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# Regenerative Agriculture for Soil Health: Insights from European, Slovak and Hungarian Contexts

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# Content

## Executive summary

This literature review synthesises existing knowledge and field evidence on regenerative agriculture (RA) with a focus on its effects on soil health across three contexts: the European Union, Slovakia, and Hungary. Regenerative agriculture is presented as a systems-oriented framework aiming to reverse soil degradation, enhance biodiversity, and strengthen farm resilience through practices such as reduced tillage, cover cropping, crop diversification, and organic matter management.

At the European level, RA has gained increasing attention in policy and research circles, despite the lack of a unified legal definition. EU-level initiatives such as the European Green Deal, the Farm to Fork Strategy, and the Soil Mission provide opportunities to support regenerative practices, but implementation varies significantly between Member States. Key drivers of adoption include farmer motivation, peer learning networks, and access to innovation projects, while major barriers remain in financing, advisory gaps, and inconsistent terminology.

In Slovakia, RA remains a marginal but growing approach. Practices such as no-till farming, diverse cover cropping, and holistic grazing are being tested by a small number of farms, often through EU-funded projects like Soil4Nature and EIT Food initiatives. However, systemic constraints—such as the lack of formal recognition, fragmented advisory services, and limited research infrastructure—continue to limit broader uptake.

In Hungary, a structured review of national scientific literature highlights the effects of various farming practices on key soil health indicators. Conservation tillage and organic amendments have shown consistent benefits for soil moisture, microbial activity, and erosion control. Cover cropping and crop rotation are also positively associated with increased soil organic carbon and nitrogen. Nevertheless, conventional tillage remains dominant, and underrepresented practices such as biochar application or living mulches require further study. The Hungarian experience underlines the importance of long-term trials, context-specific adaptation, and policy alignment for scaling regenerative soil management.

Overall, the findings demonstrate that regenerative agriculture holds significant potential to address soil health challenges in Central Europe. However, unlocking this potential will require clearer policy frameworks, investment in farmer-to-farmer knowledge exchange, improved access to technology, and long-term monitoring of soil outcomes.

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# 1. Introduction

Soil health has become a central concern in European and global agricultural policy, given its critical role in maintaining crop productivity, regulating climate, protecting biodiversity, and sustaining rural livelihoods. In recent years, regenerative agriculture (RA) has emerged as a promising framework to address soil degradation and other environmental challenges while improving the economic resilience of farming systems. Rather than prescribing a fixed set of practices, regenerative agriculture is understood as a systems-oriented, context-specific approach that aims to restore the biological functions of soils, enhance ecosystem services, and strengthen the socio-economic viability of farms.

The interest in regenerative agriculture has grown rapidly across the European Union. This momentum has been driven by several converging factors: the recognition of agriculture's contribution to greenhouse gas emissions, the degradation of natural resources such as soil organic matter and biodiversity, and the increasing vulnerability of farms to climate extremes such as droughts or floods. Policy instruments such as the EU Green Deal, the Farm to Fork Strategy, and the Mission 'A Soil Deal for Europe' reflect this shift in focus toward long-term soil health and sustainability.

At the same time, significant variation exists across EU Member States in terms of how regenerative principles are defined, interpreted, and implemented. While some Member States have piloted multi-practice incentive schemes and launched farmer-led innovation networks, others remain at an earlier stage of experimentation or awareness raising. Moreover, the diversity of farming systems, agroecological conditions, and policy environments within the EU complicates the formulation of a unified approach to RA.

This literature review synthesises existing knowledge on regenerative agriculture with a specific focus on its relationship to soil health. It draws on research, expert papers, and project outputs to explore the extent to which regenerative principles are embedded in agricultural practice and policy in three contexts: the European Union as a whole, Slovakia, and Hungary. These three levels offer complementary perspectives: from broad EU policy frameworks, through national research and advisory efforts, to regionally rooted farming practices.

The aim of the review is not only to map current knowledge but also to identify key gaps, practical experiences, and lessons learned that can inform future decision-making. Particular attention is paid to practices that directly affect soil health indicators—such as tillage reduction, organic matter management, crop diversity, and cover cropping—as well as to the socio-economic and institutional factors shaping adoption. By comparing the European, Slovak, and Hungarian contexts, this review also seeks to highlight opportunities for cross-border learning and collaboration in support of regenerative transitions in Central Europe.

