, we provide guidelines for optimized methodological and experimental approaches to study sBEF in a changing world that will provide more valuable information on the real impact of (interactive) GCDs on sBEF. Together, we highlight the need to decipher the sBEF relationship in soils to better understand soil functioning under ongoing global changes, as changes in sBEF are of immediate importance for ecosystem functioning.

KEYWORDS

biodiversity ecosystem functioning, biodiversity facets, global change drivers, interactive effects, soil biodiversity, soil biodiversity ecosystem functioning

1 | INTRODUCTION

Biodiversity, the most extraordinary feature of life on Earth, supports many essential ecosystem functions, such as food production, carbon sequestration, and nature's contributions to people (Mace et al., 2012). However, global change drivers (GCDs) including climate change and land management threaten biodiversity and its role in providing many essential ecosystem functions (IPCC, 2022). During the last three decades of biodiversity experiments, we have gained

knowledge of the relationship between biodiversity and ecosystem functioning (BEF; Cardinale et al., 2012). One of the first and most influential BEF experiments (Tilman et al., 1996) showed that plant diversity, measured as species richness, enhances plant biomass production. This early research catalyzed hundreds of experimental studies showing that the impact of increasing biodiversity on ecosystem functioning is positive but saturating, a pattern consistent across different groups of organisms, trophic levels, and ecosystems (Cardinale et al., 2012; Isbell et al., 2015). For example, pollination

and seed production was shown to increase, and eventually plateau, with higher pollinator diversity (Fründ et al., 2013). Additionally, an increased biodiversity enhances not only single ecosystem functions but also multiple functions simultaneously (multifunctionality; Hautier et al., 2018; Hector & Bagchi, 2007; Manning et al., 2018; Wagg et al., 2014), as well as the temporal stability of ecosystem functions (Cardinale et al., 2013; Craven et al., 2018; Hautier et al., 2015). The positive BEF relationship is explained by complementarity (of habitat and resource niches), facilitation, and synergies between organisms (Barry et al., 2019; Brooker et al., 2021). Despite evidence for the positive BEF link from various ecosystems and organisms, the largest body of evidence comes from studies assessing aboveground biodiversity impacts (Cardinale et al., 2012; Loreau et al., 2022).

The disbalance in BEF studies is especially evidenced by a limited number of soil BEF (sBEF) studies. For example, Guerra et al. (2020) showed that only 0.3% of 17,186 sampling sites combined data on sBEF. This is concerning given that soils are among the most biodiverse ecosystems on the planet with millions of species of bacteria, archaea, fungi, protists, and animals inhabiting a cubic meter of soil (FAO et al., 2020). In fact, soil biodiversity accounts for an estimated 25% of all species, and an even higher share of carbon bound in life on Earth (Bar-On et al., 2018; Guerra et al., 2020). Soil biota drive pivotal ecosystem functions such as the cycling of carbon and nutrients as well as controlling pests and diseases (Geisen et al., 2019). Similar to aboveground systems, sBEF relationships are often reported to be positive (Delgado-Baquerizo et al., 2020; van der Heijden et al., 1998). For instance, Hu et al. (2016) and Hol et al. (2015) showed that a higher bacterial diversity reduced the growth and density of plant-pathogenic fungi more strongly than a lower bacterial diversity. Soil biodiversity has also been proven to enhance multifunctionality (Delgado-Baquerizo et al., 2017; Hu et al., 2021) and temporal stability of ecosystem functioning (Wagg et al., 2021). Additionally, the reduction of soil biodiversity decreases soil functions, such as nitrogen turnover, C cycling, and decomposition (de Graaff et al., 2015; Handa et al., 2014; Wagg et al., 2014). However, current sBEF experiments are often relatively limited in terms of the diversity facets tested (Hu et al., 2016), mainly with species richness far lower than in natural conditions, or because findings are based on correlations in field surveys (Delgado-Baquerizo et al., 2020). Therefore, we lack a better understanding of how changes in different biodiversity facets are affecting the sBEF relationship, if linear trends are common and if sBEF relationships reach saturation like in aboveground systems (Saleem et al., 2019).

