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Soildiver Agro

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SoildiverAgro

Soil biodiversity enhancement in European agroecosystems to promote their stability and resilience by external inputs reduction and crop performance increase

D7.3- White Paper on Recommendations for EU Policies Updating

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D7.3. WHITE PAPER ON RECOMMENDATIONS FOR EU POLICIES UPDATING

Summary

One of the main objectives of Work Package 7 (WP7) of the SoildiverAgro project is to develop recommendations for updating relevant European Union policies concerning soil biodiversity in agricultural systems. Accordingly, this deliverable (Deliverable 7.3) presents a white paper that:

- Provides a comprehensive analysis of current policies related to soil biodiversity in agriculture.
- Conducts an extensive literature review to compile, contrast, and analyse policy recommendations proposed by other researchers based on studies conducted in European agricultural soils.
- Assesses and evaluates the effectiveness of existing policies in each of the six pedoclimatic regions analysed (Mediterranean South, Lusitanian, Atlantic Central, Continental, Nemoral, and Boreal) in promoting soil biodiversity, while also identifying gaps and the need for new policy measures.
- Based on the results obtained from the 15 case studies conducted across the six pedoclimatic regions within the project—where various sustainable agricultural practices were tested to improve soil biodiversity, reduce inputs, and maintain or increase yields—formulates region-specific recommendations aimed at enhancing soil biodiversity and related ecosystem services.
- Finally, evaluates the feasibility of implementing the proposed policy recommendations and their potential integration into existing legislation.

The findings and analyses presented in this deliverable are expected to support the development and implementation of new policies focused on maintaining and enhancing soil biodiversity, which is essential for ensuring the long-term sustainability and resilience of European agricultural systems.

Deliverable Number	Work Package
D7.3.	WP7_ Development of strategies and tools for sustainable crop management
Lead Beneficiary	**Deliverable Author(s)**
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Type of deliverable	R	Document, report (excluding periodic and final reports)	X
	DEC	Websites, patents filing, press & media actions, videos	
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Dissemination Level	PU	Public	X
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1 INTRODUCTION

Agricultural systems are heavily reliant on fertile soils and high levels of biodiversity to remain productive, stable, and resilient over the long term (FAO et al., 2020). However, the intensive agricultural practices implemented in recent decades—characterized by the extensive use of pesticides and fertilizers, monoculture cropping, and intensive tillage—while yielding significant short-term economic and productive gains, have led to a substantial decline in soil biodiversity (De Graaff et al., 2019). This loss of biodiversity is highly detrimental to soil health, thereby undermining the long-term productivity, stability, resilience, and sustainability of agricultural systems.

Today, it is well established that soil organisms—ranging from beneficial bacteria and fungi to earthworms—play a critical role in sustaining and enhancing key ecosystem services. These services include nutrient cycling, organic matter decomposition, biological control of pests and diseases, soil fertility and productivity, improvement of soil structure, regulation of the hydrological cycle, carbon sequestration and climate regulation, and contaminants remediation, among others (Rehman et al., 2022; Köninger et al., 2022; Robinson et al., 2024). Consequently, it is of paramount importance to implement strategies aimed at conserving and promoting soil biodiversity.

Paradoxically, farmers often lack specific incentives or institutional support to safeguard and enhance soil biodiversity. Traditionally, agricultural policies have not explicitly targeted soil biodiversity, focusing instead on above-ground biodiversity or other environmental issues (European Commission, 2020). In this context, the SoildiverAgro project was conceived to demonstrate how improving soil biodiversity can reduce the need for fertilizers and pesticides while maintaining or even increasing crop yields.

Taking all this into account, the main objective of this deliverable is to develop a white paper that thoroughly examines the current policy landscape and its effectiveness in maintaining and promoting soil biodiversity in agricultural systems. To this end, the report first provides an in-depth analysis of the current European policy context with a specific focus on soil biodiversity, including an assessment of the effectiveness of existing measures. Secondly, an extensive literature review was conducted to compile, contrast, and analyze the policy recommendations proposed by other authors based on research carried out in European agricultural soils.

Thirdly, considering that the SoildiverAgro project tested the effects of various sustainable agricultural practices—such as crop diversification, cover cropping, reduced tillage, organic amendments, the use of biofertilizers (including mycorrhizal fungi and plant growth-promoting bacteria), and integrated pest management—on both soil biodiversity and crop yields across 15 case studies in six pedoclimatic regions of Europe (Mediterranean South, Lusitanian, Atlantic Central, Continental, Nemoral, and Boreal), this deliverable evaluates and discusses the effectiveness of existing policies in each region, as well as the gaps and the need for new policy measures to enhance soil biodiversity.

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Fourth, the report presents and discusses region-specific policy recommendations for each of the six pedoclimatic zones, derived from the results of the experimental work conducted in the 15 case studies. Fifth, it also analyzes the benefits and trade-offs of sustainable agricultural practices that promote soil biodiversity compared to conventional farming practices, along with the current policy frameworks relevant to these practices and the emerging policy needs based on the project findings.

Finally, the report examines the barriers and opportunities for the implementation of the different policy recommendations and explores their potential integration within the Common Agricultural Policy (CAP) and other European Union initiatives.

The policy analyses and discussions presented in this white paper, along with the policy recommendations formulated at both the European level and for each specific pedoclimatic region, are expected to contribute to the integration of soil biodiversity considerations into agricultural policies at both regional and EU levels.

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2 WHITE PAPER

White Paper on Recommendations for *EU Policies Updating*

Soildiver Agro

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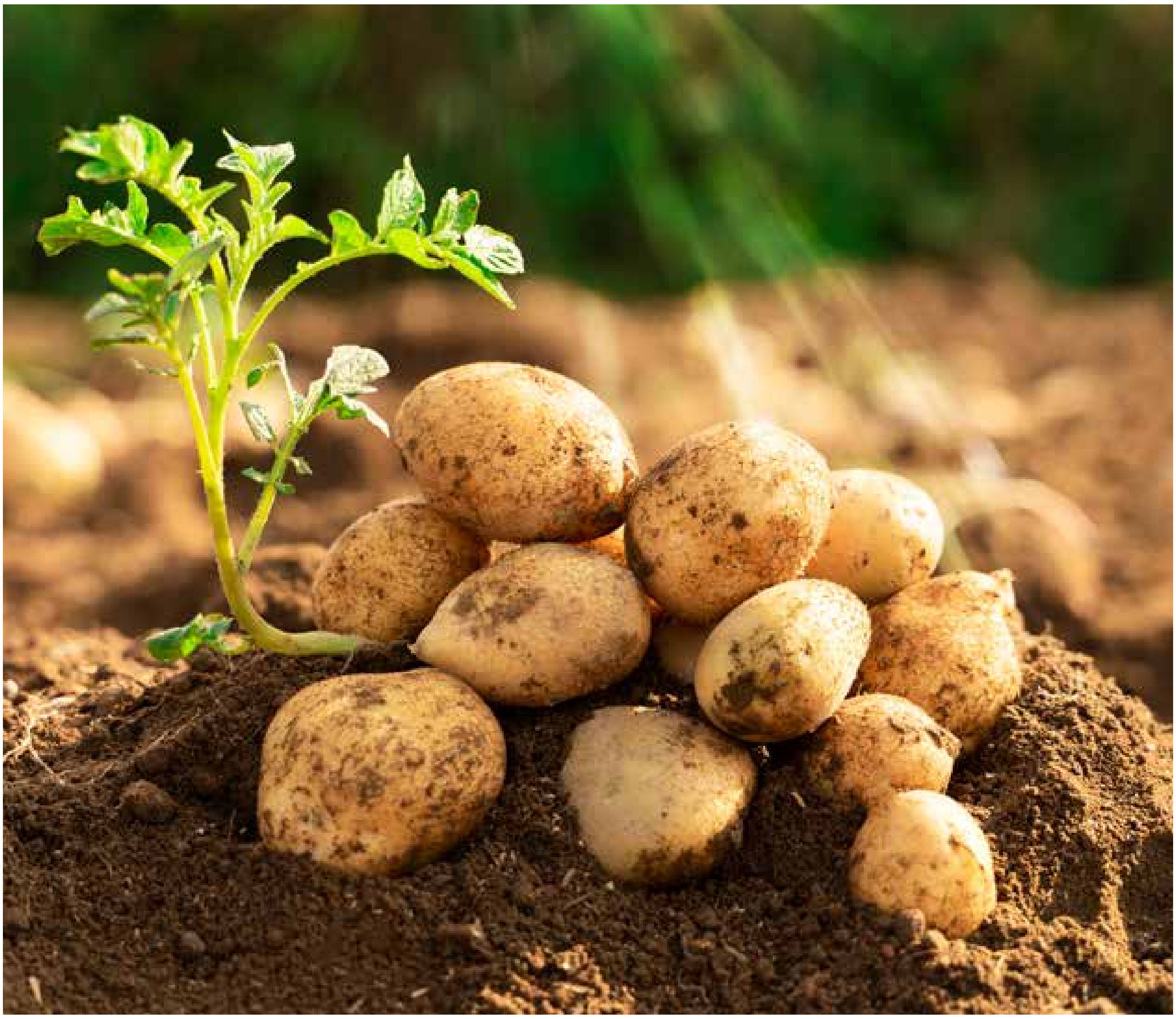


1. Introduction *and context*

European agroecosystems depend on healthy, biodiversity-rich soils to remain productive, stable and resilient (FAO et al. 2020). Soil biodiversity encompasses the multitude of microorganisms and fauna that drive nutrient cycling, soil formation, pest control and other vital ecosystem services. However, **intensive agricultural practices,** – such as high chemical inputs, monoculture and frequent tillage – **have led to a decline in soil biodiversity.** Agricultural intensification is known to decrease soil biodiversity and reduce the complexity of soil food webs. This loss of soil biodiversity is detrimental to soil health and can compromise crop productivity, stability and adaptability of agroecosystems.

Paradoxically, **farmers often lack specific incentives or support to conserve and improve soil biodiversity.** Traditionally, agricultural policies have not explicitly targeted soil biodiversity, focusing more on above-ground biodiversity or other environmental factors (European Commission, 2020a). However, **the stability of food production and the long-term sustainability of agriculture depend on soil biodiversity.** Soil biodiversity is a key element of sustainable agriculture and its preservation requires appropriate policy and economic support.

Promoting soil organisms (from beneficial bacteria and fungi to earthworms) **can improve nutrient availability to plants, naturally suppress pests and diseases, and increase crop resistance to climatic stress** (FAO et al., 2020). In short, a biodiverse soil acts as an insurance for agriculture, buffering disturbances and reducing dependence on external inputs. Thus, the **SoildiverAgro** projectwasconceivedtodemonstratehow improving soil biodiversity can reduce the need for fertilizers and pesticides while maintaining or increasing yields. **SoildiverAgro** is directly in line with the EU's vision of sustainable agriculture, which aims to promote practices that reconcile productivity with care for the environment. In parallel to research and demonstration initiatives, market-based approaches are also emerging to encourage soil-friendly farming.

Beyond public incentives, market-based approaches are also emerging to encourage soil-friendly farming. One promising idea is the development of consumer labels certifying agricultural products grown under practices that protect and enhance soil biodiversity, similar to organic or fair-trade certifications. Although no official soil-focused certification currently exists, **initiatives such as the proposed EU Soil Monitoring Law** (European Commission, 2023b) **and the "Soil Deal for Europe" mission under Horizon Europe** (European Commission, 2021a) **are working to define measurable indicators** of soil health and sustainable management, which could eventually enable such labeling. In the meantime, voluntary branding efforts around regenerative agriculture are already helping to raise awareness, laying the groundwork for future official soil-friendly labels.

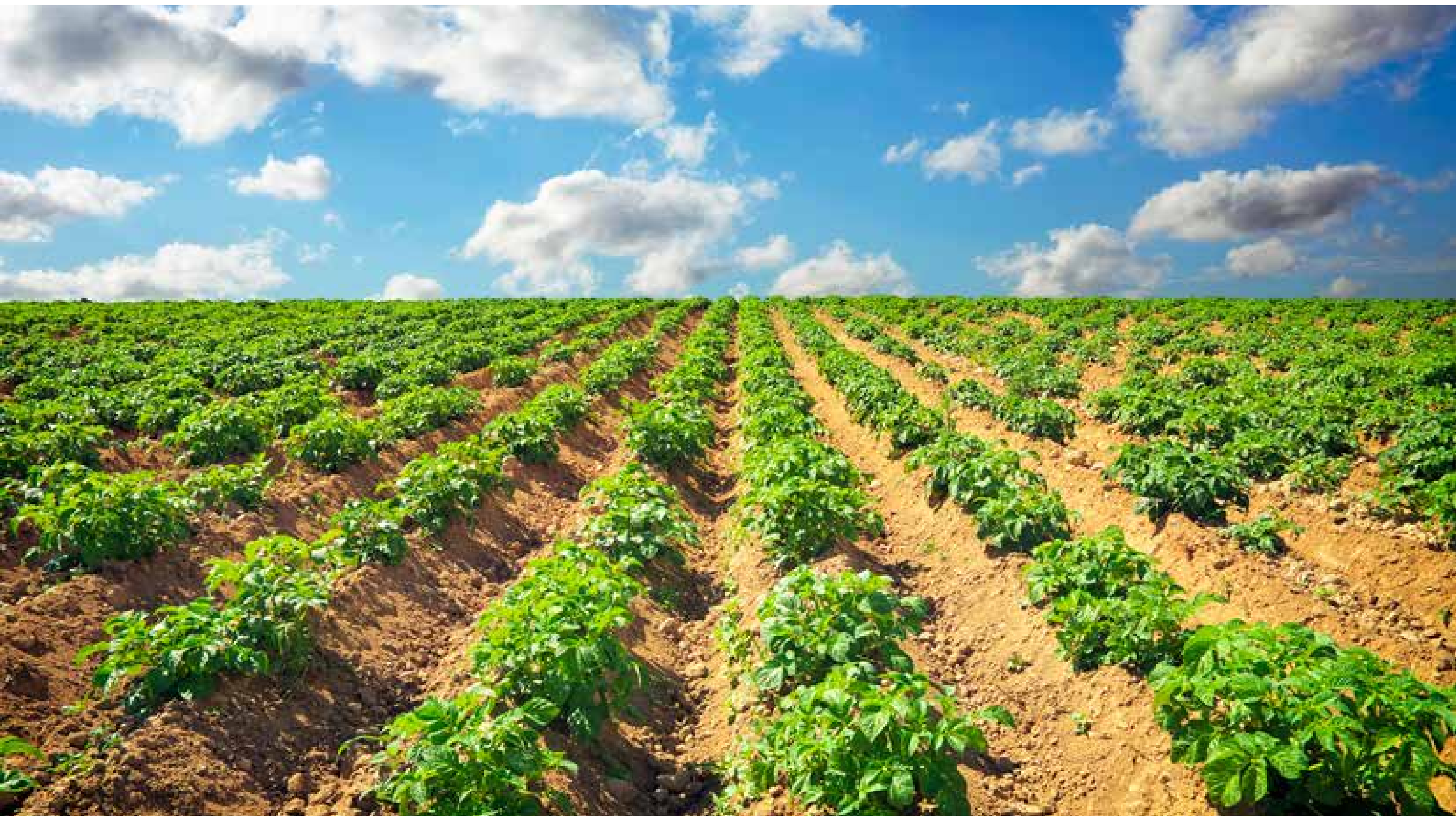
Reflecting this shift in approach, policies are beginning to adapt to encourage the use of soil biodiversity-enhancing practices. **For example, the regulatory treatment of microbial soil amendments illustrates how policy is beginning to adapt to new approaches.** The EU's fertilizing products law now classifies plant biostimulants as a distinct product category, signaling support for bio-based soil inputs (European Parliament & Council of the European Union, 2019). Yet this regulation initially permitted only a short list of microorganisms, which experts argue is too restrictive to encompass all beneficial soil microbes. Aligning legislation with scientific innovation – for instance, by updating EU lists of authorized biostimulant microorganisms – would remove barriers to adopting soil-enhancing inoculants.

In this context, there is a clear need for specific policies to protect and encourage soil biodiversity management. Inaction carries risks not only to ecosystem health, but also to long-term food security and farmers' livelihoods. As outlined in this **White Paper, improving soil biodiversity offers a pathway to more sustainable and resilient agriculture across Europe.** The following sections provide an overview of the policy landscape, key findings from **SoildiverAgro** field studies, and specific recommendations for integrating soil biodiversity into agricultural policies at regional and EU level.

2.

Political relevance *and European context*

European policymakers are increasingly recognizing that soil biodiversity is key to environmental health and agricultural resilience. The The **EU Biodiversity Strategy 2030** explicitly aims to **"put Europe's biodiversity on the path to recovery by 2030"** as part of the European Green Deal (European Commission, 2020a). This strategy stresses that the protection of soils is essential for the benefit of people, the climate and the planet. It calls for the restoration of degraded ecosystems and highlights the interdependence of biodiversity and food security. However, efforts under the previous 2011 strategy failed to stem the loss of biodiversity on agricultural soils (European Court of Auditors, 2020), indicating that stronger measures and implementation are needed moving forward. In particular, the loss of agricultural soil biodiversity has continued despite existing agri-environmental programs, indicating a gap that soil-focused actions can help to address. Currently, the EU agricultural policy framework still lacks explicit soil biodiversity measures, calling for their inclusion to enable an effective transition to sustainable land use and the achievement of healthy soils by 2050 (European Commission, 2021b).



A core component of the **European Green Deal** is transforming agriculture to a more sustainable model. The Green Deal's goals include **reducing pollution, moving to a circular economy, fighting climate change, and reversing biodiversity loss.** Healthy soils are integral to these goals: soils store carbon (mitigating climate change), filter water, and preserve biodiversity. Taking this into account, the European Commission introduced the **EU Soil Strategy for 2030,** which outlines a roadmap for soil protection and restoration. This strategy foresees that **all EU soils should be healthy by 2050,** with concrete actions to be achieved by 2030. It links to the Biodiversity Strategy and Green Deal, noting that **healthy soils are essential for climate neutrality, biodiversity restoration, and a sustainable food system** (European Commission, 2021b).