## 2. Evolution of Regenerative Agriculture

Regenerative agriculture is a relatively recent term, but it builds upon decades of experimentation, traditional knowledge, and agroecological thinking. The concept emerged in response to the limitations of conventional and even organic systems in addressing long-term soil degradation, biodiversity loss, and climate instability.

The term regenerative agriculture was first coined by the Rodale Institute in the early 1980s to describe a system that not only sustains but also improves the quality of soil, water, and biodiversity over time. In contrast to "sustainable agriculture", which focuses on maintaining existing resource levels, regenerative approaches aim for active renewal of soil biological function, carbon storage, and ecosystem resilience.

This distinction was proposed in a 2024 EU CAP Network Focus Group 'Regenerative agriculture for soil health', which states that regenerative agriculture "is not a fixed set of practices, but rather a systemic transition built on outcome-based principles". It emerged as part of a broader agroecological movement but has gained visibility due to its strong emphasis on soil health and climate resilience.

The regenerative agriculture became more prominent in European debates after 2018, partly driven by the EU Green Deal, the Farm to Fork Strategy, and the Soil Mission. Major agrifood actors and networks such as Yara, Nestlé, and Danone have also contributed to the term's uptake by associating it with "nature-positive" and "climate-smart" farming.

Although many regenerative practices (e.g. cover cropping, reduced tillage, compost use) are shared with organic and conservation farming, the regenerative framework differs by emphasising soil function as a central performance metric. In this view, improvements in soil organic carbon (SOC), microbial activity, water retention, and nutrient cycling are not just side benefits — they are the core indicators of success.

As of 2024, there is still no common EU-level legal definition of regenerative agriculture. However, the concept is increasingly used in policy discourse, innovation funding (e.g. Horizon Europe), and farmer-led projects aiming to build resilient and place-based farming systems. This growing momentum is reflected in the rise of cross-border projects such as #soil4nature and focus groups coordinated by the EU CAP Network, 2024, which link regenerative farming directly to soil health goals for 2030 and beyond.

# 3. Regenerative Agriculture in Europe

## 3.1. Framing and conceptual diversity

A comprehensive overview by Manshanden et al. (2023) identifies four major perspectives on regenerative agriculture in Europe: soil-focused, systems-based, indigenous and traditional, and carbon/market-driven approaches. These perspectives coexist but are often emphasised differently across contexts and stakeholder groups, contributing to conceptual ambiguity. The report underlines the need for shared understanding of regenerative principles, particularly in light of emerging policy frameworks and private-sector claims.

Across the European Union, regenerative agriculture (RA) is gaining visibility in research, policy debates, and field practice. However, no singular, unified definition exists. Instead, RA is often described as a set of guiding principles and outcome-oriented practices that aim to restore soil functionality, enhance biodiversity, reduce dependency on external inputs, and build climate resilience. The EU CAP Network Focus Group on Regenerative Agriculture (2024) emphasises that regenerative agriculture should be understood as a system-level transition rather than a fixed list of techniques. Practices such as reduced tillage, cover cropping, integration of legumes, and organic matter management are contextually combined to improve soil health and farm viability.

This definitional diversity is also reflected in papers by Wageningen University & Research and private-sector actors such as Yara International (2023), which describe RA as a paradigm shift towards “nature-positive outcomes” and “systematic, farm-specific optimisation” across five key domains: soil health, climate impact, biodiversity, resource efficiency, and farm profitability.

Yara International (2023), a global fertiliser company, defines regenerative agriculture as a "systematic, outcome-based approach" structured around five key themes: climate, soil health, resource efficiency, biodiversity, and prosperity. Their framework combines digital technologies, precision nutrition, and both organic and mineral inputs, adapted to regional and farm-specific conditions. Yara also provides detailed outcome-based indicators to monitor progress across environmental and economic dimensions, including soil carbon, nutrient efficiency, crop yield, biodiversity metrics, and farm profitability.

Despite differences in scope and emphasis, most interpretations of RA converge on its systemic, adaptive, and iterative character, requiring site-specific knowledge, learning processes, and monitoring mechanisms.

## 3.2. Core Practices and Their Soil-Related Impacts

Regenerative agriculture in Europe is not based on a rigid, universal set of techniques. Rather, it promotes a flexible system of mutually reinforcing practices adapted to specific ecological and agronomic conditions. Despite regional differences, certain strategies are widely recommended due to their positive effects on soil structure, biology, and functionality. These include practices that restore soil organic carbon (SOC), improve aggregate stability, enhance microbial diversity, and increase resilience to climate stressors.