What is already known is that soil biodiversity is shaped by physiochemical properties such as pH, soil moisture, and soil organic matter content (Delgado-Baquerizo et al., 2018; Tedersoo et al., 2014; van den Hoogen et al., 2019). These physiochemical properties might be changed by the influence of GCDs (FAO et al., 2020), here considered as “a human or natural-driven exogenous perturbation that changes abiotic (e.g., temperature, pollution, drought) and/or biotic (e.g., agricultural practices, habitat fragmentation, invasive species) conditions typically occurring as widespread chronic presses”

according to Avolio et al. (2015). Therefore, similar to aboveground organisms, GCDs alter the sBEF relationship mainly via changes in soil biodiversity. For instance, Zhang et al. (2019) showed that warming increased the nitrification process in paddy soils by impacting the abundance of ammonia-oxidizing bacteria and archaea. This effect of GCDs on sBEF via changes in soil biodiversity was also shown in a meta-analysis by García-Palacios et al. (2015), which demonstrated that the effects of warming and N addition on microbial abundances were correlated to changes in ecosystem functions such as plant biomass or C cycling. Still, studies exploring sBEF as affected by GCDs are scarce, partly due to the complexity of interactions as GCDs co-occur in space and time, limiting our understanding of the potential interactive effects of GCDs on sBEF.

Here we examine the sBEF relationship and explain the multiple aspects involved such as ecological functions or biodiversity facets. Furthermore, we illustrate the importance of investigating the effects of GCDs on sBEF by exploring the effect of single and interactive GCDs on sBEF relationships before we provide future directions to optimize methodological and experimental approaches to study sBEF in a changing world.

2 | sBEF RELATIONSHIPS DEPEND ON THE FUNCTION AND BIODIVERSITY FACET CONSIDERED

sBEF relationships are context-dependent as they show variability across environmental conditions (Eisenhauer et al., 2019) or depend on the ecosystem functions under investigation. For example, Wagg et al. (2014) showed that ecosystem functions, such as carbon sequestration or phosphorus leaching, correlate differently with the complexity of soil biodiversity, with trends ranging from positive linear to negative exponential. Only when sBEF relationships were integrated with multiple ecological functions, Wagg et al. (2014) found an overall positive linear relationship between soil biodiversity and ecosystem multifunctionality. In addition to function-specificity, sBEF links also depend on the biodiversity facet considered (species richness, activity, functional & phylogenetic diversity, biomass, and abundance [Figure 1a]). In this paper, these facets represent the variation of traits in a soil community which could have an impact on ecosystem functions and we refer to them as the following: Species richness as the number of species present in a given soil community; activity as the level an organism is performing its function(s), being important to distinguish between active and inactive and their asynchrony (Craven et al., 2018). Functional diversity as the diversity of organisms or groups of organisms performing different functions (such as place in the food web or process performed in the nutrient cycle); phylogenetic diversity is a generic term for a measure of phylogenetic distances between species; abundance is the number of individuals belonging to a given taxon; biomass, which can be related to abundance, as the grams of C, N, or P stored in soil organisms per unit of soil. We acknowledge that biomass can be considered both a function or facet of biodiversity. If the focus is BEF with comparable