In 2023, **the European Commission's Soil Strategy highlighted the importance of soil biodiversity** within the broader concept of soil health and advocated for the establishment of a new Soil Monitoring Law to ensure sustainable soil use. Subsequently, the Commission presented its first-ever legislative proposal focused on soils, known as the **Soil Health Law,** aiming to establish a comprehensive framework for monitoring and improving soil health across Member States. Notably, the terms "Soil Monitoring Law" and "Soil Health Law" refer to the same legislative initiative. Initially referred to as the Soil Health Law, the proposal was renamed the Soil Monitoring and Resilience Law to better reflect its content and objectives. The law's objective is to ensure all soils are in healthy condition by 2050, reflecting the Soil Strategy's vision. It addresses key gaps: historically, unlike water or air, soil had no dedicated EU legislation. The lack of such legislation has been cited as a major reason for the **"alarming state of EU soils",** prompting this policy intervention. The proposed Soil Monitoring Law will require Member States to **monitor soil biodiversity and other soil indicators,** set national targets or trigger values, and define what constitutes sustainable soil management within their territories (European Commission, 2023b). This creates an enabling policy environment to integrate soil biodiversity considerations into law, which is an opportunity to put many of **SoildiverAgro**'s findings into formal requirements.

According to the European Commission (2021c), the **Common Agricultural Policy (CAP)** has been undergoing changes to better integrate environmental objectives. The post-2020 CAP (2023–2027) includes tools such as **eco-schemes and agri-environmental measures** that Member States can use to reward farmers for sustainable practices, including those beneficial to soil health. Currently, the CAP's stated objectives encompass environmental and climate protection, with soil fertility and biodiversity mentioned as priorities. In fact, enhancing soil biodiversity aligns with one of the new CAP's specific objectives of protecting biodiversity and ecosystem services of agricultural soils. For instance, CAP conditionality standards (GAECs) already address issues like soil cover, crop rotation, and maintaining organic matter, which indirectly support soil biodiversity. In the framework of eco-schemes, many countries have introduced payments for practices such as cover cropping, reduced tillage, or integrated pest management that benefit soil health. However, these measures vary by country and often do not explicitly target soil biodiversity.

The European Court of Auditors recently found that the prior CAP did not halt farmland biodiversity loss, implying that more ambitious integration of soil biodiversity into the CAP is needed (European Court of Auditors, 2020). A positive development is that the new CAP Strategic Plans explicitly mention soil biodiversity indicators, which allows more flexibility for Member States to introduce soil-focused interventions. Still, ensuring soil biodiversity is prioritized will require political will and knowledge transfer.

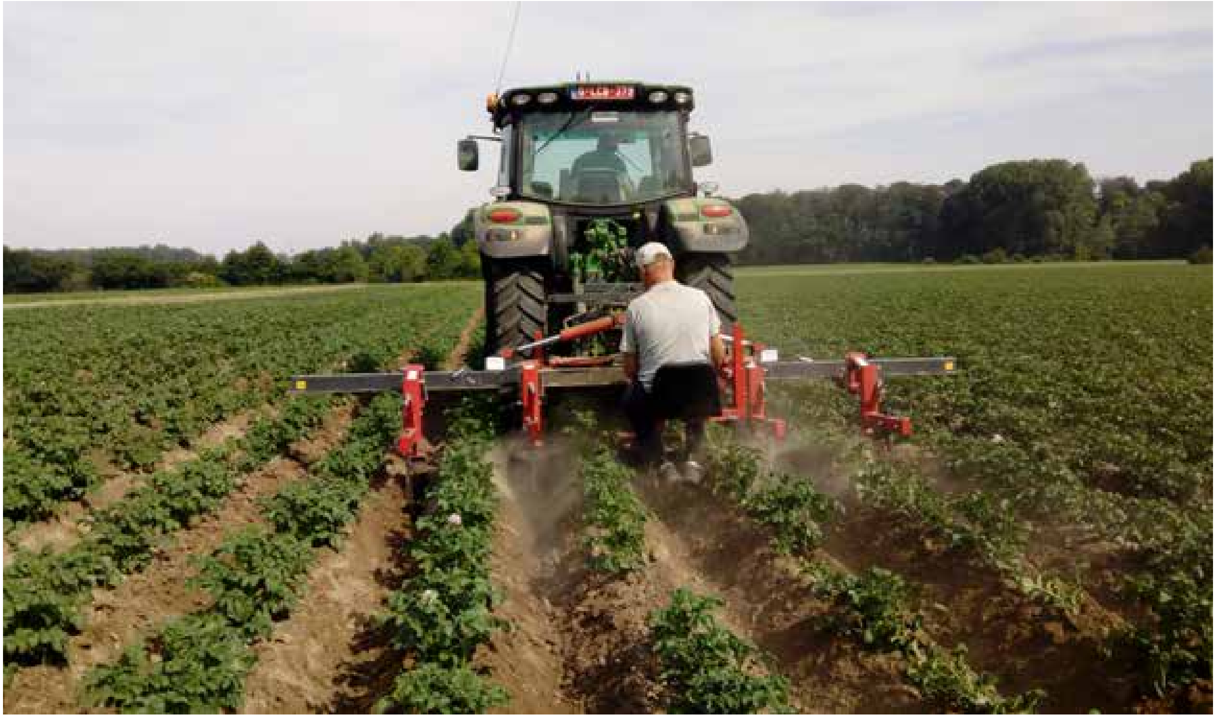
In overview, the European policy context is increasingly favorable for addressing soil biodiversity. The **EU Biodiversity Strategy 2030** provides the overarching vision of biodiversity recovery with soil as a key component, the **Green Deal** and **Farm to Fork** set relevant targets to transform agriculture, the **EU Soil Strategy 2030** and proposed **Soil Monitoring Law** establish a concrete framework and legal incentive for soil protection, and the reformed **CAP** offers tools to incentivize on-farm changes. These strategies and policies recognize that to maintain Europe's food security and climate resilience, soil degradation and biodiversity loss need to be addressed. Therefore, the capacity now exists to develop and implement specific policies targeting soil biodiversity, translating **SoildiverAgro** results into field actions.

In addition to broad policy frameworks, there are also specific technological and market innovations that can directly support soil biodiversity and sustainable soil management. Two notable examples are the promotion of microbial biostimulants and the development of a "soil-friendly" farming label.

A **key technological innovation involves the use of microbial plant biosti-**

mulants— inoculants containing beneficial microorganisms that stimulate plant nutrient uptake, growth, and stress tolerance. The EU has recognized **biostimulants under its fertilizer legislation:** Regulation (EU) 2019/1009 provides a legal definition and a harmonized framework for placing these products on the market (European Parliament & Council of the European Union, 2019). However, **current EU rules permit only a limited range of microorganisms** (e.g., specific nitrogen-fixing bacteria) as active ingredients (European Parliament & Council of the European Union, 2019). Many other beneficial soil microbes, such as *Bacillus* and *Pseudomonas* species that enhance plant growth, are not yet included, creating a regulatory bottleneck for innovation. Until the EU expands its list of authorized microorganisms — a process requiring scientific evaluation and delegated acts — products based on novel strains face barriers to EU-wide commercialization. This regulatory gap highlights the need to better align legislation with scientific advances. Accelerating the inclusion of new beneficial microbes would support the adoption of microbial solutions that improve soil fertility while reducing external inputs.

Complementing technological innovations, market-based approaches could also drive adoption of soil-friendly practices. One innovative idea is the development of a consumer label for "soil-friendly" farming similar to organic or fair-trade certifications, rewarding producers who conserve soil biodiversity. Such a label would enable retailers and brands to promote products grown using practices that protect and enhance soil life, meeting rising consumer demand for sustainable food systems. **Currently, no official soil-focused certification exists.** Establishing one would require agreed metrics for soil health and biodiversity (such as soil organic carbon, earthworm populations, or microbial activity) and a verification system for farm practices — elements that are still under development. Initiatives such as the proposed Soil Health Law (European Commission, 2023b) and the **Horizon Europe "Soil Deal" Mission** (European Commission, 2021a) are working towards defining sustainable soil management and measurable indicators.



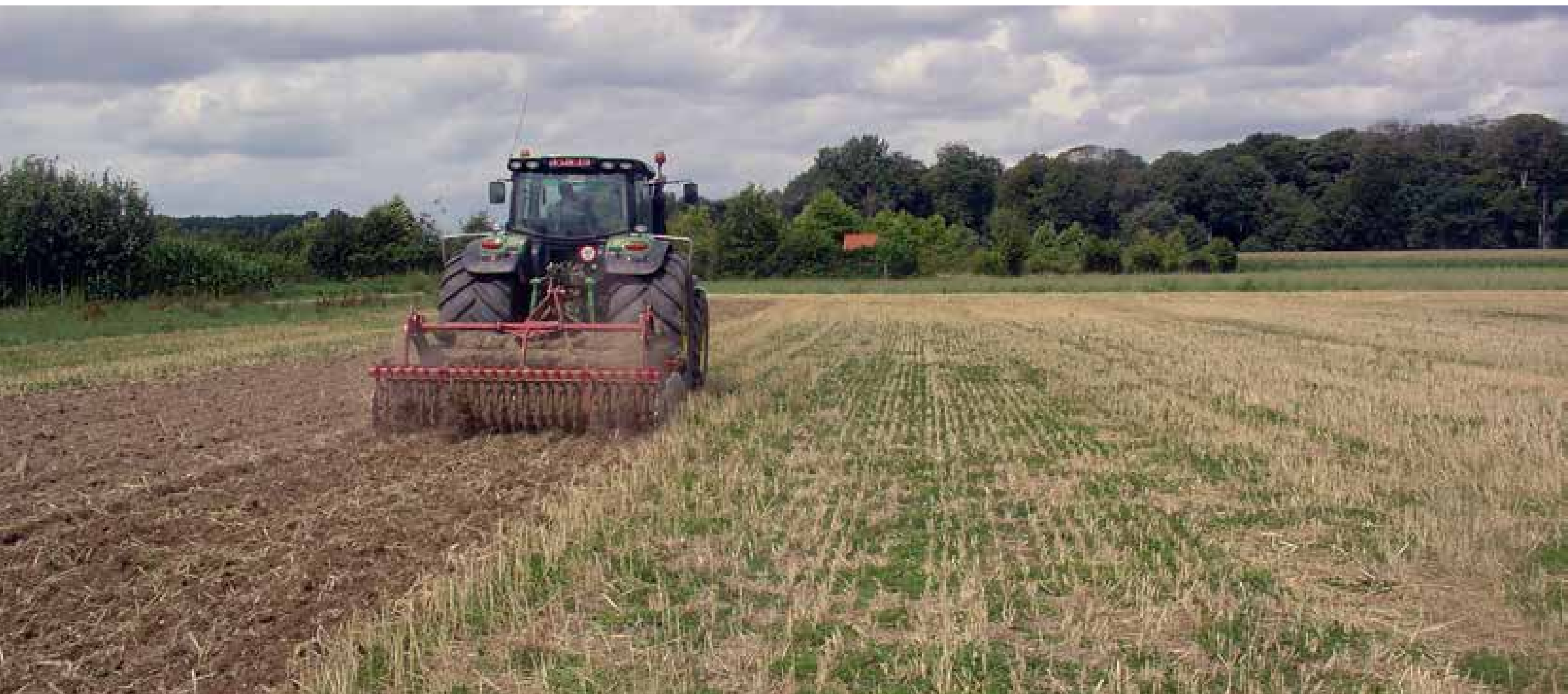
3.

Policy insights from *literature review on soil biodiversity*

Recent scientific literature review performed by **SoildiverAgro** partners provides overarching policy recommendations for soil biodiversity protection in Europe. Two notable review papers offer insights (Köninger et al., 2021, 2022):

Protect soil biodiversity through EU-wide policy and better monitoring: Current policies in the EU only partially address soil biodiversity, often indirectly. A comprehensive review by Köninger et al. (2022) found that only **8 EU Member States** have regulatory instruments explicitly targeting threats to soil biodiversity, while 6 countries do not consider soil biodiversity at all. At the EU level, existing directives (e.g., those on nitrates, pesticides, habitats) tackle individual issues but **lack an integrated focus on soil life.** The literature strongly calls for an EU-wide, legally binding framework to ensure a minimum level of soil biodiversity protection across all Member States (Kotschik et al., 2024). The authors argue that a dedicated **"Soil Biodiversity Law"** (now taking shape as the EU Soil Monitoring Law) is needed to prevent the escalating costs of inaction and to harmonize efforts. Such a law could, for example, mandate regular soil health monitoring and set targets for improving soil biodiversity indicators. Crucially, these researchers emphasize coupling regulatory protection with incentives for land managers. They point out that the proposed Soil Monitoring Law **should link good soil management practices with incentive-based instruments** – in other words, farmers should be rewarded for actions that benefit soil biota. This could be achieved by aligning the CAP's payments and rules to the soil legislation's objectives, something we also advocate in this white paper. Additionally, literature stresses improving our knowledge infrastructure: to support policy, we need better models and predictive tools for soil biodiversity (Zeiss et al. 2022). For instance, the developing models that can **predict soil biodiversity distributions and trends** under different land uses and climates. This would help identify priority areas for action and tailor measures to local conditions, acknowledging soil biodiversity's spatial heterogeneity. In summary, scientific consensus is that soil biodiversity loss must be tackled with an EU-wide legal instrument combined with robust monitoring and knowledge-based tools. The ongoing work on the EU Soil Strategy and Soil Monitoring Law is a direct response to these recommendations, aiming to institutionalize soil protection and integrate it into agricultural and environmental governance.

Integrate soil biodiversity into manure and nutrient management policies: Another crucial policy gap highlighted by researchers is the treatment of manure and organic waste in farming. Europe generates over a billion tonnes of manure annually, most of which is applied to soil. While manure can be beneficial (as a source of organic matter and nutrients), **current European regulations on manure management are fragmented and largely ignore soil biodiversity.** A review by Köninger et al. (2021) warns that policies like the Nitrates Directive focus on preventing water pollution but do not account for how manure quality and application methods affect soil organisms. The authors find that **manure quality is more important than quantity for soil biodiversity** – for example, manure containing heavy metals, antibio-



tic residues, or applied in unstable form can harm soil life regardless of meeting N load limits. They advocate for a paradigm shift in manure management: improving the **quality of manure through proper treatment (composting, anaerobic digestion, removal of contaminants) and timing/application techniques** that favor soil biota. Some of their specific recommendations include setting threshold limits for heavy metals and pharmaceutical residues in manure that is spread on fields, requiring that manure from antibiotic-treated animals be **treated (e.g. composted) before land application** to break down antibiotic compounds, and encouraging separation of solid and liquid fractions to better target nutrient placement and reduce soil compaction. Notably, the review suggests **integrating these practices into subsidy schemes** – for instance, farmers could receive support for building manure composting facilities or adopting advanced manure spreading technology. By including soil health criteria in nutrient management policies, such as under the CAP's Good Agricultural Practices, the EU could drastically reduce the negative impacts of manure on soil biodiversity. The broader takeaway from the literature is that a **"radical transformation" in agricultural practices is needed to reconnect nutrient management with soil biology.** This means moving away from viewing manure just as a waste to dispose of, and instead managing it as a valuable resource that must be handled in ways that nurture the soil food web. The concept of circular agriculture emerges: by improving manure management, we not only prevent pollution but also enhance the soil's biological functioning, creating more sustainable food systems. Policymakers are urged by scientists to update regulations so that, for example, **national manure standards include protections for soil biota,** and CAP measures incentivize farmers to adopt soil-friendly manure practices (like composting, precise application, use of bedding materials to bind nutrients). By doing so, Europe can address multiple goals at once: improving soil biodiversity, reducing emissions and runoff, and returning valuable carbon and nutrients to the land in a safe way.

This scientific literature reviews goes further to push for systemic policy changes. The key messages are:

(1) Establish strong, EU-wide legal protection and monitoring for soil biodiversity, integrating it into all relevant policies (agriculture, climate, etc.);

(2) Reform manure and input management rules to foster practices that benefit soil organisms.

4.

SoildiverAgro *General Policy Analysis across pedoclimatic regions*

The **SoildiverAgro** project carried out **15 field case studies across six pedoclimatic regions of Europe** (Mediterranean South, Lusitanean, Atlantic Central, Continental, Nemoral, and Boreal) to test how innovative soil management practices can enhance soil biodiversity and improve agroecosystem performance. These case studies, conducted in real farms and experimental plots, addressed a range of prevalent agricultural challenges by applying soil biodiversity-based solutions tailored to each pedoclimatic region. Over multiple crop cycles, the project assessed the effects of practices such as crop diversification, cover cropping, reduced tillage, organic amendments, use of biofertilizers (like mycorrhizal fungi and plant growth-promoting bacteria), and integrated pest management on both soil biodiversity and crop yields. The key findings from these field case studies demonstrated that enhancement of soil biodiversity can be associated with maintaining or even increasing agricultural productivity and profitability, which provide a strong evidence base for the policy recommendations that follow.