According to Manshanden et al. (2023), the most commonly mentioned regenerative practices in European policy and practice discourses include no/reduced tillage, cover crops, organic fertilisation, crop diversification, agroforestry, and managed grazing. However, the implementation and interpretation of these practices vary significantly across countries and farming systems. The authors stress that evaluating soil health outcomes requires a context-specific and multi-indicator approach.

### Reduced Tillage / No-Till

Tillage reduction is a cornerstone of regenerative systems. Conventional ploughing accelerates soil organic matter (SOM) mineralisation, disrupts soil structure, and increases erosion risks. In contrast, reduced tillage methods (e.g. shallow cultivation, strip-till) help retain soil moisture, stabilise aggregates, and maintain surface-level SOM. No-till systems further enhance microbial biomass, fungal hyphal networks, and earthworm populations, although they may require careful weed control and specific seeding equipment (Rempelos, L, et al, 2013).

Evidence from long-term EU and Hungarian trials confirms these benefits: reduced tillage increases water infiltration rates, lowers bulk density, and boosts earthworm abundance and enzymatic activity. However, success depends on soil type and cropping system – clay soils or poorly drained fields may need adapted solutions.

### Cover Crops and Green Manures

Cover cropping is a widespread regenerative strategy promoting year-round soil coverage and biological activity. Sown between main crops, species mixtures (grasses, legumes, brassicas) reduce erosion, suppress weeds, fix nitrogen, and add organic residues. These systems support diverse microbial populations and increase enzymatic activity, enhancing nutrient cycling and SOM accumulation.

According to the EU CAP Network (2024) report and multiple field studies, multi-species cover crop mixtures improve infiltration, increase mycorrhizal associations, and buffer soil against drought and compaction. In Hungary, trials have shown increased microbial activity and improved soil respiration under cover crops.

While many studies highlight the potential benefits of no-till and cover crops, recent analysis by Zimmer et al. (2025) cautions against overestimating their impact on soil carbon sequestration. Meta-analyses show that no-till often results in redistribution rather than net gains in soil carbon, with increases in the topsoil offset by decreases at deeper layers. Additionally, cover crops may have only modest climate benefits and face agronomic limitations under specific climatic or cropping conditions. These findings suggest that soil sampling depth, management context, and permanence of practices must be carefully considered when evaluating the true carbon mitigation potential of regenerative approaches.

### Crop Rotation and Diversification

Rotational diversity breaks pest and disease cycles and improves nutrient availability. Rotations including legumes (e.g. clover, vetch), oilseeds, root crops, and cereals enhance SOC levels, microbial diversity, and soil structure. In Hungary and other parts of Central Europe, crop rotations have increased total nitrogen and improved aggregate stability, particularly when combined with minimal tillage. Diverse rotations also support soil macrofauna and beneficial arthropods, helping create a resilient soil food web (Rempelos, L, et al, 2013).

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### Organic Amendments: Compost, Manure, and Biochar

The addition of organic amendments enhances cation exchange capacity, stimulates microbial life, and improves water retention. Manure and compost provide slow-release nutrients and organic matter, while biochar can act as a stable carbon sink in the soil. However, results vary – some biochar types may reduce water-holding capacity or alter pH, particularly on sandy soils.

A comprehensive study from Florida (Xu et al., 2022) investigated the individual and combined effects of cover crops and organic amendments (bagasse and horse bedding) on 11 soil health indicators across 13 experimental farms. The findings showed that the combination of organic amendments with cover crops significantly improved organic matter (OM), maximum water holding capacity (MWHC), total phosphorus (TP), and Mehlich-3 phosphorus (M3P), while reducing bulk density (BD). In contrast, cover crops alone did not significantly influence most soil health indicators. Strong positive correlations were found between OM and other indicators such as CEC, TKN, and soil protein, confirming the central role of OM in regenerative systems. The study underlined the importance of integrating organic inputs for measurable improvements in soil health within mineral soils.

### Livestock Integration and Managed Grazing

Grazing animals – especially under rotational or holistic grazing regimes – contribute to nutrient cycling and stimulate plant-soil interactions. Well-managed grazing increases surface biomass, enhances root exudation, and improves aggregate stability. It also supports dung beetles and beneficial microbes. Studies from regenerative farms in Western and Central Europe show that integrating livestock enhances microbial biomass, SOM content, and nitrogen retention. However, grazing intensity and timing must be carefully managed to prevent compaction or overgrazing (Rempelos, L, et al, 2013).