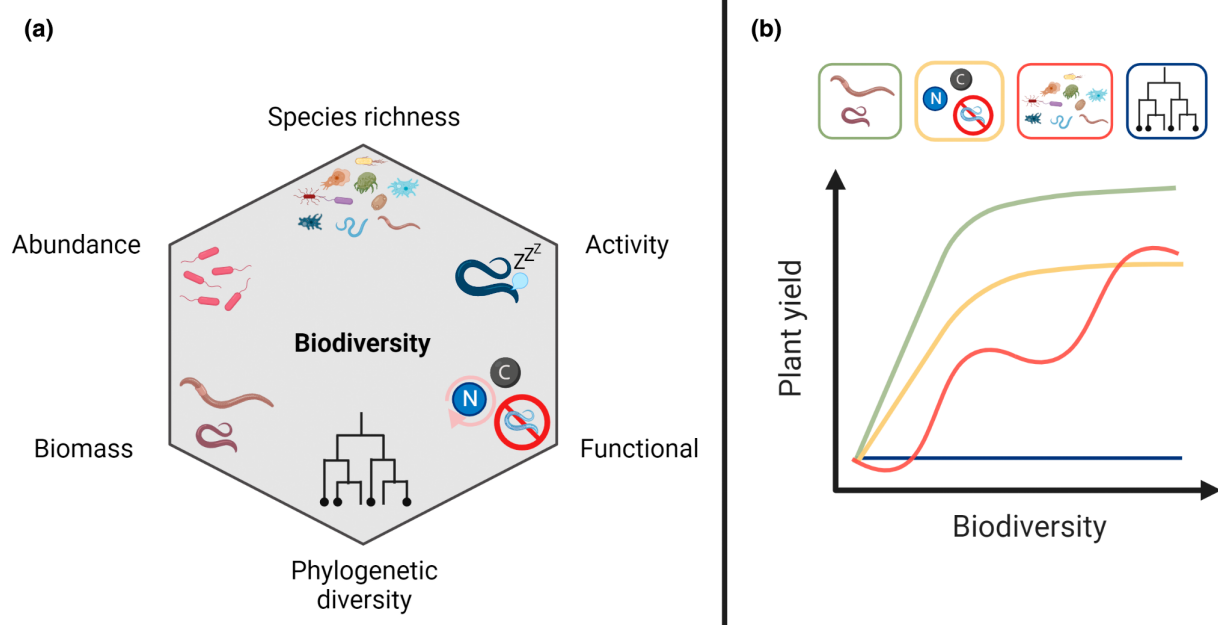


FIGURE 1 (a) Conceptual illustration of the different facets of soil biodiversity that underlie soil biodiversity and ecosystem functioning (sBEF). (b) Hypothetical representation of the sBEF link depending on the biodiversity facet considered. The icons on top are related to the functions depicted by having the same color and are the same as in (a), representing biomass, functional diversity, species richness, and phylogenetic diversity as four different biodiversity facets.

species (e.g., in size) as often in plant BEF studies that control for species identity and manipulate richness, biomass is considered a function. However, when species are not comparable in terms of size or traits, biomass might play a key role in delivering ecosystem functions. Soil ecologists commonly study microbial biomass as a biodiversity facet independent of species richness as it drives changes in ecosystem functions such as the cycling of C and N (see i.e., Singh & Gupta, 2018; Walker et al., 2018). Therefore, we here treat all biodiversity facets independently through their potentially unique role in affecting ecosystem functions (Figure 1b).

Currently, most studies investigating sBEF relationships focus on species richness (Coleman & Whitman, 2005; Delgado-Baquerizo et al., 2020; Fraser et al., 2015; Saleem et al., 2019). This limits our understanding on the importance of sBEF relationships. For example, Zhou et al. (2020) and Singh and Gupta (2018) showed that microbial biomass rather than species richness most strongly determined microbial functioning, soil fertility, and ecosystem productivity. Apart from species richness and biomass, other facets such as abundance, phylogenetic diversity, or functional diversity have also been shown to impact, for instance, stability of ecosystem functions or litter decomposition (Beaumelle et al., 2020; Craven et al., 2018). In addition, biodiversity facets do not always positively link to ecosystem functions. For example, Pérez-Valera et al. (2015) showed that the phylogenetic diversity of bacteria was negatively related to ecosystem functioning, as few productive and functionally important clades outcompeted other groups. Another possible pattern is the absence of an enhanced functioning with increasing biodiversity, as shown by Hu et al. (2016), where soil bacteria richness did not impact soil multifunctionality in soils with high aridity. sBEF

relationships might also be non-linear and, in fact, likely are never perfectly linear. This deviation from the theoretically linear relationship originates from differences in the functional effect-size performed by different taxa that is never identical. The most extreme cases for deviations from non-linear relationships are keystone taxa with a disproportionately strong effect (Banerjee et al., 2018) and functionally redundant taxa that occupy the same niche (e.g., nutrients, space; Saleem et al., 2019). These patterns are well known especially from plant BEF studies with, for example, studies showing that functional redundancy is of vital importance to maintaining ecosystem functioning across climate gradients (Robroek et al., 2017). Thus, and due to a profoundly higher biodiversity in soils compared with aboveground systems, functional redundancy as a mitigator of negative impacts induced by GCDs is likely common in soils.

3 | IMPACTS OF SINGLE GCDs ON SOIL BIODIVERSITY AND sBEF

Physicochemical properties that shape soil biodiversity change over time in response to environmental fluctuations, such as those induced by GCDs (Kostin et al., 2021; Simon et al., 2020). Therefore, sBEF relationships are determined by GCDs, mainly as a result of their impact on soil biodiversity (Figure 2). Due to the complexity of soil biodiversity, current studies investigating the impacts of GCDs on sBEF mostly focus on the species richness of a few taxonomic groups of soil biodiversity (mainly bacteria and fungi) (Barrett et al., 2008; Lesaulnier et al., 2008; Ma et al., 2018; Peguero et al., 2021; Rillig et al., 2019; Treseder, 2004), or specific functions

