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The options of different actor groups to address drivers of soil biodiversity change

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Abstract

Soil biodiversity change is the consequence of a broad range of direct and indirect anthropogenic drivers. Understanding these drivers and the options to address them is essential for sustainability. However, evidence especially on indirect drivers of soil biodiversity change is scarce and limited. In this paper, we synthesize the available evidence on direct and indirect drivers with a focus on Germany. Building on this overview, we outline the roles played by three broad groups of actors – land users and land owners, policy makers and administration as well as consumers, citizens and civil society – in the context of soil biodiversity change. We use this evidence to propose options for action that are available to each group of actors. We conclude by arguing that, given the role of soil biodiversity as the invisible foundation of all terrestrial ecosystems and the associated complexity of the challenge, a concerted effort across actor groups is likely necessary to effectively address and protect soil biodiversity.

Keywords biodiversity change | collective action | environmental change | soil biodiversity | soil governance | soil policy | soil protection | stakeholders

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1 Introduction

Public attention towards biodiversity change and its consequences for human well-being exhibits a strong aboveground bias – most initiatives, protests and campaigns focus on well-known, visible, charismatic species: tigers, elephants, rhinoceros, wolves, honey bees (Courchamp et al. 2018, Eisenhauer et al. 2019, Phillips et al. 2017). They all live above the ground. This is the case even though the (ant) lion's share of terrestrial species live below ground (Anthony et al. 2023). Notwithstanding, soils are very much part of the global trend of rapid biodiversity change; and while the details of soil biodiversity's contributions to human well-being are still to be settled, it is pretty clear that these contributions are substantial (Creamer et al. 2022, Kleemann et al. 2025).

Soil biodiversity change is affected by a myriad of drivers, direct and indirect ones. Behind most of these drivers stand human agents (Phillips et al. 2024) – often without knowing it, people make everyday-life decisions that have consequences for soil biodiversity. Halting and reversing negative trends of soil biodiversity change requires (i) understanding how different groups of human agents (or actors) drive them and (ii) identifying options to change the relevant behaviours (Eisenhauer et al. 2024). The options are likely to operate at different levels, from individual consumption decisions to collective action, institutions and governance systems (including e.g. policies, but also social norms). In the following, we will speak of "actors" (and "actor groups") rather than "agents" or the quite common "stakeholders". This choice is deliberate, as it puts emphasis on action and agency, which are not necessarily characteristics of all "stakeholders" (who may be quite passively affected, yet still "holding stakes"). In that sense, "actors" are a subset of "stakeholders" with substantial action space.

Social science perspectives on soil biodiversity are generally scarce and usually focus on particular contexts and challenges, mainly related to its various beneficial effects for crop production (Droste et al. 2020, Phillips et al. 2020, Plaas et al. 2019, Scherzinger et al. 2024, Sidibé et al. 2018, Weituschat et al. 2022). In this paper, we provide a somewhat broader, interdisciplinary perspective: we identify main drivers of soil biodiversity change, the actor groups associated with them, their relationships to soil biodiversity change and the options for action available to them. We use Germany as a case study. This article is based on parts of the German biodiversity assessment, the *Faktencheck Artenvielfalt* (Wirth et al. 2024), and the authors are most familiar with Germany. Given that governance systems and actor constellations are usually specific to a given country or region, focusing on a specific country allows for a level of detail that would be difficult to achieve at a higher spatial level. Also, given Germany's size and geopolitical importance (at least within the European Union), we consider it an interesting and relevant case also in more general terms. We focus mainly on agricultural, forest and urban soils, as these three land uses make up ca. 90% of the German land area (Statistisches Bundesamt, 2023). We then build on this overview of drivers to outline and characterize three major actor groups that (have the potential to) affect the state of soil biodiversity via different drivers. We suggest their options to address the identified drivers and to contribute to improving the state of soil biodiversity. We hope to demonstrate the multitude of human impacts on soil biodiversity, while also sketching ways for their management by pointing to the different kinds of options available. We do so especially by distinguishing between individual and collective action.