### Agroforestry and Perennial Systems

Agroforestry – the integration of trees or shrubs into crop and livestock systems – is gaining interest for its long-term soil and biodiversity benefits. Practices such as alley cropping and silvopasture reduce erosion, increase carbon sequestration at deeper soil levels, and create habitat for beneficial insects and microorganisms.

Although still emerging in Central and Eastern Europe, early trials show positive effects on water retention, below-ground biomass, and microclimate regulation. Perennials also maintain year-round living roots, reducing nutrient leaching and supporting symbiotic microbial communities (EU CAP Network, 2024).

*Table 1 Summary of Soil Health Benefits*

| **Practice** | **Main Soil Benefits** |
|---|---|
| **Reduced tillage** | Improved structure, water retention, reduced erosion, increased earthworms |
| **Cover crops** | Higher SOM, microbial activity, weed suppression, erosion control |
| **Crop rotation** | Nutrient cycling, pathogen suppression, increased carbon and nitrogen stocks |
| **Organic amendments** | Microbial enhancement, improved nutrient holding, increased SOC |
| **Livestock integration** | Nutrient recycling, aggregate stability, support of soil biota |
| **Agroforestry** | Deep rooting, erosion control, improved moisture regulation, biodiversity |

## 3.3. Drivers and Barriers to Adoption of Regenerative Practices in Europe

The implementation of regenerative agriculture across Europe is shaped by a complex interplay of personal, social, economic, and institutional factors. While interest in regenerative approaches is increasing, actual on-farm adoption remains uneven and context-dependent.

### Farmer motivations and values

Evidence from the EU CAP Network Focus Group (2024), and Manshanden, M. et al., 2023, suggest that farmers who adopt regenerative practices are often driven by:

› concern for long-term soil degradation on their land;

- experience with extreme weather events (e.g. drought, heavy rain) prompting them to seek more resilient systems;
- value-based motivations, such as environmental stewardship, intergenerational responsibility, or ethical food.

In addition, farmers with previous experience in organic or conservation agriculture are more likely to adopt RA practices, as they are already familiar with low-input systems and soil-oriented thinking.

### Role of social learning and networks

Participation in farmer-led networks, pilot projects, or peer-exchange schemes significantly increases adoption likelihood. The CAP Focus Group (2024) highlights that peer-to-peer knowledge sharing is often more effective than traditional advisory services, particularly when advice is co-created and based on local trials. Trust and credibility of the information source play a major role. Moreover, local champions or demonstration farms can act as leverage points to normalise new practices and reduce perceived risk.

### Economic and practical barriers

Despite promising outcomes, many farmers face financial and operational constraints, including:

- High initial costs for specialised machinery (e.g. no-till or strip-till seeders),
- Uncertainty about economic returns or transitional yield dips,
- Lack of price premiums for regenerative produce,
- Difficulty accessing tailored advisory services,
- Bureaucratic complexity of existing agri-environment schemes.

Evidence from the SoilValues project (Mathijs et al., 2024) shows that the long-term business case for regenerative agriculture can be compelling, but the risks associated with transitioning practices remain high for farmers. Interviews with stakeholders across Europe reveal that no single incentive mechanism is effective in isolation; instead, successful uptake relies on a coordinated mix of outcome-based and practice-based schemes, blended finance models, and technical support. Crucially, the burden of transition costs cannot rest solely on farmers, and greater policy coherence and stakeholder collaboration are needed to de-risk adoption.

One of the main economic barriers, especially in Slovakia, is the perception of risk related to lower initial yields, coupled with a lack of confidence in support mechanisms and limited access to context-specific knowledge (Rovný et al., 2022). While the potential for long-term profitability exists, regenerative farmers often face higher labour needs and must invest in new equipment and training. At the same time, institutional separation between agronomists and economists prevents integrated assessment of both agronomic and financial performance.

### Terminology, trust, and perception

Another barrier is the lack of clarity and standardisation around what qualifies as "regenerative." This can lead to confusion or scepticism, particularly among conventional farmers who associate RA with niche or ideological movements. van den Hoorn, H., et al., 2024 stresses the need for consistent language and well-defined objectives, especially if RA is to be included in policy schemes or certification systems.