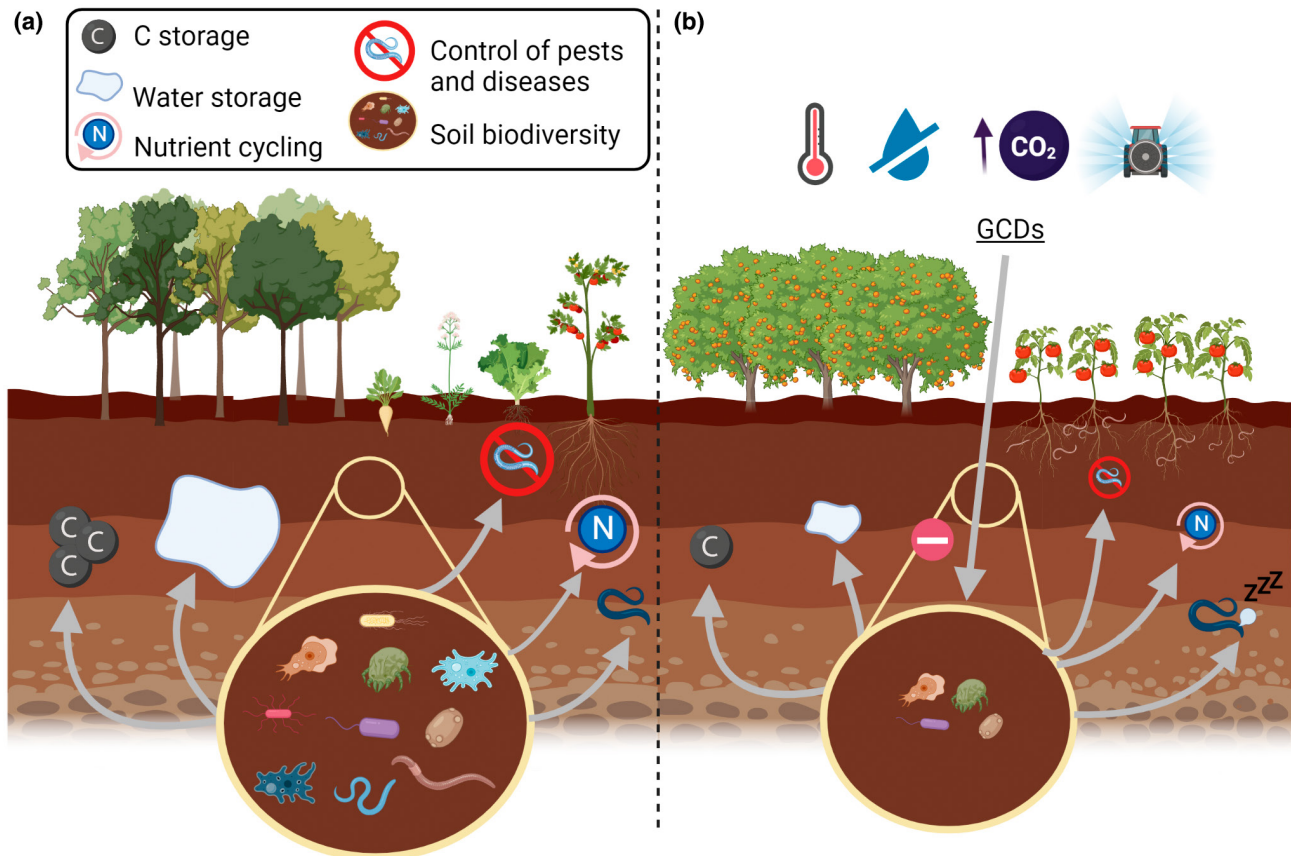


FIGURE 2 Conceptual figure of links between soil biodiversity as underlying several key ecosystem functions (a) and how a decrease in soil biodiversity, driven by global change drivers (GCDs) (here exemplified by higher temperature, drought, CO₂ increase, and land-use-derived methods), lower a given function (b). Symbol sizes represent the conceptual magnitude of a given ecosystem function (C storage, water storage, etc.). Changes in plant species from (a) to (b) represent land use intensification as GCDs. Note, that the concept of soil biodiversity and ecosystem functioning is not that a given function is or is not performed by soil biodiversity, but that there is a clear link between a change in soil biodiversity and the magnitude of the corresponding function.

(mainly biogeochemical processes as litter decomposition or C and N cycles) (Hou et al., 2016; Mueller et al., 2013; Zhou et al., 2019). Arguably the dominant GCD affecting soil biodiversity and, therefore, likely sBEF is drought, as most soil biota are water-bound (bacteria, archaea, protists, nematodes; Schimel, 2018). As such, many studies show a negative impact of drought on sBEF, including reduced carbon and nutrient cycling, as well as decomposition rates that are largely driven by the reduction of microbial biomass and activity (Chomel et al., 2019; Schimel, 2018). Similarly, land use and management, such as the use of pesticides, might compromise ecosystem functioning by negatively affecting the abundance of different soil organisms (Karas et al., 2018) and, consequently, ecological functions, such as decomposition and nitrogen cycling (Chagnon et al., 2015; Cycon & Piotrowska-Seget, 2015; Gan & Wickings, 2017; Handa et al., 2014). However, GCDs do not only negatively affect sBEF. Warming, for instance, can enhance the cycling rates of N and other nutrients by increasing the abundance and activity of microorganisms and their nematode consumers (Ma et al., 2018; Mueller et al., 2016; Siebert et al., 2019). Another example is the facilitation of C cycling under increased CO₂ through an increase in microbial biomass and activity (Lesaulnier et al., 2008).

