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POLICY BRIEF

How soil biodiversity can strengthen resilience and ecosystem services in agricultural landscapes

Main findings

- Soil biodiversity supports a wide range of ecosystem services including yield stabilization over time, control of soil pathogens, and improved resilience of crops exposed to water defecits or other climatic stresses.
- Soil biodiversity influences crop properties beyond productivity, e.g. nutrient and antioxidant profiles of a range of crops, spoilage and water loss potential.
- Despite this, the benefits of soil biodiversity are often not well recognized and thus undervalued by the agricultural sector.
- Improving soil biodiversity can be challenging. Soil biodiversity responses to management practice and factors like drought are highly variable and site-specific, but cover crop duration, crop termination method and crop diversity generally increase soil biodiversity.
- The EU aims to have 25% of farmland in organic management by 2030; organic farming has an overall positive effect on above-ground biodiversity. There is also strong evidence for positive impacts on soil fauna diversity, although responses are less predictable for larger soil-dwelling organisms.

Key policy recommendations

- **Consider soil biodiversity as a stand-alone aspect of soil health** and provide **incentives for farmers to ensure better soil protection** and strengthened provision of soil-driven ecosystem services.
- Look beyond yield to support **long-term joined up thinking** that prioritises aspects of soil health and soil biodiversity management to ensure **longer-term resilience**.
- Support locally adapted implementation plans that respect environmental variability, to complement implementation of continent-wide objectives and policies through the revised Common Agricultural Policy (CAP) and New Green Deal.
- Effectively **integrate production and conservation considerations** and ensure that agricultural policy provides win-wins for both ecosystem services associated with soil biodiversity and the economy.

Context

There is widespread understanding that the needs of both crop production and soil conservation must be combined in order to effectively maintain soil health within cropping systems. In practice, this means balancing long-term, stable, high crop productivity with environmental sustainability of essential soil ecosystem functions such as soil fertility, water quality regulation, biodiversity conservation, and integral stability and support. The importance of **physico-chemical properties** such as soil structure and nutrients are essential drivers of soil health processes and sustainable fertility is well established and widely monitored among land managers. But the significance of **biological properties** such as soil biodiversity and activities[1] have only more recently been recognised. Soil biota, including animals, fungi and bacteria, plays a key role in agroecosystem functioning. It is involved in the processing of organic matter, breakdown of chemical inputs, soil aggregation, biocontrol of crop disease, and reduction of nutrient losses. However, comprehensive knowledge on how different agricultural practices and climate change may impact soil biodiversity remains scarce.

This policy brief considers the results of several **BiodivERsA-funded research** projects funded under the 2015-2016 Call for Proposals (www.biodiversa.org/922) in the context of how they can inform the debate surrounding the EU Green Deal and the CAP post 2020. Specifically, in terms of restoring and conserving soil biodiversity, delivering essential ecosystem services, and ensuring resilience of yield variability to climate change. It specifically builds on results from research projects SoilMan, Digging-Deeper, and SOILCLIM.

Key results

Crop management and drought can have positive or negative influences on soil biodiversity

There is strong evidence that climate change and anthropogenic disturbances may not have a consistent effect on soil biodiversity, i.e. they can increase or decrease soil biodiversity according to a range of factors, supporting the argument for locally adapted approaches to agricultural management.

Assessment of drought induced changes in abundance, activity and diversity of soil organisms in wheat fields across four European countries demonstrated that different groups of soil organisms responded quite differently to drought conditions. Drought led to reduced decomposition activity in temperate (German, Swiss and Swedish) soils, but not in drier Spanish fields, suggesting that soil fauna in semi-arid regions are more adapted and resilient to the lack and variability of rainfall[2].

In addition, abundance of arbuscular mycorrhizal fungi (AMF) responded positively to drought in both conventionally and organically managed wheat plots[3]; AMF benefit agricultural crops: they help plants to capture nutrients from the soil via a close symbiotic relationship in which plant roots are penetrated by the fungi, which also stretch out into the surrounding soil. Soil bacterial communities exhibited relatively high resistance to drought conditions[4]. AMF are beneficial to agricultural crops; they have a symbiotic relationship with plants whereby they penetrate crop roots and help plants to capture nutrients from the soil.