2 Direct and indirect drivers of soil biodiversity change in Germany

Drivers of soil biodiversity refer to any factors that can directly or indirectly cause a change in soil organisms. Anthropogenic factors or processes that go beyond the regulatory effect of natural biological, chemical and physical factors on individual species, communities of organisms or entire ecosystems are regarded here as direct drivers. Direct drivers influence biodiversity and ecosystem processes in an unmediated manner and are also referred to as "pressures" (Phillips et al. 2024). Indirect drivers are drivers that operate more diffusely by altering and influencing direct drivers as well as other indirect drivers and are therefore regarded as "underlying causes" (IPBES 2019).

2.1 Direct drivers

Direct drivers can be differentiated e.g. based on their mode-of-action or their nature (biological, physical or chemical; Rillig et al. 2021), their effect direction (positive, negative; Rillig et al. 2021), the effect duration (Phillips et al. 2024) or the impacted ecological scale (Rillig et al. 2024, Simmons et al. 2021). They may affect the entire soil biota simultaneously and homogeneously, or gradually via food chains as a cascade effect (Rillig et al. 2021). Such classification systems facilitate an understanding of the underlying driver mechanisms; yet, in reality, an interaction of drivers can often be observed with potential synergistic influences, making it difficult to analyse each effect separately (Rillig et al. 2019). Keeping this in mind, we will summarize in the following the current state of knowledge of direct drivers on soil biodiversity using the IPBES categorization (IPBES 2019) with slight modifications for Germany as case study to accommodate its specificities (see Wirth et al. 2024).

2.1.1 Changed landscape structure

Changes in the landscape structure (e.g. removal of landscape elements) can increase the soil's susceptibility to erosion and thus indirectly influence soil biodiversity. Erosion has a negative impact on soil biodiversity through the loss of habitat (EEA et al. 2024). Aboveground measures, such as the creation of landscape elements (agroforestry, hedges), reduce the risk and intensity of erosion and thus contribute to the protection of soil biodiversity (Le Provost et al. 2021). Estimates show that small landscape elements have the potential to reduce water erosion in Germany by 1.1% (Syrbe et al. 2018). Landscape fragmentation is generally considered an important driver of biodiversity, as it changes habitat quality, patch size and connectivity (Grilli et al. 2015, Kiesewetter & Afkhami 2021, Vannette et al. 2016).

2.1.2 Land-use change and resource exploitation

A change in land use, e.g. conversion of grassland to arable land or drainage of peatlands, can change the amount of organic carbon bound in soils (Emde et al. 2024, Leifeld et al. 2020). This has direct consequences for the food supply of soil organisms and thus leads to changes in biodiversity and food webs. Moreover, land-use change (e.g. the drainage of peatlands or use of heavy machinery) has consequences for physico-chemical conditions in the soil, which can lead to changes in species composition, with ambiguous net effect on soil biodiversity (Frouz et al. 2010, Wu et al. 2017). European and global studies have shown that conversion from other land uses to arable land had a strong impact on the soil microbiota (Finn et al. 2023, Szoboszlay et al. 2017).

The intensity of agricultural management (e.g. tillage, application of fertilizers and pesticides, crop rotation, machinery traffic) also influences soil biodiversity as it changes e.g. soil structure or nutrient availability (Phillips et al. 2024). Tillage reduces the abundance and diversity of many different soil biota (de Graaff et al. 2019, van Capelle et al. 2012). Extensive management, e.g. integration of cover crops, mixed cropping and diverse crop rotations, generally have a positive effect on soil biodiversity (Scherber et al. 2010, Venter et al. 2016, Filser et al. 2025, in this issue).

In addition, soil sealing and soil compaction, especially of importance in urban areas, can lead to a reduction in soil biodiversity (Ferber & Eckert 2020). Partly due to the lack of vegetation, and consequently reduced carbon storage, evapotranspiration and water infiltration rates, microbial activity (Piotrowska-Długosz & Charzyński 2015) and earthworm populations (Pižl et al. 2009) are negatively affected.