4 | IMPACT OF INTERACTIVE GCDs ON sBEF

Despite the important insights gained on the impact of individual GCDs on sBEF relationships, individual GCDs occur in synergy with other GCDs in a changing world. For instance, warming directly affects other climatic GCDs, such as stimulating drought by accelerating water loss in soils (Schimel, 2018; Wu et al., 2022) and CO₂ levels by catalyzing the C cycle (Mahecha et al., 2010). The coupling of GCDs minimizes insights gained from distinct GCD studies on sBEF. Therefore, studies investigating multiple GCDs on the sBEF relationship are needed. The few existing studies show that interactive effects can be summarized in three patterns (Figure 3) according to Crain et al. (2008): (1) *additive*, where the interactive effect is the sum of both individual effects; (2) *synergistic*, where the interactive effect is stronger (positive or negative) than the sum of the individual effects; (3) *antagonistic*, where the interactive effect is weaker (positive or negative) than the sum of the individual effects.

Examples that these patterns apply for sBEF are mostly lacking, but some examples describe these interactive patterns on soil biodiversity or ecosystem functions separately, such as the following: (1)

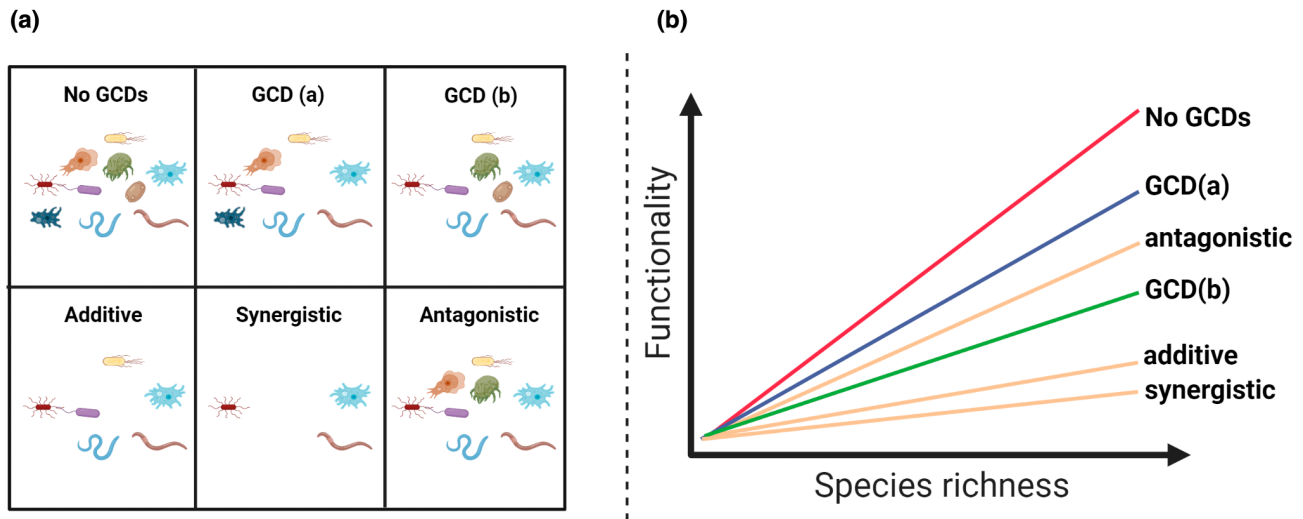


FIGURE 3 Conceptual representation of the effects of interactive global change drivers (GCDs) (here named GCD [a] and GCD [b]) on soil biodiversity, using the example of species richness (a), and the effect that this change in biodiversity has on soil biodiversity and ecosystem functioning (b). Furthermore, the three possible scenarios of interactive effects (yellow functions) are represented in comparison with the scenarios depicting a single GCD's effect (GCD[a] in blue and GCD[b] in green) as well as with the scenario without GCDs acting (red function).