Agricultural and environmental policies in Europe can have different approaches and outcomes depending on the pedoclimatic regions. The **SoildiverAgro** case studies covered a wide range of European climates, offering insights into how policy frameworks interact with local agricultural conditions. The cross-regional approach of the project showed that while all regions face the common challenge of maintaining soil health, specific needs and policy gaps may differ according to climate, soil type, farming systems and socio-economic context:

4.1 Mediterranean South

This pedoclimatic region is characterized by semi-arid climate, with periodic droughts, high erosion risk, and often soils with low organic matter. Key policy issues here include water scarcity management, desertification prevention, and soil erosion control. EU policies like the Nitrates Directive and national laws on soil conservation (for instance, Spanish programs to combat desertification) play a role, but traditionally these focus on preventing worst-case degradation rather than enhancing biodiversity (Council of the European Communities, 1991). Irrigated intensive production in parts of Mediterranean Spain (such as horticulture in Murcia or Andalusia) has benefited from CAP investments but also led to soil salinization and biodiversity loss. The policy analysis indicates that current policies in this region could better incentivize **water-efficient cropping and soil cover.** While there are requirements under CAP (e.g., maintaining soil cover during vulnerable periods under GAEC standards), enforcement has been uneven (European Parliament & Council of the European Union, 2021). Some regional governments in southern Spain have begun to support no-till and cover crops to reduce erosion on rain-fed cropland, but these practices are not yet widespread. The policy comparison shows that Mediterranean South may benefit from **stronger integration of soil organic matter and biodiversity goals in its rural development programs,** given that building soil organic carbon is decisive for water retention in these soils. Additionally, pest and disease pressure in warm climates is high, and policies promoting integrated pest management (IPM) remain nascent, indicating an area for policy growth (e.g., wider implementation of **IPM and biocontrol requirements** beyond the general EU Directive on Sustainable Pesticide Use) (European Parliament & Council of the European Union, 2009; European Commission, 2022b).

4.2 Lusitanean

The Lusitanean region has a humid Atlantic climate with mild temperatures and high rainfall. Here, the challenge is often nutrient management and disease control in mixed farming systems (e.g., rotation of cereals, potatoes, and forages) on often acidic, organic-matter-rich soils. The comparative analysis finds that policies in this region have started addressing **water quality and nutrient runoff**, due to the Nitrates Directive designating some areas as vulnerable zones (with limits on fertilizer application) (Ministry for Ecological Transition and the Demographic Challenge of Spain, 2022). For example, Galicia's regional authorities have measures to control manure spreading from livestock operations to prevent water pollution (Council of Galicia, 2025). However, soil biodiversity has not been an explicit focus. One notable difference is a stronger tradition of cooperative extension services in this region that provide guidance on crop rotation and liming acidic soils, indirectly benefiting soil biodiversity. The Lusitanean case studies (potato systems in Galicia) highlighted the lack of existing policy incentives for using bio-inoculants like mycorrhizal fungi or for adopting **trap crops for cyst nematode control**. Currently, farmers rely on chemical solutions because there are no subsidies or support for knowledge of biological alternatives. Policies may draw lessons from integrated production schemes (e.g., Portugal's Integrated Production system) (European Commission/Portugal, 2024) which encourage non-chemical pest control and soil conservation, but participation in such schemes remains limited. The analysis also noted that this region has opportunities through the CAP eco-scheme for crop diversification: Spain's CAP Strategic Plan includes an eco-scheme rewarding diversification beyond a certain number of crops. In NW Spain, many farms already have rotations, but policy could further encourage inclusion of specific biodiversity-building crops (legumes, cover crops) in those rotations (European Commission/Spain, 2022). Thus, Lusitanean regions would benefit from **policies that connect nutrient management with soil biology**. For instance, promoting the use of soil microbial amendments to improve phosphorus and potassium uptake (reducing fertilizer needs and water pollution), or the introduction of legumes in the crop rotations.

4.3 Atlantic Central

This region has intensive agriculture (both arable and horticultural) on fertile soils, but with high inputs and consequent environmental pressures such as nitrate leaching and greenhouse gas emissions. Policies are relatively stringent regarding nutrient management. For example, Flanders (Belgium) imposes strict manure application standards and has advanced manure processing regulations due to the Nitrates Directive (Council of the European Communities, 1991). The analysis found that Atlantic Central countries often lead in adopting agri-environment schemes; for instance, **cover cropping** and **buffer strips** are widely mandated or incentivized to reduce nutrient losses. Despite this, soil biodiversity indicators in intensively farmed areas remain low, suggesting that existing measures mitigate damage but do not actively restore soil biodiversity. The region's policies heavily emphasize water quality (driven by the EU Water Framework Directive) (European Commission, 2000) and are starting to incorporate climate (soil carbon sequestration is encouraged via CAP measures in France and the Netherlands) (European Commission, 2024b). There has been comparatively less policy focus on pesticide reduction historically, although that is changing with EU directives. In the **SoildiverAgro** case studies from Belgium, which dealt with organic vs conventional vegetable farming and green manure alternatives, the **policy framework supported organic farming with conversion subsidies and advisory support**. This aligns with findings that organic farming in the region can be profitable (Banse et al., 2025) and improves soil biodiversity. However, conventional farmers in the region noted that transitioning practices (like reducing tillage or switching fertilizers) can be costly upfront. Thus, policies in Atlantic Central need to strengthen financial incentives for transitioning to soil-friendly practices beyond organic farming. There are positive examples: The Netherlands' program on **carbon farming** provides payments for practices that build soil organic carbon (which also enhances biodiversity). Similarly, Belgium has piloted subsidies for precision farming that can reduce fertilizer and pesticide usage. The comparative conclusion is that Atlantic Central's dense, high-input farming regions require policies that go beyond compliance, such as **performance-based incentives**. Current CAP eco-schemes in these countries include support for reduced tillage and winter cover, which is a good foundation, but more could be done to integrate explicit soil biological health goals (e.g., rewarding increases in soil macrofauna or microbial biomass as an outcome).

4.4 Continental

Continental regions have moderate climates with cold winters and warm summers, often dominated by large-scale arable farming and some mixed systems. Policies often deal with balancing high productivity with environmental concerns like soil erosion on slopes (in loess belt areas), compaction from heavy machinery, and the degradation of landscape. Germany, for example, has a federal structure where states implement agri-environment measures, including organic farming programs, erosion control strips, and reduced tillage (European Comission, 2019). Our analysis noted that in Continental case study areas **no-till or reduced tillage** had uptake due in part to policy incentives under thre previous greening of the CAP and the current organic schemes for carbon-rich farming practices (Pouta et al., 2025). However, a gap has been identified in the uptake of biodiversity support measures such as cover crop undersowing in cereals; the case study revealed some reluctance on the part of farmers (in Germany, attitudes were negative towards clover undersowing (Pouta et al., 2025), possibly due to a lack of clear immediate benefits or insufficient advisory support. Policies could address this issue by providing demonstration trials and risk-sharing mechanisms for such practices. Eastern continental regions face different challenges: often smaller farms and historically lower inputs, but rapid modernization. The introduction of CAP standards has rapidly increased yields but also fertilizer use (European Court of Auditors, 2020). Policy comparison suggests continental regions need a **strong knowledge transfer component:** regulations alone (e.g., mandates on crop rotation) must be accompanied with education on soil biology benefits to change mindsets (Köninger et al, 2022). On a regulatory front, Germany has a Soil Protection Act, but its implementation of biological aspects is limited (focusing more on contamination and erosion). In summary, Continental policy frameworks are at an intermediate stage, basic soil conservation is addressed, but more could be done to incorporate **biodiversity metrics and targets into soil protection efforts,** using instruments such as result-based payments or specific rural development projects focused on monitoring and improving soil biodiversity

4.5 Nemoral

The Nemoral zone is a transition between Continental and Boreal, often including the Baltic States and parts of Scandinavia with mixed forest and agriculture landscapes. In Estonia, agriculture has a mix of intensified areas and more extensive, historically less industrialized areas. The policy context in Baltics newer EU Member States often involves catching up with EU environmental standards while also trying to increase agricultural output. **SoildiverAgro** partners in Estonia noted that there is relatively high interest in sustainable practices; indeed, survey results showed strong moral obligation and positive attitudes towards improving soil quality (Pouta et al, 2025). However, barriers include economic restrictions and limited specific policy instruments for soil biodiversity. Estonian and other nemoral regions benefit from EU support for modernizing agriculture, for example, investment in manure storage to comply with the Nitrates Directive and afforestation schemes on marginal land (Council of the European Communities, 1991; Köninger et al, 2022). These indirectly help soil biodiversity by reducing nutrient pollution and restoring organic matter. There has also been uptake of **agroforestry and diversified cropping** through rural development projects, which is promising for biodiversity (European Commission, 2020a). The comparative analysis suggests that one policy gap is in **integrated pest management (IPM):** in regions with smaller farms like Nemoral, advisory services for IPM and advanced tools are less developed, and farmers may still rely heavily on preventive fungicide sprays (European Parliament & Council of the European Union, 2009). Strengthening IPM mandates and support in these countries would directly benefit soil biodiversity. Additionally, Estonia's CAP plan includes support for catch crops and reduced tillage (European Commission/Estonia, 2022), but uptake depends on farmer awareness and capacity. Thus, Nemoral regions are at a crossroads where they can integrate sustainability and crop intensification. Policy can steer them toward a pathway that **avoids the mistakes of over-intensification** by building in soil biodiversity criteria (e.g., by setting national soil health targets, as required by the EU Soil Monitoring Law) (European Commission, 2021c).

4.6 Boreal

Boreal agriculture faces unique conditions: very short growing seasons, risk of soil frost and springtime erosion, and often soils with high organic content (including peat soils with carbon richness but sensitive to cultivation). Finland, for example, has made soil protection a priority in the context of protecting the Baltic Sea from nutrient runoff (European Commission, 2021b; FAO, 2020). Policies in Boreal regions strongly promote vegetation cover during winter; Finnish fields are often required to have a vegetation cover or residue during winter to prevent erosion on snowmelt and have measures to limit plowing of peat soils to reduce carbon loss (European Commission/ Finland, 2022). **SoildiverAgro** boreal case compared inversion plowing with continuous vegetation cover and surface tillage, which directly coincides with the political interest in conservation tillage (Pouta et al., 2025). The analysis revealed that **Boreal countries have some of the most progressive CAP measures for soil:** Finland's CAP includes an eco-scheme for planting a "catch crop" or maintaining grass cover post-harvest, and there are subsidies for sustainable peatland management (European Commission/ Finland, 2022). As a result, the adoption of reduced tillage and cover crops is relatively higher compared to other pedoclimatic regions. However, nutrient management remains a challenge: long winters mean a lot of stored manure and potential losses. Policies are trying to innovate, e.g., Finland is exploring carbon credit systems for carbon sequestration in soils. From a biodiversity policy point of view, Boreal regions have a rich tradition of biodiversity in forestry but less so in cropland. One could see an opportunity to adapt systems such as Finland's environmental offset system to explicitly account for soil biodiversity (e.g. through indicators such as earthworm counts or soil microbial activity as new metrics of success) (FAO, 2020, Banse et al., 2025). The comparative analysis underscores that in Boreal systems, **climate change is rapidly altering conditions** (warmer winters, new pests moving north), so policies must be forward-looking and support diversified and resilient cropping systems that can handle these changes (European Commission, 2021b). Encouraging a wider range of crops (including nitrogen-fixing legumes which historically were not common in northern rotations) is one example; Finland's current policies encourage protein crops for feed as an economic goal, which is also a biodiversity-friendly measure (European Commission, 2022b).

5.

Policy recommendations *from projects results*

Based on **SoildiverAgro** findings and the comparative analysis of existing policies, this section outlines a comprehensive set of policy recommendations to enhance soil biodiversity and reduce external inputs in European agriculture. These recommendations are organized into general strategies applicable EU-wide, and specific actions tailored to each pedoclimatic region (Mediterranean South, Lusitanean, Atlantic Central, Continental, Nemoral, Boreal). The implications of conventional versus sustainable practices, barriers and opportunities for policy implementation are also discussed. The recommendations aim to inform policymakers at EU, national, and regional levels, as well as to guide agricultural authorities in integrating soil biodiversity into their decision-making frameworks.

5.1 General strategies to mitigate negative impacts and promote soil biodiversity

Adopt a preventive, ecosystem-based approach

Policies should shift from remediating the symptoms of soil degradation to preventing them through ecosystem-based agricultural management. This means prioritizing practices that keep roots alive in the soil throughout the year, ensure diverse crop rotations and minimize soil disturbance. For example, encouraging cover crops and crop diversification on all farm types. These practices have been shown to reduce erosion, improve soil structure and enhance beneficial soil organisms (FAO et al., 2020). A general policy recommendation is to make cover crops and rotational planning a standard (and rewarded) part of farm management, potentially extending GAEC requirements or green payment schemes to mandate a minimum crop diversity and winter ground cover on cropland (European Parliament & Council of the European Union, 2021). This preventative approach will help to mitigate negative impacts such as nutrient leaching and pest buildup before they occur.

Integrate soil biodiversity criteria into agri-environmental schemes

Existing agri-environment and climate measures (AECMs) under the CAP should explicitly include soil biodiversity as both an objective and an evaluation metric. This could involve developing indicators such as earthworm counts, soil microbial biomass, or a soil biodiversity index as part of scheme monitoring. Incentivize farmers not just for actions (such as planting cover crops) but also for outcomes – e.g. **demonstrable improvements in soil health indicators.** As recommended by **SoildiverAgro** economic analysis (Banse et al., 2025), aligning policy support with performance can be effective. For instance, a scheme could offer bonus payments if a farmer's soil organic matter or biological activity increases beyond a certain threshold, reflecting biodiversity gains. This results-based incentive can encourage farmers to adopt a set of best practices to achieve the outcome.

Strengthen regulation on harmful practices and provide alternatives

To mitigate negative impacts on soil biodiversity, policies should progressively restrict the most harmful management practices. For example, discourage excessive tillage and gradually reduce over-reliance on broad-spectrum agrochemicals. However, these restrictions must be accompanied by support for alternatives. A general recommendation is to **tighten pesticide use rules** (based on the Sustainable Use of Pesticides Directive) by incorporating soil health impacts into the risk assessment of agrochemicals (European Parliament & Council of the European Union, 2009), while funding farmer training and biocontrol availability. As **SoildiverAgro** showed, methods such as trap crops or bio-based IPM can effectively replace certain chemicals. Policies can accelerate this process by fast-tracking the approval of low-risk biopesticides and biostimulants and initially subsidizing their cost so that farmers have viable alternatives to harmful pesticides and fertilizers (European Commission, 2020a). In addition, guidelines or even standards for **reduced tillage** could be introduced in areas prone to erosion or carbon loss, coupled with equipment grants to help farmers acquire especielised machinery, e.g. no-till seeders.

Economic incentives and disincentives

Apply **economic instruments to internalize the benefits of soil biodiversity**. This includes tax exemptions or rebates for farmers practicing verified sustainable soil management (for example, property tax reductions for farmland under conservation practices, as piloted in some regions), or conversely, levies for practices that cause diffuse pollution (some countries have considered taxes on nitrogen fertilizer or pesticides, with revenue recycled into agri-environmental programs). A practical incentive model is payment for ecosystem services (PES) focusing on soils – for example, paying farmers for each ton of carbon sequestered in soil or for maintaining pollinator habitat that also indicates healthy soil ecology. **SoildiverAgro** results support that such investments yield returns in the form of resilience and reduced externalities (Banse et al., 2025). At the EU level, the new CAP enables eco-schemes that could be designed as PES schemes for soil health, where farmers get a premium for achieving measurable soil improvements (European Commission, 2021c).

Enhance cross-sector collaboration and knowledge dissemination

Effective policy needs not just rules and payments, but also knowledge networks. A general recommendation is to strengthen support for **soil health extension services and multi-actor innovation networks.** This means dedicated funding for local advisers specifically trained in soil biodiversity, demonstration farms in each region that showcase successful soil-friendly systems, and farmer-to-farmer learning or mentorship programs. Many farmers are unaware of the long-term benefits or the practical "how-to" of practices such as incorporating mycorrhizal fungi or using decision support tools for pest control. Policies should facilitate open data and tools: for example, the EU could support a platform for region-specific pest alert systems (as tested in **SoildiverAgro** case study 5) and make it accessible to cooperatives and extension agents. In addition, integrate soil biodiversity into education and training – e.g., require that agricultural college curricula and vocational training include soil ecology and sustainable soil management practices. In the short term, policymakers can sponsor workshops and field days (possibly through rural development funds) focusing on the economic and agronomic co-benefits of soil biodiversity friendly management practices, thereby addressing knowledge barriers. In short, create an enabling environment where farmers feel technically and socially supported to change practices, not just financially induced.

5.2 Specific policy recommendations by pedoclimatic region (case studies)

While the general strategies above are generally applicable, nuanced approaches are needed to address region-specific challenges and opportunities. Here we present specific policy recommendations for each pedoclimatic region studied in **SoildiverAgro**, based on the results of case studies from those areas (Tables 1-6):

Mediterranean South

Case study 1 – Mediterranean South (Cartagena, Spain)

» **Problem:** In the semiarid region of Cartagena, intensive horticultural systems face multiple challenges: low soil organic matter, poor soil structure, nutrient depletion, and a high dependency on chemical fertilizers. Despite the use of crop rotations and multiple cropping to increase profitability, farmers rely heavily on mineral fertilizers and irrigation, exacerbating soil degradation and biodiversity loss.

» **Best Management Practices:** To address these issues, the **SoildiverAgro** project tested a strategy based on reducing mineral fertilizer inputs while introducing microbial biostimulants. Mineral fertilization was cut to 50% of conventional rates and combined with two types of microbial inoculants: one based on plant growth-promoting rhizobacteria (PGPR) such as *Azospirillum, Pseudomonas, and Bacillus,* and another combining these bacteria with beneficial fungi. The application of these inoculants helped stabilize yields even under reduced fertilization and improved potato quality—particularly in treatments with both bacteria and fungi, which showed better firmness and lower disease incidence from *Rhizoctonia*. Additionally, the treatments led to significant environmental benefits: CO2 emissions from soil were reduced by up to 40%, and microbial activity and prokaryotic diversity increased. The nematode community also shifted towards more beneficial functional groups, indicating a healthier soil food web. Although these biological practices did not generate direct profit gains (as the cost of inoculants offset fertilizer savings), they provide a promising model for more sustainable horticulture in Mediterranean climates—especially if economic incentives or support programs are introduced.

