Issue brief

Soil biodiversity management: A cross-system lever for climate change mitigation, ecosystem restoration and agricultural productivity

Understanding the links between soil biodiversity, crop management, and plant performance is essential for assessing the capacity of soils to mitigate climate change and for designing resilient cropping systems. The BiodivClim projects MICROSERVICES[1], GRADCATCH[2], and BIOFAIR[3] identified three key levers for improving soil biodiversity management.

Key Findings

1. Climate-driven shifts in soil biodiversity and function demand targeted responses

- Soil biodiversity and ecosystem functions react differently across climate zones, with drought and aridity posing significant threats. Regions like the Mediterranean are especially vulnerable, where increasing aridification may destabilise nutrient and carbon cycles. Anticipating these changes is essential for proactive soil management and fostering climate resilience. (MICROSERVICES - Europe, GRADCATCH - Europe, Greenland)

- Fungal diversity plays a vital role in maintaining ecosystem stability through its contribution to nutrient cycling. As fungi are particularly sensitive to temperature fluctuations, preserving fungal communities is key to safeguarding ecosystem functions in a warming climate. (GRADCATCH - Greenland, Europe, South Africa)

2. Precision in microbial management is essential for soil health and crop productivity

- More microbes do not always mean more yield. In some cases, higher microbial biomass can limit crop yields by locking up nutrients. Effective management requires moving beyond microbial abundance and focusing on microbial function—particularly those tied to nutrient efficiency. (BIOFAIR - Europe)

- Tailoring soil practices to crop traits and local conditions can enhance productivity. For example, breeding crops with efficient root systems or adjusting organic matter inputs can support nutrient uptake under specific environmental contexts. (BIOFAIR - Europe, GRADCATCH - Greenland, Europe, South Africa)

1. Footnotes can be found in the information sheet.

3. Balancing soil biodiversity, yields, and farming realities

- There are trade-offs between practices that enhance soil biodiversity and those that maximise yields. For instance, while long-term reduced tillage[4] supports microbial communities, it may lead to lower wheat yields in certain contexts. (BIOFAIR - Europe)
- Selecting beneficial microbial traits—such as drought resilience—can enhance crop performance, but strategies must be fine-tuned to specific cropping systems and local environments. (MICROSERVICES -Europe)
- Increased soil carbon does not always result in higher yields. In some systems, microbial competition for nutrients can limit the benefits of carbon-rich soils, highlighting the need for context-aware soil management. (BIOFAIR - Europe)

Context: Why focus on soil biodiversity?

Soil biodiversity both influences and is influenced by climate change. On the one hand, global warming increases the metabolic activity of soil microbes, which in turn boosts greenhouse gas emissions—creating a positive feedback loop where soils may accelerate global warming[5]. On the other hand, climate change disrupts soil microbial functions, biodiversity, and ecosystem performance.

Soil carbon sequestration in croplands and grasslands is increasingly recognised as a key mitigation option[6]. Sustainable farming practices, such as organic farming and reduced tillage, are promoted under the European Green Deal as part of the climate mitigation toolbox.

However, soil health has historically been underrepresented in policy targets[7] and in the monitoring and evaluation of restoration efforts. The EU Soil Strategy for 2030[8] and the proposed Directive on Soil Monitoring and Resilience represent important new strategic and regulatory advances in this regard.

Key results for maintaining soil biodiversity and health

Unravelling the effects of climate change on soil biodiversity and ecosystem functioning

The responses of soil organic carbon and soil microorganisms to climate change are not yet fully understood[9]. In particular, the impact of drought on soil biodiversity and functions remains unclear. To address these knowledge gaps, the **MICROSERVICES** and **GRADCATCH** projects examined the relationships between soil biodiversity, climate, and aridity patterns.

- **Fungal diversity is essential for soil health and ecosystem regulation. GRADCATCH** showed that soil functions are shaped by aridity via soil properties and microbial community structure, with fungal diversity playing a critical role—especially in temperate forests across Europe. A study in the Swiss Alps also revealed that CO_2 fluxes increased with elevation up to the treeline and declined beyond, linked to microbial activity governed by temperature and organic matter. As treelines shift upward with climate change, these dynamics are expected to intensify in mountain soils[10].

- **Agroclimatic zones** (*i.e.*, regions defined by climate characteristics that influence agricultural potential, particularly growing season length and accumulated heat regions) **strongly influence soil biodiversity and multifunctionality**. MICROSERVICES found that future climate conditions could significantly alter soil biodiversity and ecosystem services. For example, increasing aridity in Mediterranean zones could reduce microbial diversity and disrupt carbon and nutrient cycling. As these zones are projected to shift northward, early and proactive climate mitigation is essential to preserve soil functions.