Diversity at undisturbed, natural sites was a significant indicator of AMF diversity at adjacent sites subject to anthropogenic disturbance (e.g. intensive agriculture)[5]: in undisturbed plots where AMF diversity was high, fungal diversity levels in adjacent undisturbed plots was lower, but where AMF diversity was low then disturbed plots had higher AMF diversity.

These results show that studies focusing on just one management practice may not capture the reality of an agricultural field (where fertilization, agrochemical use, tillage and cropping can occur simultaneously), and that multiple management practices should be considered when assessing impacts on AMF communities[6].

1. In this brief the term "soil biodiversity" is a broad concept that encompasses various soil biota groups, microbial communities, soil biota composition, species richness, and the diversity and interactions of different groups of organisms (Rillig and coworkers, 2018).
2. Meyer and coworkers 2021
3. Kozjek and coworkers, 2021
4. Kundel and coworkers, 2020
5. García de León and coworkers, 2018
6. Rillig and coworkers, 2019

The benefit of soil biodiversity in agro-ecosystems is undervalued

Promoting soil biodiversity is not only a conservation matter, as intact and healthy soils deliver significant economic benefits to EU farmers, producers and associated supply chains. It has been argued that soil organisms support a wide range of ecosystem services that stabilise yields, control soil pathogens and ensure good quality products, whilst at the same time improving the resilience of crops that are exposed to water or other climatic stresses[7].

Further economic support for promoting soil biodiversity exists: the impacts of management practices on soil biodiversity extend to influencing beneficial crop properties such as nutrient or antioxidant profile that in turn reduce postharvest disease, spoilage and water loss [8].

Despite these beneficial effects, soil biodiversity is rarely considered in crop management plans among land managers. Adoption of environmentally friendly soil management practices is primarily influenced by economic considerations; and knowledge of soil biota among stakeholders is largely restricted to earthworms[9].

Crop management has a greater positive impact on soils than crop diversity

While crop diversification (i.e. planting multiple species together in a field) can provide various environmental benefits to European soils[10], the role of **crop management** should not be overlooked. When comparing four aspects of crop management (duration of crop cover; method of crop termination -frost, rolling or herbicide treatment; irrigation at sowing; and increased crop diversity)[11], crop cover had a greater effect in increasing the abundance and total carbon when compared against cover crop diversity.

A study of 155 cereal fields across a 3000 km North-South European gradient found that increased crop cover duration as well as crop diversity had positive effects on soil microbial diversity and yield[12]. These findings suggest that management approaches should also be considered alongside crop diversification in relevant EU agricultural frameworks (CAP and Green Deal) to ensure good soil biodiversity status and resilience, and to safeguard the provision of ecosystem services associated with soil biodiversity.

Organic farming influences soil biodiversity, but is not always beneficial for yield stability

The CAP, Farm to Fork and Biodiversity strategies of the EU's Green Deal aim for 25% of farms to be organic by 2030. Organic farming can increase **overall species richness** compared to conventional farming[13], although there is **significant variation** in response to organic management between soil organism groups. Effects of organic farming on the diversity of larger soil dwelling organisms (e.g. spiders, beetles and pot worms) are often not predictable; in contrast, nematodes, fungi and bacteria are more abundant in long-term organic systems[14].

Organic farming will also need to deliver an EU food production system that is resilient to climatic fluctuations, but it was found that production stability for organic agriculture was significantly lower (−15%) compared to conventional agriculture [15]. These results suggest that policy makers should help in developing a management framework for organic farming that considers soil biodiversity and ensures minimal yield variability, e.g. by promoting soil management tools and the development of resistant crop cultivars.

Wheat production practices: effect on soil biodiversity, opportunities and limitations

Practices in wheat	Effect on soil biodiversity	Opportunities for farmers	Limitations for farmers
Increased duration of crop cover through diversification & extensive rotation	• Increased soil invertebrate richness & microbial diversity[16]	• Less tillage which reduces costs • Reduced soil erosion & need for nutrient fertilization • Rotation breaks host plant-pest cycles	• Reduced ability to grow crops that produce income.
Organic farming	• Positive effects on soil microbial abundance, diversity & microbiome network complexity • No consistent effect on community composition across different taxa[17].	• Beneficial for soil biota & more environmentally friendly • Increased environmental services (e.g. carbon sequestration, reduced soil erosion & ecotoxicity) • Product revenues generally higher	• Organic fertilizers can be difficult to standardize & control • Total yield & yield stability are generally lower
Reduced tillage	• Positive effects on soil microbial abundance, diversity & microbiome network complexity and macrofauna like earthworms. But responses are variable & may be site-specific e.g. among soils with low AMF diversity, anthropogenic disturbance can actually increase fungal diversity[18].	• Positive effect on bulk density, aggregate size & stability, water holding capacity & pH • Reduced farmer time & costs • Benefit from biodiversity services such as reduction of pathogens and toxins in soil, and yield increases.	• Risk of increased weed abundance • Impact variability, e.g. in certain soils can lead to compaction & decreased porosity