Case study 2 – Mediterranean South (Murcia, Spain)

» **Problem:** In the semiarid region of La Junquera (Murcia), agricultural systems are challenged by low soil biodiversity, poor soil structure, and limited nutrient and water availability. The predominant cropping system, based on cereals like wheat, barley, and rye, suffers from soil erosion and declining organic matter content. Although rotations are practiced to prevent monocropping issues, excessive reliance on mineral fertilizers continues, leading to low soil functionality and minimal microbial diversity, especially in a climate where evapotranspiration greatly exceeds precipitation.

» **Best Management Practices:** To address these issues, the **SoildiverAgro** project implemented a series of fertilization treatments combining reduced mineral inputs and microbial biostimulants. Mineral fertilizer was reduced by 50%, and in some treatments, replaced partially by biostimulants consisting of nitrogen-fixing and nutrient-solubilizing bacteria (*Azospirillum, Pseudomonas, Bacillus*) alone or in combination with beneficial fungi (*Azotobacter*, non-mycorrhizal species). The experimental setup included three cropping cycles—rye, wheat, and ervil (although the latter failed due to drought)—under drip irrigation. Results showed that biostimulant application did not improve yields or soil organic carbon content, nor did it affect microbial or nematode diversity in a meaningful way. The complexity of the nematode community was reduced, with an increase in taxa feeding on bacteria and fungi. Moreover, the use of commercial biostimulants proved economically unviable, reducing gross margins by 52% due to a 31% rise in production costs. On the other hand, simply halving the mineral fertilization without any biostimulants preserved yields, maintained nutrient availability, and improved profitability by 56%, highlighting that reduced fertilization alone may be a more efficient strategy under these conditions.

» **Policy recommendations**

In the semiarid Mediterranean conditions of SE Spain, **SoildiverAgro** demonstrated that integrating soil biological inputs can maintain yields with fewer chemical inputs. In irrigated horticulture **(case 1)**, applying beneficial microbial inoculants (plant growth-promoting bacteria plus fungi) allowed a 50% reduction in synthetic fertilizer with no loss in crop. Policies should support the use of such bio-inoculants (e.g. via subsidies or inclusion in CAP eco-schemes) to reduce dependence on mineral fertilizers. This would cut farmers' costs and carbon footprint while sustaining productivity and suppressing soil-borne pathogens. In contrast, in dryland cereal systems **(case 2),** adding the same commercial biostimulants had **no** yield benefit and was not cost-effective for organic farmers. Thus, for rainfed Mediterranean fields, the recommendation is to **focus on optimizing fertilization** (through precision agriculture and soil testing) rather than relying on expensive inoculants that showed no gain. Policies should encourage precision nutrient management – for example, by funding soil mapping and variable-rate applicators – since case results showed fertilizer rates could be halved with no yield penalty. Overall, Mediterranean authorities should **promote microbial amendments where effective** (e.g. potatoes and vegetable crops under irrigation) and ensure farmers are informed about where such inputs are or are not worthwhile. Support for on-farm trials and advisory services will be key so that growers in water-limited regions can confidently adopt practices that enrich soil biota (like biofertilizers or cover cropping) when they truly add value (Table 1).

Table 1. Summary of policy recommendations for Mediterranean South.

Case 1
• Promote the use of microbial inoculants in Mediterranean horticultural systems, particularly the combined application of plant growth-promoting bacteria and fungi, to reduce reliance on mineral fertilizers. This approach can lower the carbon footprint while stimulating beneficial soil microorganisms, thereby maintaining high crop yields and reducing the abundance and incidence of soil-borne pathogens. • Encourage the adoption of precision agriculture technologies to optimize fertilizer use. Fertilizer inputs can be significantly reduced without negatively affecting crop yield or quality, improving resource efficiency and environmental sustainability.
Case 2
• Encourage the optimization of fertilization practices for field crops under organic rainfed management. Fertilizer inputs can be reduced without compromising crop yield, quality, or soil health, contributing to more sustainable agricultural practices. • Advise caution regarding the use of biostimulants in organic rainfed field crops under Mediterranean climatic conditions. Field evidence showed no significant improvement in crop yield, quality, or soil health, while production costs increased, leading to a decrease in gross margins.

Lusitanean

Case study 3 – Lusitanean Region (A Limia, Galicia, Spain)

» **Problem:** In A Limia, northwest Spain, the intensive monoculture of potatoes has led to a severe outbreak of potato cyst nematodes (Globodera spp.), drastically reducing yields and forcing farmers to rely heavily on chemical nematicides. This not only increases production costs but also has detrimental effects on soil biodiversity, particularly suppressing beneficial organisms that could naturally regulate nematode populations. The lack of crop rotation and heavy pesticide use has resulted in simplified soil food webs and reduced biological resilience.

» **Best Management Practices:** The **SoildiverAgro** project explored integrated crop management strategies aimed at restoring soil biodiversity while maintaining productivity. Two main approaches were tested: introducing a non-host trap crop (*Solanum sisymbriifolium*) and diversifying crop rotations with legumes. The trap crop, when well-established, was highly effective—reducing nematode populations by nearly 89% within just 12–13 weeks. This allowed for a significant reduction in pesticide use while simultaneously increasing total organic carbon and nitrogen in the soil. In parallel, replacing traditional cereal rotations with legumes such as peas improved soil nutrient cycling, particularly ammonium and nitrate levels, and enhanced microbial functionality. Potatoes grown after legume rotations showed a 21% yield increase with 50% less top dressing N inputs. Economically, these diversified systems outperformed conventional rotations, offering better gross margins and improved long-term sustainability. However, the success of the trap crop is highly dependent on favorable establishment and weather conditions, with overly wet summers—like that of 2023—posing serious limitations.

Case study 4 – Lusitanean Region (Xinzo de Limia, Galicia, Spain)

» **Problem:** In fields devoted to potatoes severely affected by common scab, a disease caused by *Streptomyces scabies* that thrives in soils with elevated organic matter and neutral to basic pH, farmers have historically cultivated under strongly acidic conditions (pH <5.0), which inadvertently limits phosphorus availability despite high soil P reserves. Consequently, substantial applications of synthetic P fertilizers are common. These acidic, low-diversity soils support limited microbial and faunal communities, further diminishing soil health and ecosystem resilience.

» **Best Management Practices:** To address these constraints, the **SoildiverAgro** project evaluated the introduction of mycorrhizal fungi into potato cropping systems combined with reduced phosphorus fertilization. Across five treatments, combinations of mycorrhizal fungi and reduced or eliminated P fertilization were tested. The application of mycorrhizal fungi did not significantly reduce the incidence of common scab, and phosphorus availability remained unchanged, likely due to already high residual soil P levels. However, plots without external phosphorus—particularly those with mycorrhizal inoculants—showed increases in potato yield under normal weather conditions (2021) and significant improvements in soil biological indicators. These included enhanced populations of beneficial fungi (*Ascomycetes* and *Basidiomycetes*), greater nematode diversity including higher levels of omnivores and carnivores (indicating a mature and resilient soil food web), and a ~20% increase in earthworm abundance. Economically, treatments without phosphorus inputs (especially with mycorrhizal fungi) yielded the highest gross margins—surpassing even the conventional system. Therefore, given the high baseline phosphorus content in this region, the study concludes that external P fertilization is unnecessary in the short to medium term, and that the addition of mycorrhizal fungi can further enhance soil quality and profitability.

Case study 5 – Lusitanean Region (Sandiás, Galicia, Spain)

» **Problem:** In Lusitanean región, fungal diseases, such as late blight *(Phytophthora infestans),* severely impacts potato production, leading to frequent fungicide applications based on pre-established calendar routines. These blanket treatments are applied regardless of actual disease risk, resulting in overuse of chemicals, higher production costs, and potential environmental contamination. The climatic conditions of the area—humid with moderate temperatures—favor the proliferation of the pathogens, especially in seasons with early emergence and sustained leaf wetness.

» Best Management Practices: To reduce fungicide use while maintaining crop health and productivity, the **SoildiverAgro** project tested a fungal **Decision Support System (DSS)**, comparing its effectiveness to conventional routine applications and untreated controls (without fungicide application). In both 2021 and 2023, potato plots were treated under three strategies: no fungicide (Control), calendar-based routine spraying, and DSS-guided treatments. The DSS relied on real-time aerobiological monitoring fungal sporangia and/or meteorological risk modeling, allowing fungicide applications to be timed precisely to actual infection risk. Results showed that DSS-guided applications drastically reduced the number of fungicide sprays—only 3 were needed in 2021 and 4 in 2023, compared to 6 and 9 respectively under the routine method. Disease severity remained low in DSS plots, with observed severity at 1% in 2021 and 4% in 2023, comparable to or only slightly higher than routine-sprayed plots (0% and 2%, respectively). Importantly, DSS use cut fungicide input nearly in half without compromising yield or marketable tuber quality.

» Policy recommendations

In the humid Atlantic zones (e.g. Galicia/northwest Spain and northern Portugal), **SoildiverAgro** case studies focused on potato-based systems and showed the value of biologically-based pest control and soil fertility enhancements. One key finding was that deploying trap crops can drastically reduce a persistent soil pest. In **case study 3** (intensive potato rotations plagued by cyst nematodes), planting the trap crop *Solanum sisymbriifolium* in rotation cut cyst nematode infestation levels without chemical nematicides. The recommendation is to **promote trap crops regionally** for potato growers facing cyst nematodes – for example, provide subsidies or seed support for planting *S. sisymbriifolium* on infested land. Agricultural policy can integrate this into existing schemes (such as making trap crops an eligible practice under agri-environmental measures) and ensure technical guidance is available, since proper establishment of the trap crop is crucial (e.g. appropriate sowing date and depth). In addition, Lusitanean authorities should **strengthen support for diversified crop rotations,** especially by increasing the presence of legumes. In this sense, case study 3 also demonstrated that incorporating a legume (pea) into the rotation naturally fixed nitrogen, thereby reducing the need for synthetic fertiliser application. This, in turn, contributed to lower input costs, decreased environmental pollution, and improved biodiversity. Therefore, policies should continue to incentivize legume cover crops or break crops (building on CAP provisions for crop diversification), with enhanced payments if needed to reach regional targets for legume area. Another major result was from **case study 4,** where potato fields on acidic, P-binding soils were treated with **arbuscular mycorrhizal fungi (AMF)** inoculants. Introducing AMF (while reducing phosphorus fertilizer) may lead to improved potato yield and soil biodiversity. This suggests policymakers should **encourage the use of mycorrhizal fungi bio-inoculants** in potato cultivation – for instance, by recognizing inoculation as a nutrient management tool in advisory services and cost-sharing the purchase of certified mycorrhizal fungi products. Farmers could be reimbursed for part of the cost of AMF inoculants under rural development programs. It is also recommended to update fertilizer guidelines to account for more precise recommended P fertilizer rates. Lastly, Lusitanean case studies highlighted **digital IPM tools.** In this sense, **case study 5** demonstrated that a decision support system (DSS) for disease forecasting could cut fungicide use without hurting yields. To capitalize on this, policies should invest in pest/disease **warning systems** – for example, installing regional weather stations and spore traps and providing farmers with alerts on infection risk. The **integration of DSS into crop protection standards** is advised, potentially by requiring or incentivizing its use under national Integrated Pest Management programs. Moreover, offering training and technical support for these smart farming tools will lower adoption barriers. In summary (Table 2), the Lusitanean region should pursue an approach of **"biological reinforcement"** – replacing agrochemicals with biological solutions (trap crops, mycorrhizal fungi, DSS-based targeted spraying) – supported by CAP mechanisms. These measures would reduce chemical inputs and enhance soil life, aligning farming practices with the region's environmental and public health goals.

Table 2. Summary of policy recommendations for Lusitanean.

Case 3
• Promote the use of *Solanum sisymbriifolium* as a trap crop in fields infested with cyst nematodes at the regional level, providing farmers with an effective biological control option. • Explore the potential application of *Solanum sisymbriifolium* in other pedoclimatic regions through regional trials and knowledge transfer initiatives. • Include subsidies for the use of trap crops within the CAP framework, similar to existing support provided for wheat and other strategic crops. • Promote the inclusion of legume crops in crop rotations at the regional level to improve soil fertility, enhance biodiversity, and reduce reliance on chemical fertilizers. • Strengthen CAP incentives to further encourage the cultivation of legume crops as part of sustainable agricultural practices.

Case 4

- Encourage the optimization of P fertilization practices for potato crop. Fertilizer P inputs can be reduced without compromising crop yield, quality, or soil health, contributing to more sustainable agricultural practices.
- Include subsidies for application of mycorrhizas in the CAP.

Case 5

- Promote long-term research on this agricultural practice (DSS, Decision Support System), gathering crop yield, soil fertility, and other ecosystem services data over an extended period and under varying climatic conditions. This will allow for a more precise determination of the agronomic and economic long-term benefits of implementing this agricultural practice.
- Encourage the use of these systems to reduce the number of chemical fungicide applications by addressing the trade-off between fungicide use and productivity reduction.
- Invest in enhancing these systems through the incorporation of aerobiological data into the Decision Support System, enabling more accurate predictions of disease onset within the study area.
- Compensations off losses via PAC to farmers implementing DSS in their fields.

Atlantic Central

Case study 6 – Atlantic Central (Merelbeke-Melle, East Flanders, Belgium)

» **Problem:** In the region of Flanders, Belgium, high-intensity agricultural systems face growing pressure to address excess soil phosphorus levels, nitrate leaching, and declining soil health. Organic growers, in particular, must balance the benefits of manure application with the risk of nutrient runoff, which threatens both water quality and the delicate balance of rhizosphere microbial communities essential for plant nutrition. The challenge lies in optimizing soil inputs to sustain productivity while preserving ecosystem health—especially under organic regulations that prohibit synthetic fertilizers and herbicides.

» **Best Management Practices:** To address these issues, the **SoildiverAgro** project evaluated six different combinations of organic fertilization and cover crop management strategies under an organic farming system. The most successful approach was the use of traditional farmyard manure (not co-composted) combined with the incorporation of diverse cover crop mixtures into the soil (SM_BAU). This strategy significantly improved yields—particularly for nitrogen-demanding crops like potatoes and savoy cabbage—and enhanced soil fertility indicators such as organic carbon content and nutrient availability (notably nitrogen, phosphorus, potassium, and magnesium). In contrast, co-composted manure showed lower effectiveness, and no-fertilizer treatments yielded the poorest results. Although microbial diversity did not differ significantly between treatments, a clear trend indicated improved genetic activity under the SM_BAU system. Cover crops supporting carbon cycling also played a key role: when incorporated into the soil rather than harvested, they enhanced crop yields and nutrient cycling, especially for N-demanding crops, further supporting the resilience of the system. Although changes in nematode communities were not statistically significant, the treatments did shift fungal composition towards more saprotrophs and fewer plant pathogens—another indicator of improved soil health.

Case study 7 – Atlantic Central (West Flanders, Belgium)

» **Problem:** In West Flanders, one of Belgium's most productive agricultural regions, intensive vegetable and potato production has resulted in concerns over soil organic matter depletion, nutrient losses, and declining soil health. Organic farmers in particular face a delicate balance between productivity and sustainability, often relying on complex rotations and organic inputs. Regional stakeholders have identified poor soil structure, limited biological activity, and insufficient nitrogen availability as pressing issues requiring innovative solutions.

» **Best Management Practices:** To improve soil biodiversity and agronomic performance under organic farming conditions, the **SoildiverAgro** project implemented a multi-year field experiment assessing the use of species-rich cover crop mixtures. Four treatments with increasing plant species diversity—ranging from two to twelve species—were established over three consecutive seasons. These mixtures incorporated both non-leguminous species (e.g., Phacelia, black oat) and nitrogen-fixing legumes (e.g., vetch, lupin, clover), aiming to enhance multiple ecosystem services such as nitrogen capture, soil structure improvement, and biological activity. The trials followed reduced-till and Controlled Traffic Farming (CTF) practices to minimize soil disturbance. Preliminary results suggest that high-diversity cover crop mixtures, particularly those that include legumes, offer several significant benefits. These mixtures promote substantial aboveground biomass production, which in turn enhances nitrogen availability for subsequent crops, thereby improving soil fertility. Furthermore, they contribute to increased potato crop yield and support greater biodiversity, especially in relation to genes associated with denitrification, which enhances nitrogen turnover and optimises the cycling of excess nitrate. Additionally, these practices help reduce water pollution by minimising nitrogen leaching into groundwater, while simultaneously maintaining economic profitability.

Case study 8 – Atlantic Central (Sint-Katelijne-Waver, Antwerp, Belgium)

» **Problem:** Vegetable production in Mid-Flanders region, Belgium, is characterized by intensive systems with limited crop rotation, deep tillage, and high synthetic input usage. While these methods maximize short-term yields, they degrade long-term soil quality and biodiversity. Excessive fertilizer use, combined with soil disturbance and simplified crop rotations, leads to nutrient runoff, increased pest and disease pressure, and a decline in soil fauna and microbial complexity. The region's sandy loam soils, though productive, are especially vulnerable to these impacts, with risks of flooding enhanced by an underlying clay layer.

» **Best Management Practices:** The **SoildiverAgro** project compared intensive, extensive, and organic vegetable farming systems in neighboring fields to evaluate their effects on soil biodiversity and ecosystem functioning. Transition practices toward extensification—such as non-inverting tillage, greater use of organic amendments, and integration of cover crops—were tested and found to improve soil conditions significantly. Organic fields showed higher microbial diversity and more stable nematode and fungal communities, attributed to their broader rotations and greater organic matter inputs. Within intensive systems, switching to more extensive practices (e.g., reduced tillage and organic fertilization) also yielded positive effects, albeit to a lesser degree. This suggests that a gradual adoption of such practices can offer meaningful improvements in soil life without requiring full organic conversion. Importantly, the study also revealed variability within organic farms themselves, highlighting that extensification is a continuous process rather than a binary system shift. Farmers were more receptive to practices that demonstrated clear agronomic and environmental co-benefits, suggesting the potential for broader adoption if paired with advisory support and incentive programs.