Case study 1: How soil life reacts to climate change around the world.

The **GRADCATCH** project investigated how soil microbial communities respond to climate change across temperature and aridity gradients in Europe, Greenland, and South Africa. These included north–south transects in Greenland and Europe, an elevation gradient in the Alps, and aridity gradients ranging from moist northern Spain to dry southeastern Spain, as well as from humid mountain areas to hot deserts in South Africa.

In **Europe**, they found that fungi in the soil played a key role in keeping important processes like nutrient cycling running smoothly, especially in temperate forests. In the Alps, **soil organic matter** strongly influenced microbial activity and greenhouse gas (GHG) emissions. In the **Iberian Peninsula**, even though the microbial community composition changed as the climate got drier, the soil continued functioning well, suggesting nature has built-in backups—where different microbes perform similar roles

In **Greenland**, the environment was more fragile. Soil in the far north did not cope well with drought. Microbial activity spiked briefly with moderate drying but dropped sharply during more severe droughts, pointing to a tipping point where soil would not function adequately anymore, not providing completely its ecological role in the ecosystem.

In **South Africa's drylands**, microbes are already toughened to extreme heat and dryness, but they may still be at risk. If the region keeps getting hotter and drier, their ability to support plant growth and store carbon could decline—harming the global carbon cycle and local farming.

These findings highlight that soils around the world react very differently to climate stress, depending on their location and current condition.

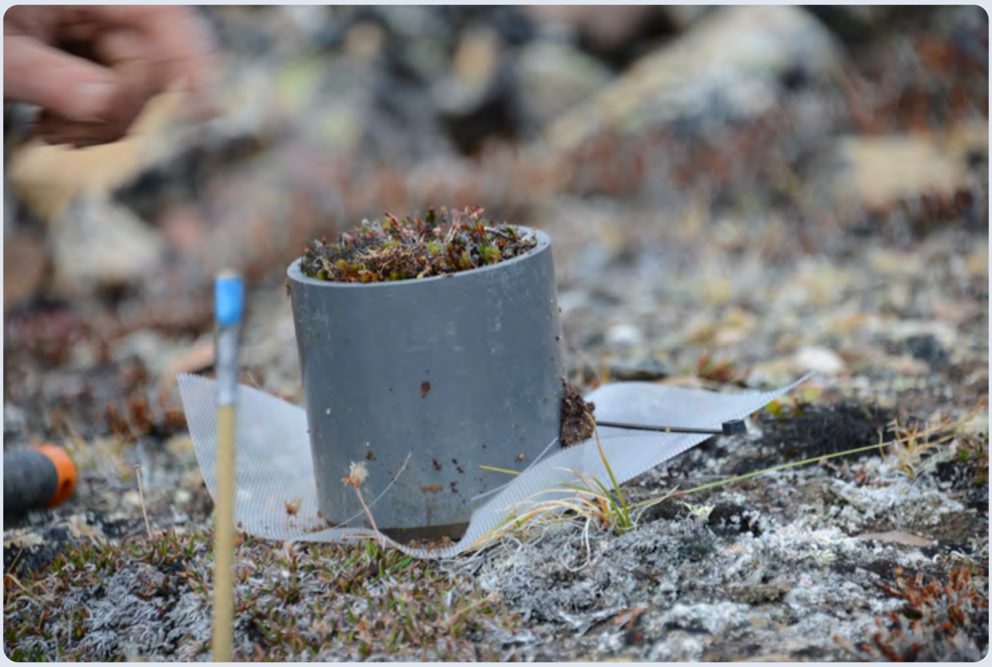


Fig. 1. Soil core extracted near Qaanaaq, North Greenland (Photo credit: Anders Priemé).

Understanding how below-ground microbial processes affect plant productivity

Soil biodiversity supports ecosystem services in agroecosystems through complex, non-linear interactions among many species. Understanding how microbial processes below ground influence plant productivity and nutritional quality can help identify farming practices that protect soil health and conserve key organisms.