2.1.3 Pollution

Soils are an accumulation site for various types of organic and inorganic pollutants introduced by agriculture, transport, industry, waste disposal etc. Numerous pollutants are persistent to virtually non-degradable under environmental conditions (e.g. per- and polyfluoroalkyl substances (PFAS), microplastics). Organic pollutants that are degradable in soils include e.g. many pesticides, pharmaceuticals, cosmetics and industrially used chemicals. However, the effects of the many pollutants on soil biodiversity are largely unknown as their fate depends on both soil and pollutant properties (Rillig et al. 2019) and might be temporally delayed or indirect due to changes in vegetation, such as herbicide application.

Contamination with microplastics has been shown to lower microbial biodiversity in soil and to enrich pathogen and antibiotic resistance genes (Rillig et al. 2024, Wei et al. 2022). Pesticide residues can be detected in many conventionally and organically farmed arable soils (Riedo et al. 2021). Due to their residence times and various release routes, pesticides can have substantial impacts on soil biodiversity. Meta-analyses have shown that over 70% of the considered biological parameters for soil invertebrates are negatively affected by pesticides (Gunstone et al. 2021) and that pesticides reduce the abundance and diversity of soil fauna (Beaumelle et al. 2023).

2.1.4 Climate change

Possible effects of climate change on soil biodiversity include a change in soil temperature and moisture affecting habitat conditions for soil life. For Germany, only a few studies about springtails, earthworms, small annelids and millipedes are available (Daghighi et al. 2017, David 2009, Plum & Filser 2005). Importantly, the interaction of climate change with other drivers leads to both amplification and buffer effects. For example, negative consequences of agricultural intensification can be amplified by climate change (e.g. increased soil erosion due to localised heavy rainfall events or a combination of dry spells and wind), which can lead to changes in soil properties and thus impact soil biodiversity and multifunctionality (Bartkowski, Schepanski, et al. 2023; Sünnemann et al. 2023). The strength of the combinatorial effect of climate change and land use depends on the respective soil organism group (Gruss et al. 2023, Siebert et al. 2020, Sohlström et al. 2022) and the buffering capacity of the soil (Phillips et al. 2024, Singh et al. 2019). Extreme weather events like droughts, which are predicted to become more frequent due to climate change, are likely to pose a significant threat to soil biodiversity (FAO et al. 2020, Phillips et al. 2024).

2.1.5 Invasive, non-native species

Organisms can be introduced into soils intentionally (e.g. biocontrol agents) or unintentionally (e.g. through nurseries) and can become invasive if they establish and out-compete local and indigenous species for natural resources (IPBES, 2019). The data available on invasive species in soils, particularly fungi, bacteria, archaea and protists, is very limited, which is partly due to technical limitations in detecting and identifying such invasive species compounded by the lack of baseline data. For example, invasive soil fungi are usually recorded when forming conspicuous fruiting bodies (Dickie et al. 2016) or when causing diseases in plants. Possibly as a result of climate change and global action, more and more reports of invasive flatworms and plant pests in soils have emerged in recent years (IPPC Secretariat 2021, Justine et al. 2014).

2.2 Indirect drivers

The impacts of indirect drivers on soil biodiversity have not yet been well investigated. Therefore, causal relationships between indirect drivers and observed changes in soil biodiversity are still unclear. In the following, we will discuss the indirect drivers that might be relevant for soil biodiversity with focus on Germany. We will use the IPBES classification into (i) political and legal drivers, (ii) economic and technological drivers and (iii) sociocultural drivers (IPBES 2019), with some slight modifications regarding specific drivers. Note that some drivers span multiple categories – for instance, consumption patterns, which we included under sociocultural drivers, has also a strong economic component (by determining prices of e.g. food products).