Case study 9 – Atlantic Central (Flanders, Belgium)

» **Problem:** Agricultural activities in Flanders are influenced by the region's varied landscapes and soil types, affecting the production of key crops such as sugar beets, cereals, potatoes, and vegetables. Despite the introduction of sustainable practices, particularly organic farming, the area devoted to organic agriculture remains limited, and biodiversity is notably low, presenting challenges for ecosystem conservation. A major barrier to the widespread adoption of biodiversity-supporting practices, such as agro-ecology, is the reluctance of many farmers, who perceive these methods as unprofitable and overly dependent on subsidies, despite increasing evidence suggesting that they can be economically viable. Moreover, research on the long-term benefits of agro-ecological farming is still limited, with insufficient evidence to conclusively prove its potential to enhance profitability, reduce input costs, improve soil health, and increase biodiversity. Additionally, the continued use of pesticides and chemical fertilisers remains a significant challenge for advancing sustainability in the region.

» **Best Management Practices:** The **SoildiverAgro** project tested a variety of organic fertilisation treatments to address challenges in agroecological farming systems. Different sources of organic fertilisers were evaluated, including farmyard manure (FYM), compost (COM), and fermented organic material (FOM) such as grass silage. These treatments were compared with a control (BAU), where no organic fertilisation was applied, to assess their effects on soil organic matter, soil structure, and plant health. The goal was to promote more sustainable farming, reduce dependency on chemical inputs, and enhance biodiversity in agricultural ecosystems. Incorporating compost (COM) and fermented grass silage (FOM) in potato cultivation has shown significant benefits, particularly when compared to farmyard manure (FYM). Both treatments have improved potato yield and provided greater economic benefits in potato farming. Additionally, FOM has positively influenced soil dynamics by increasing earthworm populations, which helps improve long-term soil structure. While these results suggest that both compost and fermented grass silage offer consistent advantages, further research is needed to confirm these outcomes and establish the most effective practices for sustainable potato cultivation.

» Policy recommendations

In high-production temperate regions, such as Belgium, the Netherlands, and north-western France, where intensive farming prevails, **SoildiverAgro** trials have demonstrated that **organic amendments and diversified agricultural practices can sustain yields while improving soil health, offering clear guidance for policy.** A notable example is case study 6 (the organic system in Flanders), where the use of farmyard manure combined with high-carbon materials and cover crops successfully maintained potato yields while enhancing microbial and fungal communities in the soil. **Case studies 7** reinforce that cover crops, including multi-species mixtures, offer numerous benefits, from improved nitrogen retention to an increase in earthworm populations, particularly in Atlantic climates. Therefore, Common Agricultural Policy (CAP) eco-schemes or agri-environmental measures should incentivise the widespread integration of cover crops the results from the multi-species mix in **case study 7** were inconclusive in the short term, the emerging positive trend underscores the importance of long-term research and support for diverse cover cropping systems. **Policymakers should invest in multi-year trials across different regions to determine the most effective cover crop mixtures and management practices.** In the interim, voluntary adoption should be encouraged by covering establishment costs or offering small experimental grants to innovative farmers. It is essential, however, not to mandate overly complex mixes prematurely, but rather to build an evidence base while offering basic incentives (even simple two-species covers can represent progress).

Another key finding from the Atlantic Central region was that extensive or regenerative practices outperform intensive farming systems in the long term. **Case study 8**, which compared intensive with extensive vegetable farming, revealed that more diversified, low-input systems achieved equal or superior yields, increased soil organism populations (e.g., earthworms), and enhanced soil structure. This supports broader observations that **transitioning towards**

extensive farming can maintain productivity while bolstering resilience. Consequently, policy should prioritise incentives for regenerative farming as a form of sustainable intensification. For instance, payments for reduced tillage, longer crop rotations, and integrated crop-livestock systems should be scaled up. This direction aligns with EU objectives such as the Green Deal and the Farm to Fork strategy and can be linked to food security considerations: slightly lower peak yields are offset by greater stability and enhanced ecosystem services. **Authorities could establish targets to increase the proportion of farmland under extensive practices** (e.g. cover crops, no-till, greater use of agriculture amendments) and reward farmers who adopt these approaches through result-based payments (e.g. a soil health index, with bonuses awarded for improvements).

Furthermore, the Atlantic Central trials (**case study 9**) highlighted the potential of alternative organic fertilisers, such as compost and fermented green manure. The use of compost or fermented grass silage, as opposed to fresh manure, resulted in improved crop yields (notably potatoes) without the negative effects commonly associated with raw manure, which caused phosphorus imbalances and reduced biota activity in the trial. This suggests that **policy should facilitate access to high-quality compost and innovative fertilisers,** possibly by supporting farmer cooperatives that produce and distribute compost, or by subsidising equipment for the production of silage-based amendments. Training programmes can also educate farmers on how to produce or properly utilise these amendments. In conclusion, **the recommendation for Atlantic Central is to accelerate the transition towards more integrated nutrient management:** moving away from surplus chemical inputs and raw slurry, and towards systems that combine composted manure, cover crops, and precision application. This will require adjustments to regulatory frameworks (e.g. manure application standards that account for soil biodiversity) and economic support for the necessary changes, but it will yield multiple benefits, including cleaner water, healthier soils, and climate mitigation. Ultimately, only a profound transformation in manure and input management will enable soil biodiversity to flourish alongside productive agriculture—a transformation that pilot cases in this region have proven to be both feasible and beneficial.

Table 3. Summary of policy recommendations for Atlantic Central.

Case 6
• Promote the combination of farmyard manure application with cover crop incorporation in organic farming systems, as demonstrated to improve crop yields, enhance soil fertility, and foster healthier microbial and fungal communities.

- Support organic farmers in transitioning to or maintaining the use of organic fertilizers like farmyard manure by providing subsidies or incentives for organic manure production and application.
- Encourage the integration of cover crops as a standard practice for nutrient cycling and soil health management, recognizing their role in improving both soil structure and biological diversity.
- Develop and promote fertilization standards that address a holistic nutrient management approach, focusing not only on nitrogen but also on phosphorus, carbon, and other key elements essential for long-term soil fertility.

Case 7

- Prioritize long-term research funding to investigate the effects of species-rich cover crop mixtures across different environments, focusing particularly on maintaining biodiversity and optimizing biomass and nitrogen cycling.
- Encourage on-farm experimentation and collaboration between farmers and researchers, fostering adaptive management strategies that are locally tailored and evidence-based.
- While broad mandates for complex cover crop mixtures are not yet advisable, provide incentives for the voluntary adoption of these biodiversity-supporting practices within both organic and conventional farming systems.

Case 8

- Prioritize and incentivize extensive farming systems as a sustainable intensification strategy, achieving stable or improved yields while enhancing soil structure, microbial diversity, and ecosystem resilience.
- Align agricultural support measures with the environmental and food security goals outlined in the EU Green Deal and the Farm to Fork Strategy by promoting practices that maintain soil health and reduce dependency on intensive input use.
- Where nitrogen leakage is a concern, further encourage organic extensive farming systems to mitigate environmental impacts while sustaining agricultural productivity.
- Foster a transition toward regenerative agricultural models that emphasize long-term environmental stewardship, soil health, and biodiversity as central pillars of sustainable food systems.

Case 9

- Promote the adoption of agroecological farming systems that incorporate compost and fermented grass silage as organic fertilizers, based on their demonstrated benefits for crop yields and reduced environmental impacts compared to farmyard manure.

- Implement subsidies or cost-sharing programs for composting infrastructure, silage production, and technical training on composting and on-farm fermentation techniques to facilitate the adoption of these practices.
- Support the formation of farmer cooperatives to promote the local production and distribution of high-quality compost and silage, strengthening regional agricultural sustainability.
- Formally recognize agroecological farming as a strategic pathway toward climate-resilient, biodiverse, and economically viable agriculture in policy frameworks.
- Acknowledge the need for continued long-term, context-specific research on agroecological practices, soil conditions, and climate variability to inform flexible, evidence-based policy interventions.
- Design policies that avoid one-size-fits-all approaches and instead prioritize and reward measurable improvements in soil health through flexible and integrated management strategies.

Continental

Case study 10a – Continental Region (North Rhine-Westphalia, Germany)

» **Problem:** In conventional wheat cropping systems, managing soil-borne fungal pathogens like *Fusarium* heavily relies on the intensive use of fungicides and fertilizers. This chemical-dependent approach negatively affects soil biodiversity, particularly reducing beneficial soil organisms such as collembolans, and weakens natural soil self-regulation processes. Over time, soils under such regimes become more vulnerable to pest outbreaks, nutrient imbalances, and degradation of ecosystem functions, threatening the sustainability and resilience of wheat production systems.

» **Best Management Practices:** To mitigate these impacts, the **SoildiverAgro** planned the application of plant biostimulants in combination with plant adjuvants was tested as an alternative soil management strategy. This combined practice was shown to promote the diversity of soil collembolans and to support the abundance of fungivorous fauna, contributing to healthier soil microbial communities and enhancing natural disease suppression. Additionally, the use of biostimulants enabled a reduction in chemical fertilizer and fungicide inputs without compromising wheat yield, helping to restore the soil's biological functions while maintaining agricultural productivity.

Case study 10b – Continental Region (Saxony-Anhalt, Germany)

» **Problem:** Organic potato production systems face different but equally important soil health challenges. These systems often experience soil structure degradation, reduced soil fauna diversity, and yield instability, partly due to limited active soil management practices. In particular, without targeted practices to enhance soil biodiversity, organic fields can still harbor high levels of soil-borne pathogens and face reduced resilience to environmental stressors.

» **Best Management Practices:** The introduction of broad undersown crops such as *Vicia sativa, Linum usitatissimum, Lolium perenne, Trifolium resupinatum,* and *Guizotia abyssinica* proved effective in promoting soil faunal diversity and increasing the abundance of saprotrophic fungi. This practice enhanced soil biological activity and contributed to a healthier soil ecosystem capable of better supporting potato crops. Although some short-term yield reductions were observed, the long-term ecosystem service benefits, including improved soil structure and enhanced disease suppression potential, were notable outcomes of adopting undersowing strategies.

Case study 11 – Continental Region (North Rhine-Westphalia, Germany)

» **Problem:** Conventional wheat monocultures with narrow seed row spacing and intensive pesticide regimes contribute to low levels of soil biological diversity and limited natural disease suppression. These farming practices create simplified, uniform environments that do not support diverse soil microbial communities, reducing the system's ability to regulate harmful fungi like Fusarium. Furthermore, inappropriate selection of cover crops (such as red and white clover) can unintentionally foster phytopathogenic fungi, exacerbating soil health problems.

» **Best Management Practices:** To address these challenges, the adoption of wider seed row spacing (20 cm) combined with the strategic undersowing of non-host clover species, such as yellow clover and birdsfoot trefoil, was recommended. These practices promote greater diversity in soil faunal and microbial communities, enhance soil structure, and improve the natural regulation of soil pathogens. Selecting appropriate undersown species that do not host harmful Fusarium strains is crucial to maximizing soil health benefits and maintaining or even improving crop yields over time.

» Policy recommendations

Policy recommendations for the Continental region should focus on fostering soil biodiversity, promoting **sustainable crop management practices,** and reducing **dependence on chemical inputs.** To achieve this, policy frameworks should encourage the adoption of **biostimulants and adjuvants** in conventional wheat production, recognizing their role in supporting **soil faunal diversity** and enhancing **natural disease suppression** while reducing the need for fungicides and synthetic fertilizers. **Financial incentives** should be introduced to support **broad undersowing practices,** particularly in organic potato systems. These incentives should acknowledge the **ecosystem service benefits** provided by increased soil faunal and fungal diversity, even where short-term yield trade-offs may occur. Special emphasis should be placed on **advisory and training programs** that help farmers optimize species selection for **undersowing,** minimizing the risk of inadvertently fostering phytopathogenic fungi. In conventional wheat systems, **structural diversification measures** such as **wider seed row spacing** and the strategic integration of **non-host clover species** should be promoted. These practices enhance the complexity of the cropping system, improve soil structure, support beneficial soil organisms, and strengthen the natural regulation of soil-borne pathogens. Overall, Continental agricultural policy should transition towards an **integrated biodiversity-enhancing approach.** This can be achieved through **targeted subsidies, technical support,** and **knowledge transfer initiatives** that collectively promote resilient, self-regulating, and ecologically sustainable cropping systems.

Table 4. Summary of policy recommendations for Continental.

Case 10a
• Promote the application of plant biostimulants combined with plant adjuvants in conventional wheat systems to enhance collembolan diversity and contribute to a broader range of ecosystem services provided by soil fauna. This strategy also helps to reduce fungal pathogen incidence and increase plant health, thereby supporting more resilient and sustainable cropping systems. • Encourage the use of biostimulants and adjuvants as a complementary tool to decrease fungicide applications. These practices can contribute to lowering soil-borne fungal pathogen loads while maintaining crop performance, offering an effective pathway to reducing chemical inputs in conventional farming. • Subsidise the use of biostimulants and adjuvants in conventional wheat production to make their application an attractive and economically viable alternative for farmers.
Case 10b
• Promote the use of undersown crops in organic potato cultivation to enhance the abundance of microarthropods and the diversity of collembolan communities, thereby strengthening the ecosystem services they provide. Undersown crops have demonstrated positive effects not only on soil biological activity but also on yield quality and quantity in subsequent growing seasons. • Support the practice of broad undersowing, as it has been shown to be more beneficial than strip undersowing for promoting soil faunal diversity, saprotrophic fungal abundance, and overall soil health. Financial incentives and advisory support could encourage wider adoption of this biodiversity-enhancing practice within organic farming systems.

Case 11

- Encourage the implementation of clover undersowing in wheat cultivation to promote fungivorous soil fauna that act as natural antagonists to soilborne fungal plant pathogens. This strategy can strengthen natural disease suppression processes and improve soil ecosystem resilience.
- Provide advisory services and technical guidelines to ensure appropriate clover species selection, emphasizing the use of yellow clover and birdsfoot trefoil, while avoiding white and red clover varieties known to potentially harbor phytopathogenic fungi such as *Fusarium* species.

Nemoral

Case study 12 – Nemoral Region (Estonia)

» **Problem:** In the Nemoral region, cereal production systems face substantial challenges related to soil biodiversity loss, soil structure degradation, and persistence of pesticide residues. Conventional tillage practices significantly reduce earthworm abundance and biomass, impairing nutrient cycling and soil aeration, which are critical for sustainable agriculture. Although no-tillage and organic farming practices promote higher earthworm diversity and lower pesticide residues, transitioning to these systems remains difficult due to economic barriers, such as higher input costs, initial investment requirements for specialized equipment, and yield instability in organic systems. Moreover, persistent pesticide residues were detected even in organically managed fields, suggesting long-lasting impacts of past conventional practices on soil ecosystems.

» **Best Management Practices:** To promote soil biodiversity and long-term soil health, the adoption of no-tillage and organic farming practices is recommended, particularly tailored to soil type and field conditions. No-till practices enhance earthworm abundance and biomass, while organic farming further boosts biodiversity by eliminating synthetic chemical inputs and promoting the use of organic amendments. Incorporating short-term grasslands into crop rotations can also significantly improve soil biota communities. However, successful implementation requires careful management to address potential challenges, such as weed pressure in no-till systems or labor demands in organic farming. Integrated Pest Management (IPM) strategies should be combined with reduced tillage to mitigate pest issues without increasing chemical dependence. Regular soil health monitoring is essential to track the impact of management practices over time and to adapt strategies as needed.

» Policy recommendations

Policies should promote the transition towards no-tillage and organic farming practices by providing targeted financial incentives, particularly for investments in specialized machinery and for the adoption of practices that enhance soil biodiversity. Subsidies for organic fertilizers and compost amendments could support decomposer activity and improve soil fertility. Furthermore, policy frameworks should encourage Integrated Pest Management (IPM) approaches to reduce pesticide use while maintaining crop protection. Soil health assessments and monitoring programs must be institutionalized to evaluate the long-term effects of different soil management systems. In addition, rural development programs should promote the incorporation of grasslands into crop rotations to support soil biota. Finally, policymakers should recognize the economic trade-offs associated with different tillage systems and provide transitional support to ensure that no-tillage and organic systems become both agronomically and economically viable for farmers in the Nemoral region.

Table 5. Summary of policy recommendations for Nemoral.

Case 12
• Promote no-tillage and organic farming practices adapted to soil type to enhance earthworm abundance and soil biota diversity. • Encourage the use of organic fertilizers to improve soil fertility and support decomposer organisms essential for soil health. • Implement regular soil health assessments and monitoring to track the impacts of agricultural practices on nutrient cycling and biodiversity. • Advocate for Integrated Pest Management (IPM) strategies to reduce chemical pesticide use while maintaining crop protection. • Support the integration of short-term grasslands into crop rotations to promote soil biodiversity and improve soil structure. • Recognize the economic trade-offs of no-tillage and reduced tillage systems and provide transitional support to maintain farm profitability.

Boreal

Case study 13 – Boreal Region (Laitila, Southwest Finland)

» **Problem:** In Southwest Finland, early potato production is common, but its short cropping period (1.5–2 months) leaves soils bare for most of the year, increasing vulnerability to erosion, carbon loss, and nutrient leaching. This issue is particularly pressing in coarse soils subject to annual ploughing and frequent pesticide applications, which degrade soil structure and hinder the development of a resilient biological community. Farmers in the region face challenges in maintaining soil fertility and biological diversity under these constraints.