The **BIOFAIR** project assessed soil functions, nutrient cycling, greenhouse gas emissions, and microbial diversity at various sites across Europe. It compared soil management strategies and tested future climate scenarios. Key findings include:

- **Biodiversity alone does not guarantee higher productivity**. Functional traits and the complexity of nutrient cycling networks matter more. Soil functions depend more on how organisms interact than on how many different types are present. This means we need to look at what organisms actually do in the soil, not just list which ones are there.
- **Soil organic matter and microbial activity do not always boost yields**. Under future Central European climate conditions, increases in soil organic matter and microbial biomass did not consistently improve crop productivity—likely because nutrients were taken up or immobilised by microbes. Climate-driven changes in water availability may destabilise microbial communities and reduce their efficiency.
- **More microbes can mean lower yields if not managed carefully**. Fields with larger microbial communities (e.g. from no-till or organic amendments) often had reduced grain yields and nutrient uptake. To avoid this, soil management strategies must be fine-tuned. Options include breeding crops with better root architecture to access nutrients, or using cover crops, hedgerows, or agroforestry to support balanced plant-microbe relationships.

Case study 2: How climate change affects wheat and soil life in controlled environment room (CER).

As part of the **BIOFAIR** project, two experiments were conducted to (1) assess the effects of climate change on bread wheat productivity and (2) test soils from Innovative Farming Practices under future climate scenarios to evaluate their ability to conserve sensitive soil taxa and maintain food quality.

Fig. 2. Controlled environment room: Ecotron experiments provide controlled environments to study the impacts of climate change on ecosystems and biodiversity processes (Photo credit: Pierre Delaplace).

In the first experiment, they tested how wheat grows under future climate conditions—like hotter weather, more carbon dioxide, and uneven rainfall. While the plants initially grew more leaves and stems, their roots did not grow enough to keep up. This made them weaker during dry periods later in the season. As a result, they produced fewer grains (lower yields)—but those grains had more protein (nitrogen), so better for nutrition.

The second experiment compared wheat grown in soils that had either been well cared for with organic material or not, under climate conditions expected in the years 2013, 2068, and 2085. In the short term, both soil types gave better yields, but in the longer term, the high-input soils (with lots of past fertiliser or compost use) did worse. Interestingly, some signs suggested the plants were activating natural defences to cope with stress, but their overall nutritional quality still dropped.

Together, these experiments showed that climate change may induce adaptive shifts in microbial communities. Some microbes may thrive, while others disappear—changing how soils function and how well they support crops. Adding more organic carbon to soil will not always improve results in the future, suggesting that we may need to rethink how we manage soil for food production.

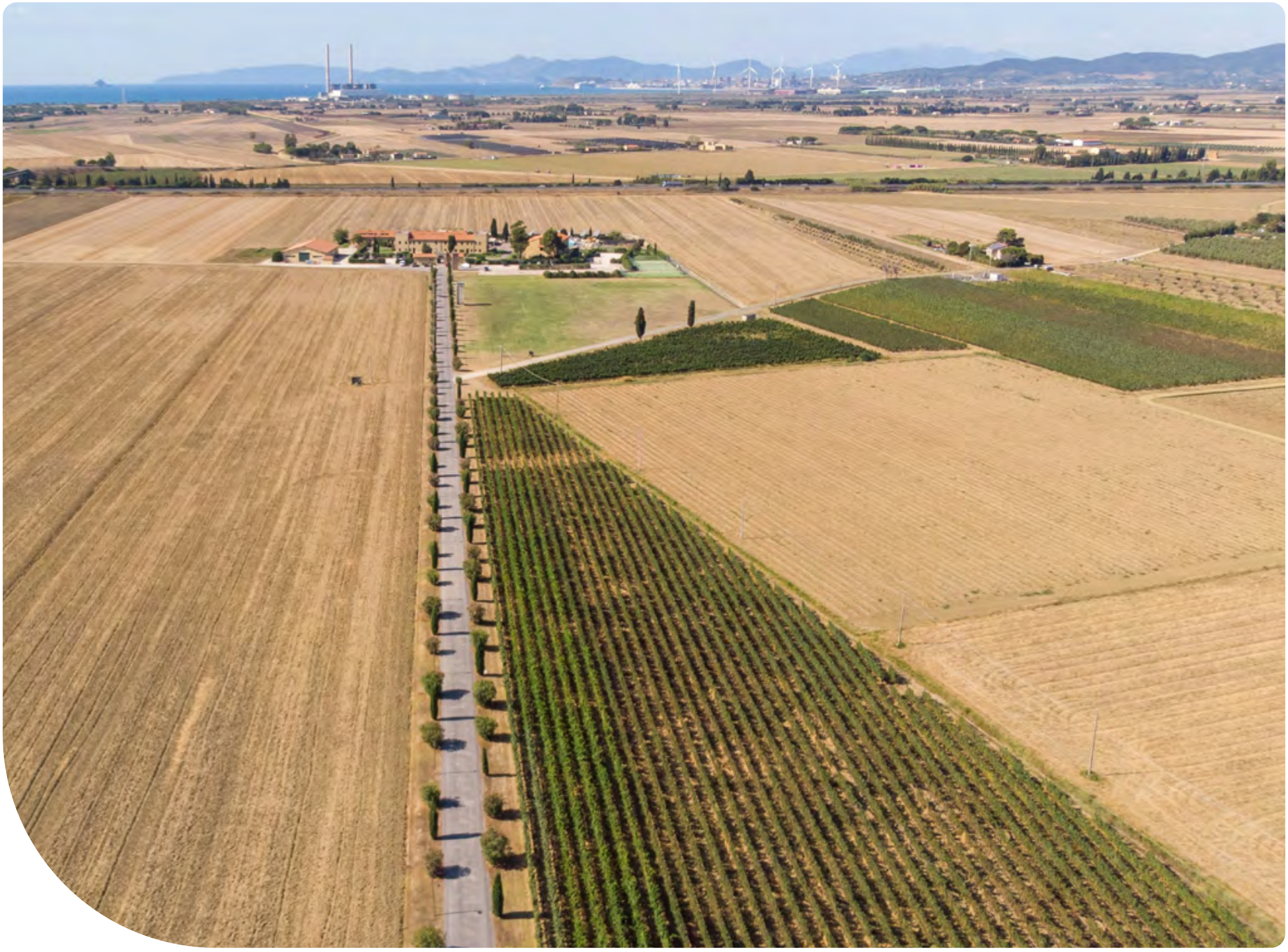
Identifying agricultural practices that support soil health and food security