Zhou et al. (2019) showed an additive effect of grazing and warming on soil respiration (ecosystem function). Here, the negative effect of grazing was canceled out by the individual warming-induced increase in soil respiration. This additive result might be linked to changes in soil biodiversity as it is known that grazing modulates microbial communities by reducing dominant taxa of bacteria and reducing soil carbon, therefore reducing microbial respiration (Eldridge et al., 2017), while warming stimulates N availability and microbial respiration (Waqas et al., 2021; Zhou et al., 2012). (2) In the same study, Zhou et al. (2019) also detected a synergistic effect between warming and increased precipitation on soil respiration. In this case, warming ($+2.12 \pm 1.03\%$) and increased precipitation ($+13.44 \pm 2.30\%$) had a positive effect on soil respiration while their interactive effect showed a stronger positive response ($42.49 \pm 4.78\%$) than the sum of both effects. The positive effect of warming on sBEF is usually dependent on soil moisture, as the positive link can turn negative under drought, accelerating the desiccation process and reducing the species richness and abundance of microbial communities among others (Sheik et al., 2011). However, the combination with increased precipitation, which tends to enhance plant biomass, therefore likely maximizing soil C cycling (Flanagan et al., 2002; Liu et al., 2016), could be the explanation for a synergistic effect. (3) The interaction of warming and elevated CO_2 triggered an antagonistic effect on bacterial diversity (Yang, Chen, et al., 2021; Yang, Li, et al., 2021), as warming and elevated CO_2 separately increased bacterial diversity but the combination of both GCDs decreased bacterial richness. As the authors suggested, this pattern could have resulted from a local drought induced by the combination of elevated CO_2 and warming that reduced microbial diversity, which likely impaired ecosystem functioning. This result is similar to the one shown by Li et al. (2022), who did a meta-analysis of 1071 observational data of different GCDs and their effects on microbial communities both functionally

and in terms of species richness. In this study, microbial richness did not show a general pattern under warming, but increased with CO_2 , while the interaction of both GCDs negatively affected microbial richness. These changes were related also to ecosystem functioning as the interaction of the same GCDs (warming and CO_2) had an additive effect on the abundance of genes related to C cycling, drawing a clear effect of interactive GCDs on sBEF.

5 | GUIDELINES FOR SBEF STUDIES IN A CHANGING WORLD

5.1 | Synthesis of current experimental designs to uncover sBEF relationships under interactive GCDs

Effects of GCDs on sBEF are investigated through observational or manipulative studies (Saleem et al., 2019; Figure 4). Observational studies follow temporal or spatial sampling schemes that correlate biodiversity and functional measures with physicochemical parameters (Arai et al., 2018; de Vries et al., 2013; Saleem et al., 2019). The spatial method consists of studying different sites which show variation in both biotic and abiotic parameters as affected by GCDs (de Vries et al., 2013) and/or represent presumably different stages of a system under given GCD conditions (space-for-time) (Damgaard, 2019). The advantage of observational studies is that natural and diverse environments are covered, being closer to representing the full biodiversity present in soils, as well as complex patterns of interactive GCDs, which would be impossible to mirror in a manipulative experiment. However, the tight connection and co-occurrence of GCDs, and the near endless biodiversity in soil that is never possible to study even close to its full extent, especially under non-controlled natural conditions, explains why many