» **Best Management Practices:** The **SoildiverAgro** project explored the potential of using organic forest-derived amendments—byproducts of the pulp and paper industry—to improve soil health and biodiversity in early potato systems. Three types of amendments were tested: nutrient-poor fiber sludge (FS) and two nutrient-rich sludges, composted pulp mill sludge (CPMS) and lime-stabilized pulp mill sludge (LPMS), applied at 50 t/ha. These amendments were chosen for their organic content and potential to enhance microbial activity, organic matter, and soil structure. Over three years of monitoring, the study did not observe significant changes in soil prokaryotic or fungal diversity, nor in earthworm populations. While some shifts were detected in nematode communities, they appeared to reflect seasonal dynamics more than treatment effects. Economically, the use of these amendments was not profitable; application costs exceeded the revenue from harvests, and the break-even point was only achievable under yield increases not observed in the trial. These findings suggest that, under current conditions and without economic incentives, forest-based soil amendments are not a viable strategy for improving biodiversity in early potato production. However, they may hold long-term promise if yield responses improve or if market conditions change.

Case study 14 – Boreal Region (Finland)

» **Problem:** In Finnish boreal agricultural systems, intensive cereal cultivation (notably wheat and barley) in clay-rich soils often results in compaction, low soil biological activity, and poor aeration. Regular ploughing, combined with short growing seasons and heavy precipitation, leads to significant structural degradation and limited resilience in microbial and faunal soil communities. There is growing interest among farmers in adopting reduced tillage to preserve soil quality, but concerns remain over potential impacts on crop yields and weed control.

» **Best Management Practices:** The **SoildiverAgro** project tested reduced tillage versus deep moldboard ploughing practices in two complementary experiments under boreal climatic conditions. In case study 14a, researchers compared conventional ploughing in spring with shallow minimum tillage in cereal (spring wheat) systems. Sudden spring ploughing did not change soil biology or physical conditions achieved by long-term minimun tillage in organic wheat farming. In case study 14b, researchers compared conventional ploughing in autumn with shallow minimum tillage in cereal (winter wheat) systems. Sudden autumn ploughing caused minor changes in soil biology, nematodes and earthworms. Across both trials, reduced tillage that has been applied in both field for a long-time tended to support higher fungal biomass and improved functional diversity among nematode communities—especially bacterivores and omnivores. Despite high interannual variability and relatively short monitoring timeframes, reduced tillage was found to have a stabilizing effect on soil biology, particularly under wet conditions where ploughing risks are elevated. However, infrequent ploughing, espacially in spring, can be applied as part of the weed management strategies in organic cereal cultivation in fields with initially good structural and functional soil.

Case study 15

» **Problem:** In early potato farming systems of Southwest Finland, the short cropping period—typically just 1.5 to 2 months—leaves the soil bare for most of the year, exposing it to significant risks of erosion, nutrient leaching, and carbon loss. This is especially problematic in coarse-textured soils frequently subjected to ploughing and pesticide use, which further deteriorate soil structure and suppress biological diversity. Farmers face pressure to identify sustainable solutions that mitigate environmental risks while maintaining productivity.

» **Best Management Practices:** The **SoildiverAgro** project investigated the use of catch crops to reduce erosion, improve nutrient retention, and promote biological activity in early potato fields. Two catch crop strategies were compared: one using **phacelia** (*Phacelia tanacetifolia*) and another combining **rye** (*Secale cereale*) with **Westerwolds ryegrass** (*Lolium westerwoldicum*). These were sown in mid-July following the potato harvest and cultivated until winter. Although no significant effects were observed on microbial or earthworm diversity, and nematode results were inconclusive, there were indications that catch crops could help regulate soil-borne pest populations. Economically, however, the implementation of catch crops proved unfeasible under current market conditions. The additional costs of seed and field management were not recovered through yields, meaning that only significant productivity gains or financial incentives would make this practice viable for farmers. The study concluded that, while promising from a conservation perspective, catch cropping requires either yield enhancement or policy support mechanisms to become economically sustainable in the Finnish early potato sector.

» Policy recommendations

In the boreal regions of Europe (Finland, Scandinavia – cold climates with short growing seasons), **SoildiverAgro** case studies underscored the need for long-term strategies and careful economic considerations in soil biodiversity measures. One insight from case 13 (early potato system in SW Finland) was that applying **organic amendments from forestry side-streams** (like composted pulp mill sludge) did not harm soil biodiversity but also did not show clear short-term gains in crop yield or soil health. Moreover, the added cost was significant, making it unprofitable for farmers without support. Therefore, policy should approach such measures cautiously: large-scale use of novel soil amendments (e.g. industrial by-products) should **not be expected of farmers unless subsidies or clear long-term evidence of benefit exist.** The recommendation is to **invest in long-term research and pilot projects** to evaluate these amendments over a longer period (5–10 years). If future data show that forest-industry composts build up soil organic matter or resiliency in the boreal context, then targeted support could be introduced to help farmers adopt them. In parallel, policymakers should explore the idea's merit from a circular economy perspective – e.g. assess at EU level whether agricultural soils in boreal areas could serve as beneficial "sinks" for certain safe organic by-products, which would require demonstrating no harm to soil biota and providing compensation to farmers for application. The **case 14** in Finland examined the impact of an abrupt return to **deep ploughing** in long-term no-till organic fields. The finding was that routine ploughing is not cost-effective in organic systems unless absolutely needed (e.g. for severe weed infestations), and timing matters.

Thus, boreal policies should discourage frequent inversion tillage on organic farms – **moldboard ploughing should only be used with clear justification,** given its disruption to soil life and high fuel costs. If ploughing is deemed necessary, it is recommended to perform it in spring rather than autumn. Spring ploughing in boreal cereals (instead of autumn) can reduce overwinter soil erosion and nutrient loss, and it gives soil biota a better chance to rebound before winter dormancy. Extension programs should communicate that shallow or minimum tillage combined with other weed control methods is preferred for maintaining soil organisms, and that deep ploughing in organic farming should be a last resort. To reinforce this, organic certification bodies or subsidy schemes could include criteria or incentives for reduced tillage, while still allowing exceptions for problem situations. The **case 15** addressed the longstanding challenge of bare fallows after early crop harvests (like early potatoes harvested by midsummer, leaving soil exposed). Two types of **catch crops** were tested (phacelia and a rye/ryegrass mix) to cover the soil until winter. The experiment found no immediate yield or soil health benefit and noted that farmers would incur costs with little short-term return. Consequently, the recommendation is to **approach catch crops in boreal rotations with adaptive support.** Policymakers should still encourage cover cropping (to prevent erosion and nutrient leaching), but they must recognize that in very short growing seasons, a single-species catch crop may not pay off for the farmer. To overcome this, provide adequate incentives (e.g. cover crop grants that fully cover seed and labor costs) and focus on the long-term soil benefits in justification. It's also advised to **expand research on catch crop species and mixtures suited to boreal conditions** – for example, test winter-hardy cover crops or mixes that could establish after early crops and survive partway into winter. Until such solutions are found, avoid imposing strict cover crop requirements that could create farmer pushback; instead, use voluntary schemes with compensation and continue trials to identify what works in the boreal context. Thus, boreal soil biodiversity policy should prioritize **continuous soil cover and minimal disturbance,** but implement these goals in a flexible, evidence-based way. Winter cover (living or dead mulch) on fields should be maximized – this could mean green cover where feasible or leaving crop residues where a planted cover won't establish – supported by existing agri-environment payments. Additionally, **drainage management and over-winter field practices** deserve attention (as healthy soil biota depend on not only what you add to soil, but also physical conditions like waterlogging and frost). For instance, controlled drainage and water table management can protect soil microbes from being flushed out during spring snowmelt – such infrastructure investments (already encouraged in Finland) benefit both water quality and soil life. Finally, given the innovative approaches being tested (from biochar to cold-tolerant microbial strains), boreal authorities should create funding streams for **R&D in cold-climate soil biology.** Developing inoculants or soil amendments specifically adapted to function at lower temperatures could be a game-changer for boreal agriculture's sustainability. By supporting innovation and remaining pragmatic (acknowledging economic realities for farmers), policy in the Boreal region can gradually achieve healthier soils without jeopardizing farm viability.

Table 6. Summary of policy recommendations for Boreal.

Case 13
• Encourage further long-term research into the use of organic soil amendments sourced from pulp-mill industry side-streams in early potato farming systems. While short-term profitability for conventional farmers appears limited, these organic materials have shown no harmful effects on soil biology during the research period. • Promote investigations at both national and EU levels into the potential of forest industry by-products to complement fertilizers within circular economy models, enhancing national supply security. Boreal fields could serve as valuable sinks for such side-streams, supporting sustainable resource management if properly assessed.
Case 14
• Advocate for the adoption of springtime ploughing in boreal cereal fields whenever agronomically feasible, as an alternative to autumn ploughing, to minimize soil erosion and nutrient runoff risks. • Recommend that mouldboard ploughing in organic wheat systems not be promoted indiscriminately. Instead, it should only be applied when justified by specific agronomic challenges, such as persistent weed infestations or phosphorus runoff concerns, considering its limited cost-effectiveness for farmers.
Case 15
• Support continued long-term research into the role of catch crops in boreal early potato systems, recognizing that short-term profitability is currently limited but that ecosystem service benefits may emerge over time. • Encourage the exploration of a wider range of catch crop species and mixtures—such as *Phacelia*—as well as improved methods for pest and disease management in boreal conditions. Emphasize the need to evaluate catch crop benefits within more diversified crop rotations rather than under single-crop systems.

6.

Impact of conventional *vs. sustainable practices: Benefits and trade-offs*

The contrast between conventional intensive agriculture and more sustainable, biodiversity-enhancing practices has important policy implications. Conventional systems typically rely on external inputs (synthetic fertilizers, pesticides, intensive tillage) to maximize short-term yields, often at the expense of soil biodiversity and long-term soil fertility (European Commission, 2021b).

Sustainable practices, by contrast, work with ecological processes (e.g. crop rotation, organic inputs, reduced chemicals) and tend to have multiple benefits – including environmental gains and greater economic resilience. **SoildiverAgro** results allow quantifying some of these differences, which can guide policymakers in evaluating the full costs and benefits of each approach.

» Environmental and agronomic benefits

Sustainable soil management yields significant environmental benefits over conventional methods. For example, reduced fertilizer regimes combined with organic inputs were shown to **lower nutrient losses** to the environment without harming yields (case studies 6 and 9). This implies less water pollution (nitrates, phosphates) and a lower risk of eutrophication downstream (European Commission, 2019; Council of the European Communities, 1991). Conventional high-input farming often ignores such external costs, whereas sustainable practices internalize them by cycling nutrients on-farm. Another example is greenhouse gas emissions: conventional systems with frequent plowing and heavy machinery use emit more CO_2 and N_2O, while no-till or minimum-till systems with cover crops can sequester carbon and cut emissions (case study 14). A life-cycle assessment (LCA) in the project found that some alternative treatments had markedly **lower carbon footprints** per hectare than business-as-usual operations (case studies 6 and 8) (Banse et al., 2025). Thus, from a climate policy perspective, sustainable practices confer mitigation benefits. Additionally, more biologically diverse soils in sustainable systems show greater resilience to climate extremes – they retain more moisture in droughts and drain better in floods, leading to more stable yields (FAO et al., 2020). From an agronomic perspective, sustainable practices improve soil structure and fertility. Conventional practices that degrade soil (like over-tillage) cause compaction, erosion, and ultimately yield decline (case studies 13 and 15), resulting in a loss of natural soil capital. In contrast, practices like adding compost or maintaining living roots year-round build soil structure and increase nutrient availability through biological nitrogen fixation and enhanced mineralization (case studies 1, 3 and 4). The result is often improved yield stability and in some cases yield increases after an initial transition. For example, in **SoildiverAgro** trials, yields of crops in rotation with legumes and cover crops equaled or exceeded yields in monoculture with heavy fertilizers, thanks to improved soil health (case studies 2,5, and 7) (Banse et al., 2025). These benefits are mutually reinforcing: healthier, more biodiverse soil requires fewer remedial inputs (e.g. less need for soil fumigants or corrective fertilization), creating a positive feedback loop of reduced inputs and improved soil function.

» Economic benefits and trade-offs

Crucially for policy, many sustainable practices are economically competitive with conventional ones, especially over a medium-to-long term horizon (case studies 6, 9 and 12). **SoildiverAgro**'s farm-level economic analysis found that input-reduction strategies often saved costs without significantly reducing revenue (cases studies 6 and 8) (Banse et al., 2025). For example, in conventional vs. sustainable comparisons, a farmer cutting synthetic nitrogen fertilizer by growing legumes saved input costs; if yields held (as they often did, thanks to improved soil nitrogen supply), profit margins improved (European Commission, 2022a). Similarly, switching to low-till saved fuel and labor costs, which in some cases outweighed small initial yield dips (case study 14). The project noted that organic and conservation farming can be more profitable in several cases, partly due to price premiums and partly due to input cost savings (case studies 12 and 13). This runs counter to the common assumption that eco-friendly farming is always less productive or profitable. However, some trade-offs exist: certain sustainable practices may require upfront investment or have a learning curve (case study 9). For instance, adopting a pest alert system (DSS) initially required investing in monitoring equipment and trusting an unfamiliar system; some farmers might experience slight yield losses if the system is not perfectly optimized at first. This is where policy support – training, subsidies for technology, risk-sharing mechanisms– is key to managing the transition. Another economic consideration is risk and resilience. Conventional systems often maximize short-term returns but can be vulnerable to shocks: a pest outbreak can devastate a monoculture, or a spike in fertilizer prices (as seen recently) can severely hurt a high-input operation (general across all **SoildiverAgro** cases, especially case studies 9 and 15). Sustainable systems, with their diversity and lower dependence on external inputs, inherently spread and reduce risks. There is a clear policy interest in promoting this resilience. A trade-off might be that some sustainable practices produce slightly lower maximum yields under ideal conditions (e.g. organic yields can be a bit lower in perfect weather years), but they outperform under stress – yielding more in drought years or when input costs soar – leading to better multi-year average performance (European Commission, 2024b). Thus, policies aimed at long-term food security should favor the stability provided by sustainable practices.

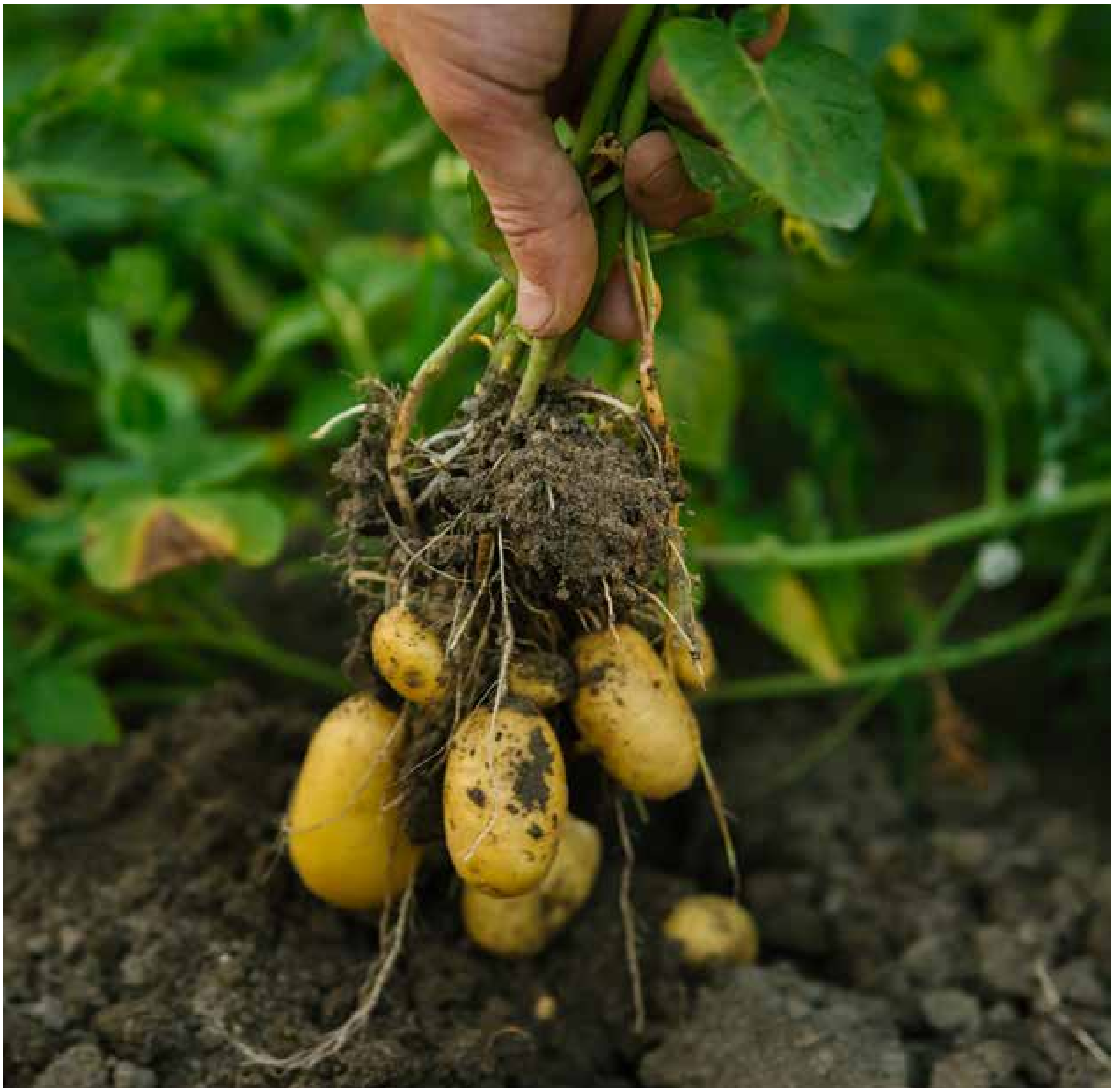
» **Public goods and externalities**

Conventional farming's negative externalities (water treatment costs, biodiversity loss, GHG emissions) are often borne by society (European Commission, 2020b), whereas sustainable farming provides positive externalities (cleaner water, carbon sequestration, pollinator habitat) (case studies 7 and 9). Policies need to account for this difference. The recommendations above about incentives are essentially ways to reward farmers for the public goods they produce with sustainable practices – and conversely, make those who contribute to external costs bear more responsibility (European Court of Auditors, 2020). For example, a performance-based incentive for biodiversity-friendly farming effectively shifts some societal value (public funds) to the farmer as a reward for delivering environmental benefits (General across all **SoildiverAgro** cases; especially 10b and 11). This helps level the playing field, which is currently tilted because conventional farmers typically do not pay for pollution cleanup or biodiversity loss. Innovative mechanisms like Payments for Ecosystem Services (PES) or results-based payments can operationalize this: e.g., a scheme could offer bonus payments if a farmer's soil organic matter or biological activity increases beyond a certain benchmark, reflecting real environmental gains (case studies 3 and 4). At the same time, "polluter pays" principles (such as penalties for excessive fertilizer or pesticide runoff) can disincentivize practices that externalize costs. Adjusting insurance and risk management tools is another angle – for instance, crop insurance could give premium discounts to farms with verified soil health improvements, recognizing their lower risk profile (European Commission, 2022a).