7. Meyer-Wolfarth and coworkers 2017; Plaas and coworkers 2019; Wagg and coworkers 2021; van Capelle and coworkers 2021
8. Rillig and coworkers 2018
9. Hervé and coworkers 2020
10. Graf and coworkers 2019
11. Romdhane and coworkers 2019
12. Garland and coworkers 2021
13. Tuck and coworkers 2014
14. Birkhofer and coworkers 2012; Rundlöf and coworkers 2016
15. Knapp and van der Heijden 2018
16. Garland and coworkers 2021
17. Kundel and coworkers 2020, Birkhofer and coworkers 2012
18. Plaas and coworkers 2019; García de León and coworkers 2018

Policy recommendations

Consider soil biodiversity as a stand-alone aspect of soil health and provide appropriate incentives for farmers to ensure better soil protection and strengthened provision of soil-driven ecosystem services.

The Green Deal improves on the CAP in terms of focusing greater attention on soil protection and soil quality. The following recommendations could achieve more promotion of interlinkages between farming activities, soil organisms and natural processes:

- **Promote increased yield resilience to climate change through appropriate management and reduce short-term pressures on the food supply chain** that prioritise immediate production goals over long-term sustainability. E.g. in the short-term there may be trade-offs between crop yield and soil organic carbon (SOC); but in the longer term, SOC increases climate change resilience through higher water holding capacity of soils[19], improved soil stability and decreased yield variability[20].

- **Focus on multivariate assessment of management practice impacts** because they interact. E.g. soils with increased microbial diversity sequester carbon more efficiently and the two interact in a positive loop, with practices that increase soil carbon in turn increasing soil biodiversity[21].

- **Enable locally adapted approaches that allow farmers to adjust decision making** based on variabilities in climate, topography, soil type and crop, and the specific challenges they face. E.g. for SOC and microbial respiration a positive link is observed across all sites studied in EU [22], while responses of AMF communities to human disturbance vary according to local conditions[23].

- **Prioritise increasing crop cover, organic matter and organic inputs and enhanced nutrient use efficiency in farming systems** to build yield resilience and stability. E.g. combining green manure with targeted fertilisation reduces the yield stability gap between organic and conventional agriculture , while keeping in mind that specific measures are highly dependent on local conditions and soil types.

- **Effectively integrate production and conservation considerations to ensure win-wins for ecosystem services and the economy**. Policy makers could utilize existing schemes to promote soil biodiversity e.g. extending the scope of the results-based agri-environment scheme to pay for improvements in soil biodiversity.

- **Research funding could be targeted so that programmes are complementary to each other and can thus contribute meaningfully to successful policy**. Multi-disciplinary, multinational projects such as these funded by BiodivERsA are critical to reinforce the knowledge base on the importance of soil biodiversity in agroecosystem functioning and climate resilience. In addition, the diverse but complementary approaches the projects utilised (research framework to extend the scope of soil biodiversity impacts in Digging-Deeper; soil biodiversity indicators for farmers in SoilMan and modelling future scenarios in SOILCLIM) form the basis of successful implementation and monitoring of policy.

19. Knapp and coworkers 2018
20. Knapp and van der Heijden 2018
21. Domeignoz-Horta and coworkers 2020
22. Garland and coworkers 2021
23. García de León and coworkers 2018

Links to sources

SoilMan project website
Digging-Deeper project website
SOILCLIM project website

Scientific publications used in this policy brief can be found in the Information Sheet of this briefing, downloadable from: www.biodiversa.org/policybriefs

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About this Policy Brief

This Policy Brief is part of a series aiming to inform policymakers on the key results of the biodiversity research projects funded by BiodivERsA and provide recommendations to policymakers based on research results.

The series of BiodivERsA Policy Briefs can be found at www.biodiversa.org/policybriefs.

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The key research results presented here were validated by researchers from the SoilMan, Digging-Deeper, and SOILCLIM research projects.

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