2.2.1 Political and legal drivers

German legislation started explicitly considering soils and soil fauna only ca. 30 years ago. The Federal Soil Protection Act of 1998 was essentially limited to prevention of harmful soil changes and the need to remediate contaminated and abandoned sites. The draft of the National Biodiversity Strategy 2030 recognized the importance of soil organisms for ecosystem functions and services and formulated specific goals and measures to promote soil awareness, active unsealing and monitoring of land use and soil biodiversity. It also aims to limit land consumption to less than 30 hectares per day by 2030, while by 2050, no further net land should be used for settlement and transport purposes (BMUV 2023).

In Europe, soil biodiversity and soil ecosystem services have so far hardly been considered in biodiversity assessments and therefore receive little attention in current nature conservation policy (Guerra et al. 2021). According to a recent study in which nature conservation areas across Europe were compared with unprotected environmentally similar areas, no significant improvement in soil-related ecosystem functions was found (Zeiss et al. 2022).

At the European level, soil protection has gained importance since 2019 in the context of the European Green Deal (Montanarella & Panagos, 2021), even though soil biodiversity continues to be included rather implicitly (Köninger et al. 2022). In 2021, the EU adopted a new Soil Strategy, announcing a Soil Health Law and, from 2023, a legal framework for the allocation of humus certificates as a climate protection instrument (EC 2021, Paul et al. 2023). In 2023, the European Commission presented a draft for the Soil Monitoring and Resilience Law (EC 2023). Overall, while progress has been made in recent years, the explicit consideration of soil biodiversity, particularly beyond strategic policy documents, remains rare.

2.2.2 Economic and technological drivers

Technological progress (e.g. precision and smart farming) can have an indirect influence on soil biodiversity, both in positive and negative terms (Techen & Helming 2017). There are interactions with other economic sectors, e.g. energy production: the switch to renewable energy sources can have substantial impacts on soil biodiversity, e.g. in the cases of bioenergy (with changes in direct drivers associated with agricultural management) or photovoltaics, which can lead to changes in soil temperature and water availability (Chen et al. 2025). This is also to be expected due to the increasing sealing of soils as a result of the growing demand for residential and industrial space (Geisen et al. 2019). The transport sector contributes to climate change through the emission of greenhouse gases (and thus has an impact on the soil), but it also has more direct soil effects e.g. due to increases in soil sealing or pollution through the use of pesticides, salt for deicing or tyre abrasion (Ding et al. 2023). Economic and technological drivers strongly interact with political drivers as well as sociocultural drivers (particularly consumption patterns).

2.2.3 Sociocultural drivers

Soils are often seen as an abundant resource. As a result, they have so far received little attention from the public or in urban and infrastructure planning, with the consequence of progressive soil degradation and associated soil loss. The loss of soil cannot be reversed in the short term, as soil formation is a very slow process (ca. 1 cm per 100 years in Central Europe; EEA et al. 2024). Strengthening society's soil awareness is challenging as the importance of soil biodiversity and the rationale for its protection is much more difficult to communicate than in the case of other environmental compartments and their biota, because the respective impairment is neither obvious nor can it be communicated via the endangerment of "charismatic" organisms (Courchamp et al. 2018, Eisenhauer et al. 2019, Phillips et al. 2017). Despite slowly growing awareness of the sustainability consequences of consumption patterns, they remain relatively persistently unsustainable (Humpenöder et al. 2024, Nielsen et al. 2021, Sun et al. 2022), which in the context of soils implies, for instance, consumption of food from intensive agriculture or of wood from unsustainable forestry.

3 Actor groups, their competing interests and action spaces

Behind the drivers relevant in the context of soil biodiversity change, there are many different groups of actors and decision makers (Figure 1). The identified groups are broadly in line with the actor groups referred to by IPBES (Chan et al. 2020). They differ in terms of agency, interests and their "proximity" to soil biodiversity. Moreover, none of the groups is homogeneous – internally, they differ in how their members behave and what drives them (e.g. Bartkowski et al. 2022, Ficko et al. 2019). Nonetheless, some general patterns can be identified across groups.

Soil biodiversity provides many different benefits (Bardgett & van der Putten 2014, Delgado-Baquerizo et al. 2020, Scherzinger et al. 2024, Ruess et al. 2025, this issue, Kleemann et al. 2025). Most of them can be considered public goods (Bartkowski et al. 2018), i.e. it is difficult or impossible to exclude anyone from the benefits they provide (e.g. climate regulation or flood protection).