The 2025 EARA report highlights that farmer-led research and innovation play a crucial role in overcoming knowledge gaps and scaling regenerative practices. However, farmers often face structural barriers such as inadequate support for experimentation, limited access to tailored advisory services, and rigid agri-environmental schemes. The report stresses the importance of enabling frameworks that fund long-term trials, recognise on-farm knowledge, and promote co-creation between farmers and researchers as key enablers of sustainable practice adoption.

Nyssens-James, C., & Leake, A. (2023). In the AgriCaptureCO2 project policy report, six foundational principles are identified to create an enabling environment for regenerative agriculture in the EU and UK. These include ensuring policy coherence across sectors, setting clear definitions and targets, improving monitoring systems, aligning agricultural subsidies with environmental objectives, attracting private investment, and enabling behavioural change. The authors stress that current CAP frameworks and carbon policies fall short of these principles, often favouring continuity over transformation. They advocate for gradually phasing out area-based income support and redirecting funds to targeted, performance-based measures that reward soil health and biodiversity improvements.

The EASAC report (2022), Regenerative Agriculture in Europe highlights that a significant barrier to the wider adoption of regenerative farming is the structural bias of policies and subsidies toward large-scale, high-input systems. The report calls for policy reforms that support small and medium-sized farms, increase seed sovereignty, and diversify supply chains. It also stresses the importance of investing in peer-to-peer knowledge networks and community-led initiatives as pathways to sustainable transformation.

A policy analysis by van den Hoorn et al. (2024) concludes that although several EU initiatives—such as the Soil Mission, carbon farming proposals, and the Green Deal—indirectly support regenerative practices, none explicitly define or mandate regenerative agriculture. The report highlights gaps in coherence, target setting, and long-term support within the CAP framework, cautioning that current policies may reinforce business-as-usual models. Clearer definitions, monitoring tools, and incentives aligned with ecosystem service delivery are seen as crucial to embed regenerative approaches into the EU policy landscape effectively.

## 3.4. Policy Context and Support Mechanisms

Although regenerative agriculture (RA) aligns with many objectives of EU environmental and agricultural policies, it is not yet explicitly defined or formally integrated into the Common Agricultural Policy (CAP) framework. Nevertheless, several EU strategies and funding instruments provide indirect pathways for the promotion of regenerative practices.

RA is strongly linked to overarching EU policy objectives, including:

- the European Green Deal,
- the Farm to Fork Strategy (F2F),
- the EU Soil Strategy for 2030,
- and the Mission “A Soil Deal for Europe” under Horizon Europe.

The EU Soil Strategy explicitly recognises the importance of sustainable soil management for climate resilience, food security, and biodiversity. It sets the ambition that all EU soils should be in a healthy condition by 2050, with intermediate milestones such as reducing soil erosion, increasing soil organic matter, and limiting land take. Although RA is not mentioned by name, the strategy promotes practices typically associated with it, such as minimum tillage, cover crops, and carbon farming.

The Farm to Fork Strategy also supports the reduction of synthetic fertiliser and pesticide use, an increase in organic farming, and the development of carbon farming schemes — all of which overlap with RA principles.

# 4. Regenerative Agriculture in Slovakia

## 4.1. Context and state of adoption

In Slovakia, regenerative agriculture (RA) is a relatively new and still marginal approach within the national agricultural landscape. While conventional and organic farming systems dominate most policy and research attention, RA is beginning to emerge as a promising alternative for addressing pressing soil health challenges. According to a recent study by Dudek and Rosa (2023), the level of awareness and implementation of regenerative agriculture in Slovakia remains relatively low, with the concept often confused with "biologised farming" or sustainable conventional approaches. While some Slovak farmers show interest in regenerative principles—particularly those related to soil protection and biodiversity—the lack of consistent terminology and institutional support limits broader uptake. The study also identifies a gap in research and advisory services focused on the Central European context.

Slovakia's agricultural sector is characterised by large-scale operations, mechanised production, and relatively high chemical input use. However, the country faces acute challenges related to soil degradation, including water and wind erosion, declining organic matter content, and reduced infiltration capacity, particularly in intensively cultivated lowland regions. The Macák et al., 2024 showed that regenerative methods such as no-till seeding, cover cropping, and organic fertilisation can improve soil structure, reduce fuel consumption, and increase economic viability within three to five years.