In conclusion, the evidence strongly suggests (FAO et al., 2020; European Commission, 2021b) that sustainable, soil biodiversity-enhancing agriculture is not only viable but advantageous when considering full costs and benefits. Policymakers should actively communicate these benefits to stakeholders: healthier soils mean a win-win for farmers and society. Bridging the gap in the short term (through targeted subsidies, technical assistance, and transition insurance) can help farmers overcome initial hurdles. In the long term, as sustainable practices become the norm, the economic and environmental dividends – in the form of resilient production and reduced downstream costs – will far outweigh the investments.

7.

Barriers and *opportunities in implementation*



Implementing the above policy recommendations faces a range of barriers – regulatory, economic, and technical – but also presents significant opportunities. Understanding these is fundamental for developing effective and realistic policies.

7.1 Barriers

» **Regulatory inertia and fragmentation:** One barrier is the slow pace of policy change and divided competencies. Soil protection cuts across environment, agriculture, and sometimes regional authorities, yet there is no integrated legal framework addressing all soil processes. Most existing soil laws focus only on single issues (e.g. desertification or contamination) and are enacted at the national level (Van der Putten et al., 2023). Different Member States have varying priorities; some might resist stringent soil regulations due to perceived short-term costs for farmers. Additionally, existing rules (e.g. certain CAP provisions) may inadvertently discourage innovation by being too prescriptive. For example, a farmer wanting to try an unconventional multi-species cover crop might be constrained by rules that only recognize certain crop types or by insurance policies that don't cover "unusual" rotations. Overcoming this requires strong coordination and political will at the EU level – for instance, integrating soil biodiversity targets into CAP conditionality uniformly, so all countries move together. It also requires flexibility in regulations to allow local experimentation (e.g. permit derogations for on-farm trials of new practices). Furthermore, historically there has been a lack of explicit soil biodiversity policy at EU level, leading to institutional knowledge gaps and no established framework for action (Zeiss et al., 2022). This absence of clear goals has been cited as a major reason for the alarming decline of soil health, contributing to inertia in addressing soil biodiversity.

» **Economic and market barriers:** Farmers may face upfront costs for adopting new practices (buying new machinery for no-till, purchasing bio-inoculants, etc.) or potential short-term yield dips during the transition. Without assurances that they will be compensated or that markets will reward sustainably produced products, farmers can be reluctant to change. Access to finance can be a barrier; banks might be unfamiliar with lending for regenerative practices or uncertain of the returns (European Investment Bank, 2021). Additionally, some sustainable outputs (like certain cover crops or novel rotation crops) lack developed markets. A farmer might grow a soil-improving crop but find no buyer or low prices, making it economically unappealing. These market failures can stall adoption of otherwise beneficial practices.

» **Technical and knowledge barriers:** There is still a knowledge gap regarding soil biodiversity among many farmers and advisors. Traditional agricultural education often didn't cover soil ecology in depth. Farmers might not know how to measure improvement in soil biodiversity or might be skeptical of "unseen" benefits. This barrier was evident in the project: attitudes varied, and some farmers were hesitant about practices like undersowing cover crops or reducing chemical inputs without clear immediate gains (Pouta et al., 2025). Additionally, technical barriers such as lack of suitable machinery can hinder implementation. For example, not all farmers have access to no-till seeders, inter-row mowers, or precise manure spreaders that new practices may require. Equipment for some innovations (like spore traps for disease forecasting or biochar applicators) may not yet be widely available or affordable. Moreover, innovations often need adaptation to local conditions – a technique successful in one soil or climate might need tweaking elsewhere. Without on-the-ground technical support to make these adjustments, farmers can become frustrated if initial trials fail.

» **Cultural and social barriers:** Farming practices are often deeply embedded in local culture. Peer pressure or local norms can either support or impede change. In some communities, a farmer doing things differently might face social scrutiny or feel stigmatized for a "messy" farm (e.g. fields with cover crop residue instead of neatly plowed soil). On the other hand, in regions where a few innovators have led the way (like established conservation agriculture groups), there can be positive peer influence that accelerates adoption. Overcoming negative social perceptions may require visible demonstration sites and respected local "champions" to shift mindsets. It is important to frame soil-friendly practices not as a rejection of tradition, but as an evolution of the farming legacy – sometimes terminology and communication (for instance, emphasizing regenerative agriculture as restoring old wisdom) can help in culturally sensitive contexts

» **Short-term policy and funding cycles:** Many policies and funding programs run on short cycles (e.g. 5-year CAP programming or 3-year project grants), whereas soil health improvement is a long-term endeavor (European Commission, 2020a; European Court of Auditors, 2020). This mismatch can be a barrier; farmers worry that after a few years the support might vanish even though the benefits of, say, building up soil organic matter accrue over a decade or more. A farmer might be unwilling to invest in agroforestry or lengthy rotations if policy support might shift with the next government. Consistent, long-term policy commitment is needed to give farmers confidence. Similarly, research funding often focuses on short projects, potentially missing longer-term soil biodiversity dynamics (many soil changes happen slowly). Ensuring continuity – through long-term trials, ongoing advisory services, and stable incentives – is a challenge under typical funding structures.

7.2 Opportunities

» **Alignment with broader agendas:** There is strong alignment of soil biodiversity enhancement with overarching agendas like the European Green Deal, the Climate Law, and the Sustainable Development Goals. This means there is political momentum and public support that can be harnessed. For example, climate action funds can be tapped for soil carbon projects that also benefit biodiversity (two birds with one stone). The fact that soil health is now prominently on the EU policy table – with the EU Soil Strategy 2030 and the proposed Soil Monitoring Law – is a huge opportunity to institutionalize these practices (Van der Putten et al., 2023). **SoildiverAgro** results can feed directly into these policy processes as scientific evidence, helping to shape definitions and targets (e.g. what constitutes "healthy soil" or which indicators to use). Internationally, the post-2020 Global Biodiversity Framework also recognizes soil biodiversity, which could open avenues for cooperation and funding. In short, soil biodiversity has moved from an obscure topic to a recognized priority, creating a conducive environment for policy action.

» **Economic opportunities for farmers:** The transition to sustainable practices can open new revenue streams for farmers. There is growing consumer demand for sustainably produced food; certifications like organic, regenerative, or "biodiversity-friendly" can command premium prices. Also, emerging markets for ecosystem services (carbon credits, biodiversity credits) mean farmers could get paid not only for commodities but also for stewardship (European Commission 2020b; 2021b; European Investment Bank 2021). For instance, a farmer who increases soil carbon might soon be able to sell carbon credits to companies offsetting emissions. If structured well, this is an opportunity to funnel private investment into sustainable agriculture. Additionally, cost savings from reduced input use are an immediate gain: money not spent on excessive fertilizers/pesticides is money saved, improving farm profitability and resilience to input price shocks. Diversification can also improve farmers' economic stability – integrating an extra crop or enterprise (like livestock for manure, or a legume crop for a new market) can spread risk and potentially increase income. Policies that help farmers capture these opportunities (through market development, credit access, or cooperative initiatives) will make adoption of soil-friendly practices much more attractive.

» **Technological advances:** Advances in ag-tech provide opportunities to overcome previous barriers. Precision agriculture (drones, soil sensors, AI) can monitor soil conditions and crop health in real time, enabling targeted interventions that preserve soil (for example, variable-rate fertilization that avoids over-application in certain zones). Breeding and biotechnology also present opportunities: for instance, developing crop varieties that are symbiotic with specific soil microbes (such as legumes that nodulate more effectively with native rhizobia, or crops bred for deep root systems to support soil structure). Similarly, the rise of bio-inoculant industry means farmers may soon have access to microbial "cocktails" tailored for their crops and soils.

As these technologies become available, policies can accelerate their adoption through innovation grants, tax incentives, or fast-track regulatory approval for proven safe products. The EU's Horizon Europe research program and national innovation funds are already investing in such solutions, meaning a pipeline of new tools for farmers is on the way (European Commission, 2024a). This can make it easier and more efficient to implement soil biodiversity practices – for example, robotics could one day handle labor-intensive tasks like intercropping or weeding, removing a barrier to techniques that benefit soil life by reducing chemical use.

» **Multi-actor and bottom-up initiatives:** The EU and many countries are embracing multi-actor approaches in agricultural innovation. Operational Groups under EIP-AGRI (European Innovation Partnership) bring together farmers, scientists, and advisors to solve practical problems. This is an opportunity to disseminate soil biodiversity practices quickly: by funding more EIP-AGRI projects on soil health, best practices can spread rapidly via peer-to-peer networks (European Commission/EPI-AGRI, 2020). Communities of practice, like those **SoildiverAgro** fostered around its case studies, can outlast the project and become local hubs of knowledge. Policymakers can support these networks formally – for example, through continued funding for farmer field schools, "living labs" and lighthouses (as in the EU Soil Mission), or by integrating such groups into extension services. Bottom-up initiatives ensure that policies are grounded in reality and farmer experience, increasing uptake. They also encourage innovation from the ground up – farmers often adapt and improve practices in ways that top-down regulations cannot anticipate. By creating space for these grassroots efforts (via flexible funding and supportive policy frameworks), governments can capture local insights and foster a sense of ownership among stakeholders.

» **Synergies with other objectives:** Improving soil biodiversity creates co-benefits that align with other policy goals such as water protection, climate adaptation, rural development, and public health. These synergies mean a single policy action (like incentivizing cover crops) can yield multiple dividends. For example, healthier soils with more organic matter retain water better, which aids climate adaptation by reducing both drought stress and flood risk – a priority under climate resilience plans. Reducing agrochemical use through soil biology base products not only benefits soil biodiversity but also leads to cleaner water and food, aligning with the Zero Pollution Action Plan and public health goals (European Comission, 2021d, 2021e). Recognizing and communicating these co-benefits can attract funding from various sources (e.g. water utilities paying farmers for cover crops that protect watersheds, climate funds supporting soil carbon-building practices). It also helps build broad coalitions in support of implementation: environmental NGOs, consumer organizations, and farmer groups can all find common cause in soil initiatives when they see that their respective goals (be it biodiversity, clean water, or farm income) are furthered. This multifaceted value of soil biodiversity efforts is an opportunity to justify ambitious measures and secure political and societal backing for them.

8.

Integration *with the CAP and other EU initiatives*

Integrating **SoildiverAgro** recommendations into existing policy frameworks is critical for effective implementation. The Common Agricultural Policy (CAP) is the primary tool influencing farming practices in the EU, and it has undergone reforms that allow greater emphasis on environmental and climate objectives, including soil health. Additionally, a suite of other EU initiatives – from the Biodiversity Strategy to the Green Deal's climate actions and the new Soil Mission under Horizon Europe – provide entry points for embedding soil biodiversity considerations. This section discusses how the recommendations can be woven into these policies cohesively.

Common Agricultural Policy (CAP) Integration

The CAP 2023–2027 introduced Eco-Schemes (under Pillar I) and revamped Agri-Environment-Climate Measures (AECM) under Pillar II, which are ideal vehicles for soil biodiversity actions. Member States, in their CAP Strategic Plans, can include specific eco-schemes targeting soil management (and many have, e.g. support for cover cropping, precision farming, integrated pest management) (European Commission, 2023a). We recommend that the European Commission, when approving and later evaluating these plans, prioritize those that incorporate ambitious soil measures and encourage others to scale up. For instance, if a country has an eco-scheme for integrated pest management, the Commission could push to broaden it to explicitly mention reducing soil pesticide loads and increasing on-farm biodiversity, aligning it with **SoildiverAgro** insights. CAP's conditionality now includes standards like GAEC 6 (protect soil structure via appropriate tillage), GAEC 7 (crop rotation), and GAEC 8 (non-productive features like field margins), all of which relate to soil health (European Commission, 2023a). It's crucial that enforcement of these GAEC standards considers soil biodiversity – e.g., GAEC 7 requiring crop rotation could be enforced not just in letter (avoid monoculture) but in spirit (ensure rotations include legumes or deep-rooted crops that truly benefit soil life). This would integrate our recommendations at the baseline level for all farmers receiving subsidies. Moreover, CAP Pillar II can fund more tailored regional measures. Countries should use their Rural Development Programs to pilot **result-based soil payments** (paying for measured outcomes like higher soil organic matter or earthworm counts), support advisory services on soil management, and invest in soil health labs and monitoring. **SoildiverAgro** deliverables and data can serve as references for Managing Authorities designing these interventions. For example, a Managing Authority could cite project findings that reducing fertilizers and tillage is profitable to justify a new grant for farmers to purchase no-till equipment or to conduct detailed soil health assessments. Knowledge-sharing through the CAP Network can spread such best practices between countries. An important integration would be aligning CAP incentives with the forthcoming Soil Monitoring Law: once the law defines "sustainable soil management" practices, the CAP should explicitly fund those practices. If the Soil Monitoring Law sets targets (e.g. increase soil organic carbon by X% by 2030), Member States might need to adjust their CAP Strategic Plans to allocate more resources to meeting those targets. The mid-term review of the CAP plans offers an opportunity to make such adjustments in line with EU soil objectives.

Alignment with EU Biodiversity Strategy 2030

The EU Biodiversity Strategy 2030 calls for increasing farmland biodiversity, including a target to dedicate 10% of agricultural land to high-diversity landscape features. The implementation of the previously mentioned **SoildiverAgro** recommendations helps to achieve this. The Biodiversity Strategy also emphasizes reducing pesticide use and nutrient loss; those actions, if implemented via Farm to Fork targets and the proposed Sustainable Use of Pesticides Regulation, will automatically push farmers to rely more on soil biology for fertility and pest control. Thus, the Biodiversity Strategy and our recommendations are mutually reinforcing: as pesticide rules tighten, farmers will adopt biocontrol and diversified rotations – and policy should support this shift, creating a virtuous cycle. In integrating with this initiative, Member States should ensure their CAP plans and national policies explicitly link to biodiversity goals (for instance, using AECM to pay for conservation tillage that benefits soil fauna, or for mixed cropping that provides habitat diversity). The 10% non-productive area goal can be met in ways that maximize soil biodiversity. Funding from both CAP and LIFE programs could be combined to assist farmers in establishing these features.

European Green Deal and Soil Monitoring Law

The Green Deal's broad climate and environment goals give strong political backing to integrate soil measures across policies (European Commission,2019). The proposed Soil Monitoring Law (also referred to as the Soil Monitoring Law) will likely require Member States to assess soil health periodically and take action to improve soils in poor condition (European Commission, 2023b). This law can act as a lever to ensure CAP Strategic Plans pay due attention to soil. Essentially, the CAP can be one of the "implementation tools" to achieve the Soil Law's objectives. We suggest that once the Soil Monitoring Law is adopted, the Commission and Member States conduct a gap analysis. The law is also expected to define sustainable soil management – likely including many practices we recommend – and CAP should then become the funding mechanism to roll those out (with national measures complementing it). It's crucial to ensure coherence: the same definitions and indicators for soil health should be used in CAP monitoring and in Soil Law reporting so that farmers are not confused by different benchmarks and reporting duties. In preparation for the Soil Monitoring Law, some Member States (e.g. Belgium, the Netherlands) have already started extensive soil biodiversity monitoring. Their experience can guide others post-adoption, and EU-level coordination (perhaps via JRC guidelines or a Soil Health platform) can harmonize efforts. The Green Deal also encompasses the Farm to Fork Strategy – integrating soil biodiversity into Farm to Fork actions (like promoting organic farming and precision agriculture) is another avenue. For instance, when scaling up organic farming to 25%, ensuring those systems actively foster soil biodiversity (through crop rotations, etc.) will double-count towards both Biodiversity and Green Deal targets.

EU Missions and research integration

The EU Mission "A Soil Deal for Europe" under Horizon Europe is already funding **Living Labs and Lighthouses** that demonstrate soil restoration techniques (European Commission, 2024c). We recommend strong knowledge exchange between these Mission projects and CAP networks. For integration, Mission findings (including those from projects like **SoildiverAgro**, which aligns with Mission goals) should inform future policy revisions. The existence of a high-profile EU research effort on soils gives policymakers confidence to implement changes, knowing they are backed by science and on-farm testing. Additionally, the Mission can help standardize measurement methods – if every Member State starts measuring soil biodiversity differently, it will be hard to compare or aggregate data. EU-level guidance can harmonize this, perhaps via CEN (European Committee for Standardization) standards or through the Joint Research Centre. Essentially, research and innovation initiatives can serve as a bridge between pilot-scale success and large-scale adoption via policy. Member States should be encouraged to participate in these EU projects and then use rural development funds to replicate successful approaches nationally. A concrete step could be establishing national "Soil Innovation Hubs" that mirror the EU Living Labs, ensuring that locally relevant innovations find their way into policy toolkits.