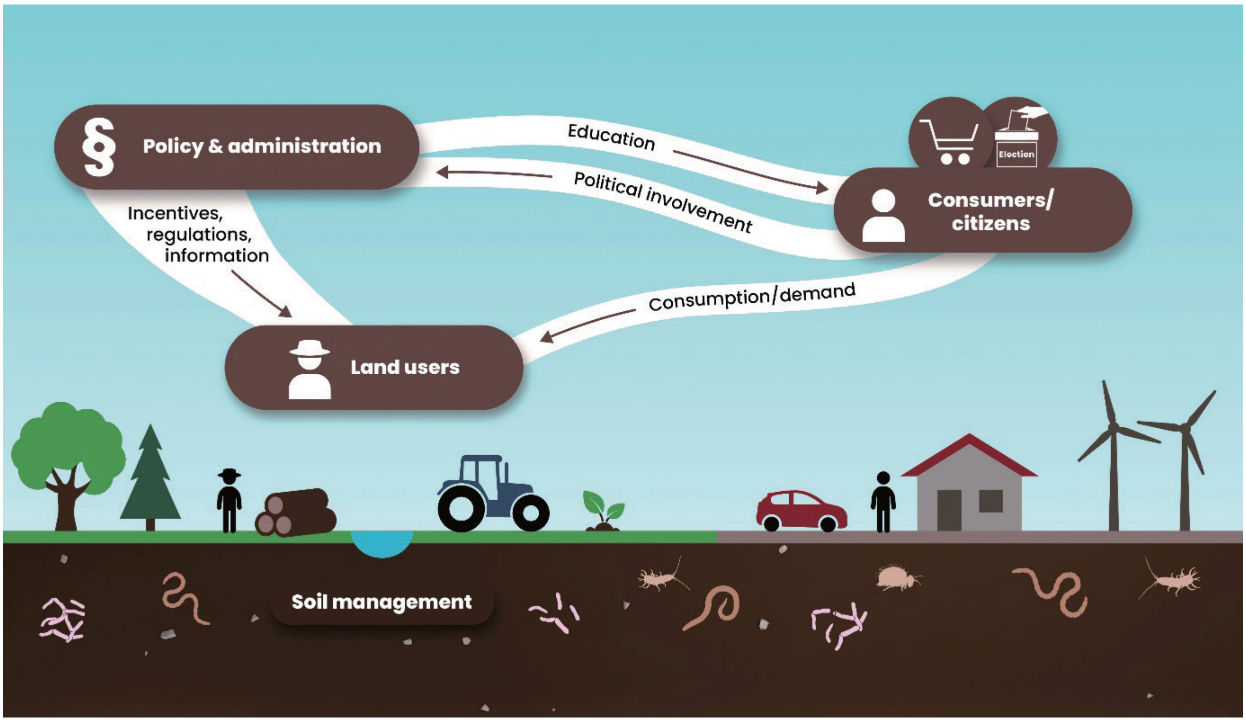

Figure 1. Overview of main relevant actor groups in the context of soil biodiversity change (adapted from Wirth et al. 2024)

The provision of public goods is prone to free riding and social dilemmas, which provides a strong rationale for collective action, including state intervention (Ostrom 1991, Samuelson 1954). While individual behaviour change plays an important role in solving sustainability challenges (Nielsen et al. 2021, 2024), many actions will require changes in the governance system (political and legal drivers) affecting soil biodiversity. This general point should be kept in mind when interpreting our analysis of the different actor groups.