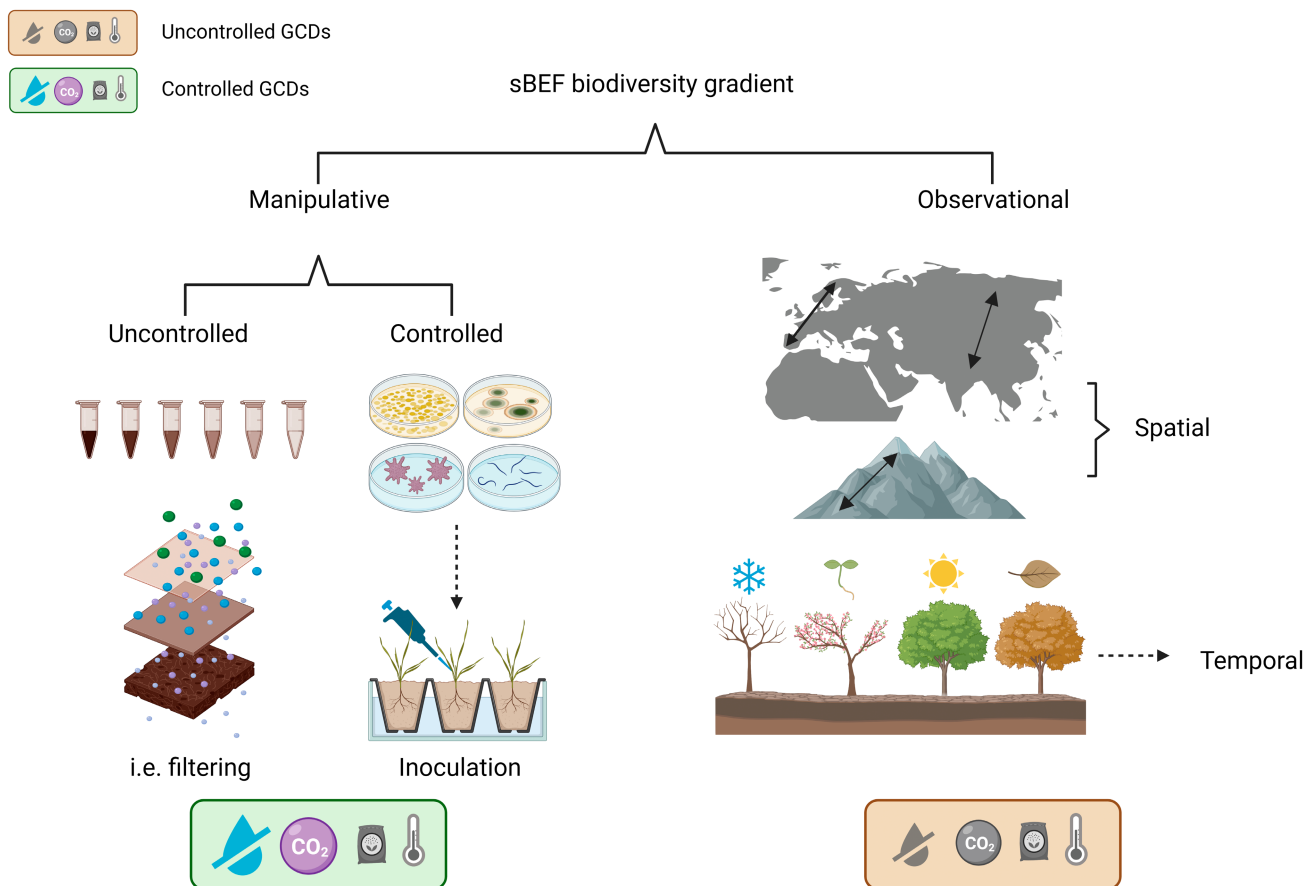


FIGURE 4 Scheme representing the two ways to test soil biodiversity and ecosystem functioning (sBEF) relationships through biodiversity gradients. An observational method by performing space-for-time or temporal sample collection where global change drivers (GCDs) and soil biodiversity are not controlled (right side of the scheme); or in a manipulative way where biodiversity gradients can be created (left side of the scheme) with techniques that reduce biodiversity in a largely uncontrolled way such as extinction by dilution or filtering, or in a controlled way by creating a synthetic community. Furthermore, with manipulative experiments, GCDs can also be controlled by changing abiotic/biotic conditions creating an artificial environment where (interactive) GCDs' effects on sBEF can be tested.

studies simultaneously target several GCDs without disentangling the effect of individual ones on sBEF. As a result, causal relationships of given GCDs on the sBEF relationship cannot be obtained from observational studies (Eisenhauer et al., 2016). For the same reason and the lack of sBEF studies under GCDs, the outcome of interacting GCDs on sBEF can currently not be predicted to be additive, synergistic, or antagonistic.

Manipulative studies aim to test the sBEF relationship by creating diversity gradients and inducing this to different GCDs in the field or the greenhouse/laboratory (see Peguero et al. 2019 for an example). While plant scientists can manipulate several biodiversity facets, such as species richness, functional trait diversity, or abundance, to field-like levels in their experiments (i.e., Reich et al., 2004; Tilman et al., 1996), soil biologists deal with orders of magnitude higher levels of biodiversity including all its facets. Therefore, targeted manipulations are difficult and approached in multiple ways. The most common way to assess soil biodiversity gradients is a partly random biodiversity reduction via dilution, fumigation, or filtering that removes rarer, more susceptible, and differentially sized soil taxa (i.e., Griffiths et al., 2000; Hol et al., 2010; Wagg et al., 2014).

The resulting biodiversity change can then be subjected to different GCDs. The advantage of these approaches is that a large proportion of soil biodiversity can be retained in the controls and even in the respective reductions. However, these protocols cannot mechanistically test sBEF relationships as the entire complexity of soil biodiversity, including various biodiversity facets, is changed, leaving mostly correlative links with the measured parameters.

Biodiversity can also be altered by creating synthetic communities such as in large plant BEF studies (e.g., Cedar Creek and Jena experiment; [Barnes et al., 2020; Tilman et al., 2006]), and test sBEF relationships under different and controlled GCDs. For instance, Geisen et al. (2021) created a synthetic community consisting of 16 species of bacteria and fungi and three different concentrations of protists. After the creation of the synthetic community, they measured litter decomposition and carbon cycling under two different temperatures and detected that protists enhanced both litter decomposition and CO₂ release under lower temperatures. The advantage of creating and inoculating these communities under individual and interactive GCDs is that biotic and abiotic conditions are mechanistically controlled, enabling to

draw causal links between sBEF and GCDs. However, we have to keep in mind that mirroring the entire soil biodiversity is impossible due to its vast species richness as well as the inability of culturing the great percentage of soil species with current techniques (Amann et al., 1995).