There are still open questions about how agricultural practices, such as organic or *regenerative farming* - an emerging, holistic approach that promotes soil health and social well-being, while remaining adaptable to local contexts - contribute not just to sustainability, but also to climate change mitigation and resilience to extreme events like drought.

The **BIOFAIR** and **MICROSERVICES** projects investigated how management systems affect soil biodiversity, function, and plant productivity:

- **Soil health benefits vary across systems and sites**. **BIOFAIR** found that the effects of practices like reduced tillage and organic farming depend heavily on soil properties and climate conditions. For example, reducing tillage increased microbial abundance in Spanish soils but showed no clear benefit at a German site.
- **Beneficial microbes and genetic traits that allow crops to cope with stresses like drought or heat vary depending on the type of cropping systems**. **MICROSERVICES** identified key soil organisms and functional genes that promote stress resistance. These varied across cropping systems, highlighting the importance of tailoring practices to local contexts.
- **Carbon-rich systems do not always boost productivity**. While biodynamic and regenerative practices improved soil organic carbon and nutrient cycling, **BIOFAIR** showed that higher microbial biomass can also lead to nutrient immobilisation—reducing nutrient availability to plants due to competition between microbes and crops.
- **Greater belowground biodiversity does not guarantee higher yields**. **BIOFAIR** showed that neither plant productivity nor nutrient uptake improved consistently with increased biodiversity, suggesting a need for deeper understanding of soil-plant-microbe dynamics.

The research reinforces that investing in healthy, stress-resilient soils is valuable under future climate pressures—but success depends on **region-specific soil conservation strategies** that reflect **local ecological conditions**.



Case study 3: How past farming methods shape soils' responses to future challenges.

The **MICROSERVICES** project investigated whether organic agriculture—promoted as a sustainable approach under the European Green Deal—can help build farming systems that are more resilient to climate stressors such as drought. A field-scale drought simulation was conducted in the world's longest-running field trial comparing organic and conventional cropping systems, ongoing since 1978.

Previous research at this site showed that organic systems have higher levels of **soil organic carbon** and **biodiversity**, suggesting greater capacity to buffer drought effects. This experiment assessed seasonal changes in **soil biodiversity** and **soil health indicators** under drought.

They found that drought reduced microbial activity in all systems, and fungi were more affected than bacteria. This went against earlier assumptions that fungi are more drought-resistant. The organisms that live close to plant roots were hit hardest, which could interfere with important underground processes that help plants grow.

Interestingly, even though both organic and conventional systems were stressed by drought, their soil microbes remained quite different from each other. These differences suggest that past farming methods shape how soils respond to future challenges. However, it is still unclear whether these microbial differences will actually help one system bounce back better than the other in the long run.

Fig. 3. Simulation of drought in the DOK long-term field experiment, Switzerland (Photo Credit: Martin Hartmann).

Link to sources

MICROSERVICES
GRADCATCH
BIOFAIR

Scientific publications used in this policy brief can be found in the Information Sheet of this briefing downloadable from: www.biodiversa.eu/policy-briefs/

Photos: Unsplash

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About this Issue brief

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