The actor group that interacts with soil biodiversity most directly is land users, particularly farmers and forest users (in Germany, agricultural land makes up ca. 50% of the surface area, forests add another ~30%). Their main interest is in extracting biomass (crops, grass, wood) from the land they use and manage. This implies a plausible interest in permanently good soil quality (a private good), though this interest may vary depending on whether they actually own the used land (Leonhardt et al. 2019) – in Germany, more than 60% of agricultural land is rented rather than owned by the farmers (Jänicke & Müller 2024). In that sense, there are at least two groups that decide how land is used and managed – in a rather stylized sense, short-term, day-to-day management decisions are made by land users (e.g. farmers), whereas more long-term decisions (e.g. conversion of arable land to grassland or the introduction of permanent landscape elements such as hedges) are usually made jointly by land users and land owners (Bartkowski, Beckmann, et al. 2023). The action spaces of many land users are rather strongly constrained – in the case of farmers, this is mainly due to their very limited market power, dependence on regional infrastructure (e.g. specialized storage facilities) and natural variability (weather, pests etc.) (Gütschow et al. 2021). This can impair their ability to act upon their own preferences or intentions (Byfuglien et al. 2025). In the case of forestry management, the long planning horizons and associated delay between investments in management changes and returns on those investments are an important decision-making factor (Hoogstra & Schanz 2009). In both cases, an important constraint is the availability of investment funds, as many management changes beneficial for soil biodiversity (e.g. to reduce soil disturbance and compaction) involve investments in new machinery (Techen & Helming 2017).

Many different actors have an intermediate influence on land and soil use by setting the constraints within which land users operate, but also by offering them support. These actors include public agencies, planning authorities, advisory services and political decision makers at different levels (municipalities, counties, federal states, countries and European Union [EU]). They can be broadly summarized as “policy actors”. The main challenge for these actors is the multiplicity of demands they have to consider in their decisions; currently, soil biodiversity does not play a large role here (Köninger et al. 2022). As outlined above, soils in general and soil biodiversity in particular are underrepresented in public and political perception, although this seems to be changing, as exemplified by the EU’s Soil Mission, Soil Monitoring Law and the ongoing reform of the Bundesbodenschutzgesetz (Federal Soil Protection Law) in Germany. Nonetheless, it is these actors who define the action space of and provide incentives for land users that then translate into how land is managed, with the associated consequences for soil biodiversity. The explicit consideration of belowground biodiversity is crucial here, as it has been shown that protection of aboveground biodiversity does not necessarily “trickle-down” to belowground biodiversity (Zeiss et al. 2022, see next section).

The third, rather heterogeneous group of actors are consumers, whose everyday consumption decisions are highly relevant for how soils are managed, although their impacts are quite indirect and these actors are often not aware of them (Xylander 2020). Especially in the context of agrifood systems, their decisions are moreover mediated and to some extent influenced by intermediaries such as retailers or processing industry (Williams et al. 2023). As a group, consumers have a substantial influence on soil management by means of their demand for different products, including particularly food and wood-based products, but also mobility or housing. Especially as owners of houses and gardens, consumers can also be considered land users, though at a relatively small scale (settlement areas make up less than 10% of Germany’s area). However, since they are not organized, this influence is highly decentralized and diffuse, which leads to social dilemmas, as the decisions of any individual consumer have a negligible impact on soils and soil biodiversity. At the same time, most consumers are at the same time citizens and thus voters – in that sub-role, they exhibit a somewhat higher degree of organization and leverage. They have a strong interest in the public goods provided by intact, biodiverse soils; but they also have an interest in consumption activities that result in pressures on soil biodiversity.

In this context, the last actor group is relevant – civil society, i.e. those who do or could make soil biodiversity and its impacts of human well-being more salient in the public discourse, education and possibly also individual decision making. This group encompasses diverse actors such as universities and schools, media, non-governmental organizations (NGOs) and lobby groups, which inform consumer-citizens, bundle their interests and actions and therefore may also influence policy actors.

In the next section, we will introduce options for action that each of the four introduced actor groups have. We consider consumer-citizens and civil society jointly, as these two groups overlap and interact particularly strongly.