National and regional implementation

While EU frameworks set the stage, integration happens on the ground via national and regional actions. Each Member State should be encouraged to develop a **"Soil Biodiversity Action Plan"** that dovetails with its CAP Plan, Biodiversity Strategy actions, and national laws. Such an action plan would compile all relevant measures (CAP, national funding, etc.) into one coherent strategy for soil. The European Commission can facilitate this by issuing guidance or organizing best-practice exchanges between countries. The EU Agricultural Knowledge and Innovation Systems (AKIS) network should be leveraged to share how different regions integrate soil health into extension and policy – ensuring that laggards catch up and leaders are acknowledged (Standing Committee on Agricultural Research, 2019).

Other EU initiatives

The Zero Pollution Action Plan aims to reduce pollution by 2030 (including 50% cuts in nutrient loss and pesticide risk) (European Commission, 2021d). Achieving these will rely heavily on improved soil management – healthy soils retain nutrients and degrade pollutants better. So integration means recognizing soil biodiversity actions (like those we recommend: cover crops, reduced pesticides, organic fertilization) as key solutions in delivering the Zero Pollution targets. Similarly, the Climate-Smart Agriculture focus under EU climate policy (with LULUCF rules now accounting for cropland and grassland carbon fluxes) intersects strongly with soil. The revised LULUCF Regulation expects Member States to maintain or increase soil carbon stocks to meet climate targets (European Parliament & Council of the European Union, 2023). What better way than promoting the soil biodiversity-friendly practices that sequester carbon (e.g., reduced-till, cover crops) Thus, national climate action plans should explicitly incorporate our recommendations. Integration here could mean, for example, allowing farmers to monetize the carbon sequestered by these practices (through carbon credit schemes) while they also get CAP support – essentially stacking benefits. Policies should ensure no double-counting, but it is feasible to have, say, a CAP payment for cover crops and a separate carbon market reward for the same practice, as long as accounting is transparent.

Finally, **monitoring and evaluation** should be integrated across policies. As we roll out soil-related measures in CAP, environment, and climate policy, continuous monitoring should feed into adaptive management. The **SoildiverAgro** project provides innoivative methodologies for assessing soil biodiversity that could be standardized EU-wide. The CAP's Performance Monitoring and Evaluation Framework (PMEF) could include more soil indicators to track progress. The Soil Monitoring Law will demand national soil reporting as well (European Commission, 2023b). Aligning these efforts means, for example, a farmer who does a soil health test for a CAP scheme is also contributing data to national soil monitoring, which simplifies bureaucracy and serves multiple purposes.

In summary, integration requires coherence across various layers of policy. The good news is current EU strategies are largely synergistic on this issue – the CAP, Green Deal, Biodiversity Strategy, Farm to Fork, and Soil Mission all recognize the importance of sustainable soil management. The task now is to implement them in a synchronized way: the CAP provides tools and funds to farmers, environmental directives and the Soil Law provide targets and enforcement, research and innovation programs provide evidence and new solutions, and Member States tailor and execute actions on the ground. When knitted together, these initiatives can drive a fundamental shift in European agriculture toward embracing soil biodiversity as a foundation of productivity and resilience.

9.

Conclusion *and call to action*

» Conclusion

The stability, productivity, and resilience of Europe's agroecosystems are inextricably linked to the health of our soils and, by extension, to the biodiversity those soils contain. **SoildiverAgro**'s research has reinforced a critical message: protecting and enhancing soil biodiversity is not an environmental luxury, but a practical necessity for sustainable agriculture. Healthy soils teeming with life underpin nutrient cycling, water regulation, carbon storage, and natural pest control – services that modern agriculture cannot afford to lose. Conversely, degraded soils with diminished biodiversity lead to a vicious cycle of increased inputs, higher costs, and vulnerability to climate and pest shocks. The findings and recommendations detailed in this White Paper demonstrate that there is a viable path forward. By adopting soil-friendly farming practices, we can maintain high yields and farm incomes while restoring ecological balance beneath our feet. This path aligns perfectly with Europe's policy direction under the Green Deal, Biodiversity Strategy, and forthcoming Soil Monitoring Law. It is a path where agricultural competitiveness and environmental stewardship go hand in hand.

The ongoing decline of soil biodiversity, with soils often the unseen casualty, demands urgent action. Yet never before we had such knowledge, technology, and policy momentum to tackle this challenge. The policy recommendations presented here provide a roadmap for turning principles into practice across the EU's diverse regions. Implementing these measures will bolster food security, help achieve climate targets, and safeguard ecosystem services for future generations. Importantly, improving soil biodiversity is a long-term investment: protecting soil health now is an investment in the future food supply and in the resilience of farmers' livelihoods. The cost of inaction – continued soil degradation, yield instability, and environmental damage – far outweighs the effort required to implement these measures.

» Call to Action

We call on all stakeholders – European and national policymakers, regional authorities, the agricultural industry, researchers, and farmers themselves – to join in advancing the soil biodiversity agenda.

- **Policymakers:** Embrace the recommendations in this paper and embed them into policy instruments without delay. Set clear targets for soil health improvement (for 2030 and 2050) and align incentives to those targets. Champion the Soil Monitoring Law through the legislative process and ensure it remains ambitious and enforceable. Additionally, recognize that soil biodiversity issues cross national borders and should be addressed collaboratively (soil life does not respect country lines, and knowledge exchange at the international level can accelerate progress). In upcoming CAP revisions or national strategic plan adjustments, integrate stronger soil measures. Ensure that funding is adequate and accessible for farmers making transitions. Consider new mechanisms, such as soil health contracts or payments for ecosystem services, to directly reward farmers for measurable improvements in soil biodiversity.
- **Member State Governments and Regions:** Take ownership of soil health at the national and regional levels. Develop integrated soil action plans as described above, and involve farmers in their design to ensure practicality. Use your CAP Strategic Plan flexibilities to the fullest to support soil biodiversity (don't leave available EU funds untapped). Improve coordination between agriculture and environment ministries to jointly address soil issues – for example, align water regulations with soil conservation efforts. Increase investment in extension services and soil testing infrastructure; farmers need on-the-ground support and data to implement changes. By acting decisively now, you will save resources in the long run and contribute to EU-wide goals.
- **European Commission and EU Institutions:** Continue to support – and pressure – the uptake of these measures. Use mechanisms like the European Semester or other coordination tools to review Member State progress on soil protection. Ensure that the CAP's performance framework and the Green Deal's monitoring include soil biodiversity metrics so that progress can be evaluated. Fund research and innovation (perhaps a follow-up to SoildiverAgro or related projects under Horizon Europe and the Soil Mission) to keep filling knowledge gaps and demonstrating solutions. Foster cross-

country learning by disseminating best practices from one region to others. As you implement the Green Deal and recovery programs, ensure that soil restoration is recognized as a key component of Europe's green transition.

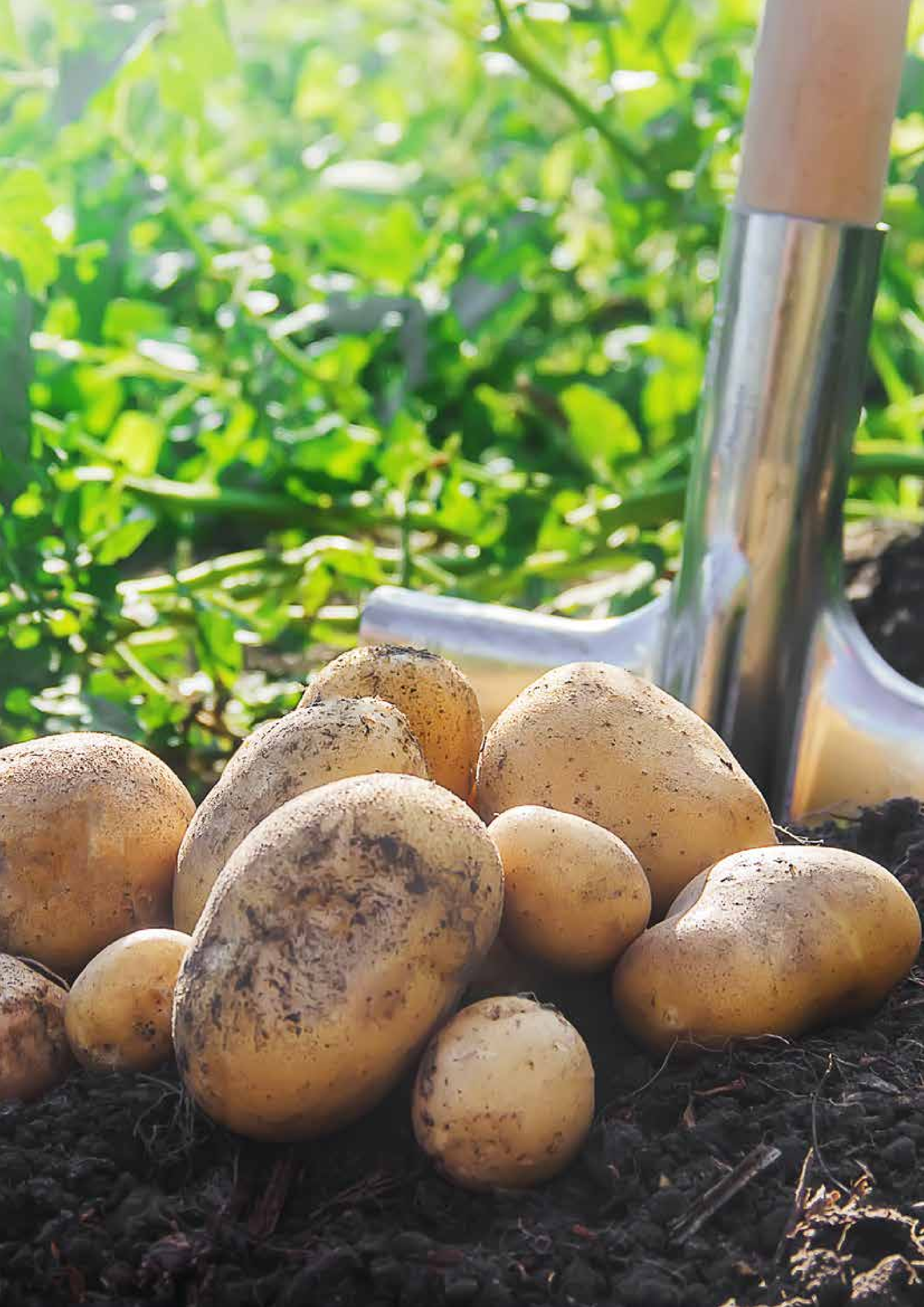
- **Farmers and Agricultural Organizations:** We urge farmers to engage proactively in this transition. The evidence shows that adopting practices that care for soil biodiversity will benefit your farm's profitability and resilience. We understand change can be challenging, but numerous peers and "lighthouse" farms have shown it can be done successfully. Seek information, participate in trainings or pilot projects, and share experiences. Farmer unions and cooperatives should advocate for supportive policies (such as those outlined here) and help their members access new tools and markets. You are the stewards of the land – your involvement and feedback are crucial to fine-tuning these policies and making them work on the ground.
- **Industry and Supply Chain:** Input providers, food processors, retailers – you also have a role. Innovate to provide products that are soil-biota friendly (e.g., bio-based fertilizers, low-toxicity pesticides, precision application equipment, cover crop seeds adapted to local conditions). The food industry can support farmers by offering contracts or price premiums for sustainably grown produce. Retailers and brands should recognize that consumers increasingly care about sustainability – labeling or marketing campaigns around "soil-friendly" farming could add value to products. However, establishing an official "soil-friendly" label or certification system is not feasible yet, because no standardized criteria or baseline indicators exist to define what "soil-friendly" farming truly means in measurable terms. We currently lack an agreed framework to quantify soil biodiversity and soil health impacts. The EU is only now developing a harmonized inventory of soil biota and soil health indicators, and researchers emphasize that we must first set consistent baselines and monitoring methods for soil biodiversity. Until such criteria are established, any soil-friendly label would be premature. In the meantime, industry can participate in and sponsor pilot initiatives that promote soil health (for example, "regenerative agriculture" programs with farmers, or R&D on soil amendments and biostimulants). Companies should also engage in developing the standards and data needed for future soil sustainability labels – for instance, by supporting soil testing programs and transparency in sourcing.

- **Researchers and Educators:** Continue to investigate soil biodiversity and its interactions with farming, reducing uncertainties and developing region-specific guidance. Help translate scientific findings into farmer-friendly knowledge – for instance, develop simple soil health test kits or decision support apps that farmers can use. Educational institutions should integrate soil health deeply into curricula for agronomy and environmental science, so the next generation of farmers, advisors, and policymakers is trained in holistic soil management. Interdisciplinary research will be valuable to design policies that are not only ecologically sound but also practical and accepted by farming communities. Researchers can also support policy by refining indicators and monitoring techniques, ensuring that progress can be quantitatively tracked (e.g. improving soil biodiversity indices that could feed into the Soil Monitoring Law reporting).

In calling all these actors to action, we emphasize that success will depend on collaboration and a shared vision. The SoildiverAgro project itself exemplified what a multi-actor, multi-country effort can achieve – now its insights must be amplified through collective will. Each stakeholder has something to contribute and something to gain: policymakers meet environmental and climate objectives, farmers gain more resilient (and often more profitable) production systems, and society gains food security, a cleaner environment, and climate mitigation.

Europe has historically led the way in sustainability efforts, and now it has the chance to lead in safeguarding the very foundation of agriculture: the soil. Implementing soil biodiversity-friendly policies can become an example of the EU's motto "United in diversity" – united in the goal of healthy soils, with diverse strategies tailored to local contexts. The window for meaningful action is open. We must not let it close, for the cost of restoring collapsed soil systems is far greater than the cost of maintaining them now.

We suggest the adoption and execution of the recommendations outlined. The coming years, leading up to 2030 and beyond, should be marked by decisive steps: new policies enacted, old harmful practices, and measurable improvements in soil biodiversity and soil health across Europe reported.



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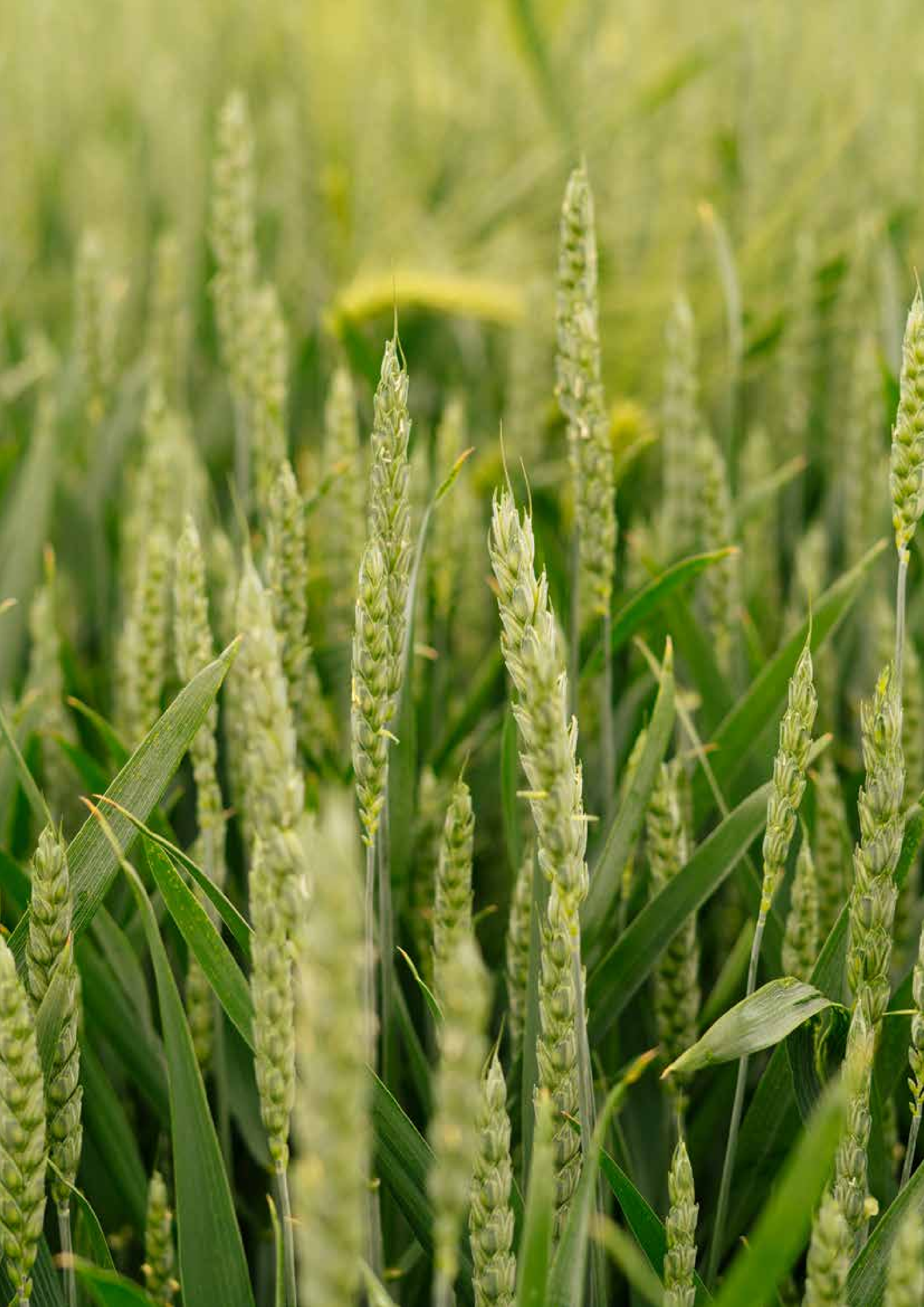

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