5.2 | Guide for future approaches

Here we propose the following to fully disentangle the sBEF relationship under the effect of (interactive) GCDs. First, if the aim is to compare our sBEF results with the available literature, we should standardize biodiversity facets across studies. When comparing with plant BEF studies, this metric should be species richness (observed or estimated, such as through Chao1 indices), as it is the equivalent of measuring the species diversity of plants. Thanks to high-throughput sequencing approaches soil biodiversity is routinely taking into account other biodiversity facets like abundance, biomass, or phylogenetic diversity using indices like Shannon, Simpson, or Unifrac (Lemos et al., 2011; Poisot et al., 2013). The selection of these indices might have an impact on the resulting sBEF relationship. As there is no optimal biodiversity facet (Díaz & Malhi, 2022), the use of multiple diversity measurements within and beyond sequencing approaches is highly encouraged to integrate different biodiversity facets to provide a more complete overview of potential sBEF relationships. In terms of biodiversity gradient, we suggest increasing the focus of sBEF studies on controlled experimental setups by implementing synthetic soil communities. Although this method lacks being representative of the immense richness of biodiversity present in soils, a more realistic community composition can be arranged by mirroring the species or taxonomic group's percentage of certain communities described in the literature. Furthermore, replicates in different biodiversity levels should be assembled with a random mix of species if richness is targeted to focus the result on the actual biodiversity facet that is manipulated (see Geisen et al. (2022) for an example).

While creating and inoculating synthetic communities is feasible, keeping the diversity levels constant during the experiment is a difficult task, especially when working with soil microbes that are often airborne and fast dispersers (de Groot et al., 2021). One option could be the use of chambers that possess air and water filters, preventing any colonization and keeping the system sterile such as done by Wagg et al. (2014, 2021). Alternatively, changes in the community driven by contaminations (e.g., by microbial spores and cysts from the air or water) can be assumed to be random across an experimental setup. As these contaminations will occur only over time, we expect that priority effects of the manipulated biodiversity gradient are likely prevailing as shown before (Debray et al., 2021; Dickson et al., 2012; von Gillhausen et al., 2014). Only the effect size and the chance of false-negative results are increased, making any potential biodiversity effects even stronger and, therefore, more relevant.

Other aspects to consider are the functions to be measured. We acknowledge that measuring soil biodiversity functions might be

among the most challenging aspects in a given study. The selection of ecosystem functions to be measured has to be made depending on the question addressed and the system studied. These ecosystem functions are mainly grouped into those related to plant performance and the biogeochemical cycling of elements. The first one, plant performance, embeds all types of plant responses to changes in soil biodiversity and GCDs, ranging from plant production (e.g., biomass or yield; Zhuang et al., 2021) or plant physiology (root architecture or above-belowground mass ratio; Franco et al., 2020) to plant resistance against pathogens (plant health, such as based on disease symptoms; Catella et al., 2021; Hu et al., 2016) and defense gene expression under abiotic or biotic stresses (Hao et al., 2011; Huang et al., 2019; Sun et al., 2011). The second group of ecological functions, the biogeochemical cycling of elements, is mainly focused on nutrient cycling, litter decomposition, and GHG emissions. Nutrient cycling and litter decomposition can be measured by investigating the content of the main nutrients in the soil, such as C, N, or P (in their different molecular forms) and changes in the mass of the elements and overall litter biomass (García-Palacios et al., 2021; Handa et al., 2014; Yang, Chen, et al., 2021; Yang, Li, et al., 2021). Another option to test the biogeochemical cycling of elements is by labelling and following nutrients in soils to detect changes in nutrient routes caused by GCD-driven soil biodiversity alterations (Cui et al., 2018). In terms of GHG emissions, the most common way to obtain measurements is by calculating fluxes of CO₂, N₂O, and CH₄ (Lubbers et al., 2013; Zhang et al., 2021). Similarly, the choice of tested GCDs should be based on the most important factors in a given system which can differ depending on the questions being asked or problems being addressed. For example, salinization is highly relevant in coastal regions, while drought is more important in continental regions predicted to receive less precipitation. We believe that this standardized sBEF set up together with the addition of interactive GCDs will provide more reliable sBEF relationships under GCDs and will allow standardizing data and knowledge, similar to those currently performed in the global network FACE in plant science (https://facedata.ornl.gov/global_face.html).

In conclusion, we highlight the current near-absence of knowledge on the effect of interactive GCDs on the various responses of sBEF that we show can be overcome with more targeted, multifaceted manipulative experimental setups. To be able to better predict changes in sBEF as induced by GCDs we urgently need to work together to increase our knowledge which we envision to be most approachable in interdisciplinary collaborative projects. With our guides, steps towards better understanding sBEF relationships in response to GCDs can even be started to be approached by individual scientists.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

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

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