4 Options for action

Each of the following groups can affect a different subset of the drivers of soil biodiversity change, as introduced in section 2. The decisions of land users and land owners mainly affect direct drivers; policy makers and administration have a major influence on political and legal drivers as well as, indirectly, on economic and technological drivers, sociocultural drivers and, even more indirectly, on climate change. Consumers, citizens and civil society play a role particularly in the context of sociocultural drivers, but have also an indirect influence on the other indirect driver categories, mainly by driving the demand for different products and by exercising their right to vote and voice their political opinions.

4.1 Land users and land owners

The evidence regarding options for action of land users is probably the most abundant and clear (Filser et al. 2025, this issue). Effectively, it boils down to a minimization of soil disturbance through the reduction of soil management intensity (e.g. conservation tillage in agriculture), avoidance of soil sealing and soil compaction as well as substantial reduction of pollution (e.g. from pesticides or microplastics) (Phillips et al. 2024).

In the agricultural context specifically, the conditionality requirements of the Common Agricultural Policy already provide a set of minimum standards. However, since these have not been formulated with soil biodiversity in mind, they need to be complemented by further, site-specific actions. These include management changes to increase soil organic carbon levels and strengthen integrated pest management to reduce pesticide application (Filser et al. 2025, this issue). Trade-offs need to be considered in this context (Schröder et al. 2020). For instance, a reduction in tillage intensity may well increase weed pressure, the conventional countermeasure to which would be an increase in herbicide application (Böcker et al. 2020; Filser et al. 2025, this issue). While the most common broadband herbicide, glyphosate, has not been found to impact soil biodiversity negatively (Beaumelle et al. 2023), empirical evidence is scarce, and its negative impacts on other environmental components, especially aquatic ecosystems, are better established (Annett et al. 2014, Hendlin et al. 2020), making this trade-off relevant for land management decision making. This is particularly important given the strong linkage between soils and aquatic systems (both surface and groundwater).

Land owners who do not manage their lands themselves are in the particular position of imposing soil-biodiversity-friendly management as part of land rental contracts. Such management actions can be considered to be in the land owners' self-interest, as they increase the long-term quality of the soil, and therefore the land's value in land markets – particularly so under climate change conditions (Hamidov et al. 2018, Stetter & Cronauer 2025).

A group with a relatively high action space (due to limited market pressures associated with their use of soils) is land owners in human settlements – garden owners, communal enterprises etc. For these, extensive recommendations are readily available for Germany (e.g. UBA 2019, see also FAO et al. 2020), which include abstaining from the use of pesticides, vegetation-free "gravel gardens" or introduction of non-native species that are considered invasive. In the context of private and commercial construction activities, a central recommendation is the minimization of soil sealing and, wherever possible, unsealing (UBA 2021). These recommendations are also relevant for local administrations that manage public green spaces.

4.2 Policy makers and administration

Soil biodiversity is relevant across habitats and is affected by different policy sectors (e.g. environment, forestry, agriculture, water, urban policy), which need to be coordinated and coherent (Köninger et al. 2022). This requires clear objectives and indicators, consideration of all relevant drivers, and the design of suitable policy instruments (Bartkowski et al. 2021). In this context, the Soil Monitoring Law of the EU might be a first important step, though it still misses an implementation component. With respect to nature conservation, the recognition that soil biodiversity does not have the same requirements as aboveground biodiversity (Zeiss et al. 2022) implies the need to rethink conservation concepts in a way that they also address soil biodiversity (Guerra et al. 2022). Similarly, land-use policies that aim at biodiversity protection of managed land (agriculture, forestry) need to adopt a more explicit soil biodiversity lens (Köninger et al. 2022). Here, the Nature Restoration Regulation of the EU also has made first steps, e.g. by including soil organic carbon levels as an indicator for agricultural lands (see also Basile-Doelsch et al. 2020). At the same time, soils in general and soil biodiversity specifically are largely absent from policy frameworks aiming at implementation and incentivization of sustainable land management, particularly the Common Agricultural Policy of the EU (Bartkowski et al. 2021, Köninger et al. 2022). To effectively protect soil biodiversity, which may well include long-term benefits to land users (Scherzinger et al. 2024), it needs to receive a more explicit attention in the design and implementation of land-use policies. In this context, an explicit consideration of trade-offs, also across policy sectors, is essential – e.g. when calls for the "valorization" and use of "crop residues" for the purposes of a bioeconomy (Brosowski et al. 2016, Hamelin et al. 2019, Szarka et al. 2021) may entail substantial reductions in biomass input into soils. Addressing this may require a rethinking of the sourcing of feedstocks for bioeconomy-related processes. Conversely, given the overlap between management practices beneficial for soil biodiversity (Filser et al. 2025, this issue) and practices attractive to farmers in terms of climate change adaptation (Stetter & Cronauer 2025), the need to adapt to climate change may create a window of opportunity for soil biodiversity protection and, more generally, incentives for more multifunctional land use (Eisenhauer et al. 2024).

4.3 Consumers, citizens and civil society

In their roles as consumers and citizens, everyone has the possibility to exert indirect influence on land users with respect to the protection of soil biodiversity: through voting, participation in public discourses and consumption choices. However, there are limits particularly to consumption as a means of improving soil biodiversity. First, the protection of soil biodiversity is a public good, which makes it susceptible to social dilemmas (the influence of individual consumption choices is negligible and, in the absence of formal or informal coordination and institutions, irrelevant) (Ostrom 1991, 2009, Samuelson 1954). Second, given the complex causal chain that links e.g. food consumption choices with soil biodiversity impacts, consumers lack important information about the effects of their choices. The common approach to address this problem is the use of labels - however, due to the proliferation of labels on consumption goods, only few particularly well-established levels are likely to be able to effectively convey decision-relevant information (Asioli et al. 2020). The sustainability claims associated with labels and certification schemes, including soil-relevant ones such as organic farming or soil carbon certificates, remain contested (Meemken & Qaim 2018, Paul et al. 2023). On the other hand, reduction in the quantity of consumed goods, including food waste (Alexander et al. 2017), can alleviate the pressure on ecosystems, including soil biodiversity. Similarly, shifts in diets, e.g. through substitution of plant-based proteins (whose production has positive effects on soils; Filser et al. 2025, this issue) for animal-based proteins, is also an option with beneficial effects on soil biodiversity, among other environmental objectives (Treu et al. 2017, Willett et al. 2019).

In their role as members of the civil society, consumer-citizens can furthermore exert pressure on policy makers and administrations by requesting policy changes along the suggestions made in section 4.2. Civil society is a driver of raising awareness of the importance of soil biodiversity, pushing it more on the agenda of political and land-use decision making. Also, in some cases, civil society organizations (such as foundations or churches) are land owners and can therefore enforce rules about how their land is managed (see section 4.1).

5 Conclusions

In this paper, we provided an interdisciplinary perspective on the role of different actor groups (land users and land owners, policy makers and administration, consumer-citizens and civil society) in addressing direct and indirect drivers of soil biodiversity change. Given the limited awareness of the importance of soils in general and soil biodiversity in particular, there is substantial room for action at different levels. The options for action available to each actor group are strongly interlinked, which is mainly due to the multi-level relationships among the different drivers. Since many functions and benefits provided by soil biodiversity are public goods, there is a need for coordination of collective action, notably through policy. At the same time, individuals – both land users and consumers – have options to contribute to the protection of soil biodiversity within their respective action spaces. Ultimately, given the role of soil biodiversity as the invisible foundation of all terrestrial ecosystems and the associated complexity of the challenge, a concerted effort across actor groups is likely to be necessary to address it and to protect soil biodiversity effectively.

Due to the scarcity of research from social sciences focusing on soils, let alone soil biodiversity, many of the insights discussed in this perspective piece are based on indirect evidence from related fields (e.g. research on farmers' or consumers' behaviour in other areas). To properly understand the drivers of soil biodiversity change, the determinants of relevant actors' behaviour and their options for action, there is a need for much more targeted research from social sciences and humanities into these questions (Eisenhauer et al. 2024). This likely implies strengthening the role of social science and humanities in national and EU funding programmes (Mission Soil Board 2024).

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