A national analysis by Ekopolis Foundation (Čaja et al., 2021) confirms that regenerative agriculture is practiced on less than 0.4% of Slovakia's arable land, with approximately 6 000 hectares under such management. The report highlights significant barriers to wider adoption, including conservative mindsets, the separation between agronomic and economic decision-makers in farms, and lack of technical equipment.

According to Rovný et al. (2022), most adopters are either smaller self-employed farmers or two larger agricultural enterprises. The authors highlight that although regenerative practices can reduce diesel use (from 110–120 l/ha/year to approximately 45 l/ha/year), the transition is slowed by economic conservatism, limited advisory capacity, and farmers' fear of yield losses during early adoption. However, they estimate that a 30–40% reduction in production costs typically offsets any yield reduction during the transition.

Despite this potential, regenerative agriculture remains poorly institutionalised. The Slovak CAP Strategic Plan 2023–2027 does not explicitly recognise RA as a system or category. Instead, scattered eco-schemes offer support for individual practices (e.g. catch crops, minimum tillage) without a coherent framework for systemic adoption. Additionally, advisory services and agricultural education have not yet integrated RA into standard curricula.

## 4.2. Practices and knowledge base

Slovak farms adopting regenerative agriculture typically apply the following practices:

› No-till or strip-till cultivation, often using project-supported or imported equipment;
› Diverse cover crops, including legumes (vetch, clover), brassicas, and grasses to maintain permanent soil cover;
› Crop rotation with legumes and oilseeds, sometimes including niche crops such as buckwheat or mustard;
› Organic amendments (e.g. manure, compost) instead of synthetic fertilisers;
› On-farm composting and mulching;
› Precision application of inputs (fertilisers, herbicides), based on in-field monitoring;
› Use of biological pest control, including microbial preparations.

While some of these practices overlap with those in organic or conservation agriculture, the RA approach emphasises soil restoration, biodiversity, and whole-system resilience. However, a lack of coordinated research and advisory infrastructure means that most knowledge sharing happens through pilot projects, informal networks, or farmer-led experimentation.

Projects like Soil4Nature and the EIT Food Regenerative Agriculture Revolution have started building a national knowledge base through workshops, field demonstrations, and case studies. Nevertheless, there is no centralised platform, database, or advisory service explicitly dedicated to RA in Slovakia.

### 4.3. Practical examples and pilot initiatives

Although still rare, several Slovak farms are pioneering regenerative approaches:

- PD Krakovany–Stráže (Trnava region) introduced no-till technology, cover cropping, and field-scale soil monitoring via the Interreg VI-A project Soil4Nature. The cooperative reports improved soil water retention, reduced erosion, and stable yields without synthetic inputs.
- PD Čingov Smižany (Spiš region) applies permanent soil cover, intercropping, and organic inputs. Around 80% of their arable land is covered year-round. They use minimal tillage and biological plant protection (e.g. Trichoderma fungi). Livestock manure and a diverse crop portfolio (~15 species) support system resilience and soil biodiversity.

- Imrišek s.r.o. (Malanta, Nitra) is a family farm experimenting with no-till, cover crops, and composting. It participates in the EIT Food RA Revolution, hosting field workshops and monitoring trials to demonstrate soil health improvements.
- “Living Lab” Radošina (Topolčany region) integrates agroforestry, poultry grazing, and alley cropping. The farm uses no synthetic fertilisers or pesticides and tests how regenerative principles function in mixed systems combining trees, crops, and animals.
- TatraKap (Švábovce, Poprad region) experiments with planting vegetable (e.g. cabbage) directly into cover crops like vetch and rye. This helps suppress weeds and improves soil microclimate and fertility in vegetable systems.
- SHR Pavol Borko (Michalovce) applies holistic rotational grazing on permanent grassland, mimicking natural animal movement to improve pasture structure, infiltration, and organic matter content.

Additional farms involved in pilot projects or peer exchange through the EIT Food programme or regional innovation partnerships include: Agromačaj, Radar Zbehy, PD Paňovce, PD Uhrovec, and Rodinná farma Brdárka.

These examples show that RA can be successfully implemented in various production systems—from arable and mixed farms to vegetable production and grassland management—when supported by local experimentation, peer learning, and targeted investment.

## 4.4. Challenges and limitations

Despite encouraging results, regenerative agriculture in Slovakia faces structural constraints:

- Lack of clear policy definition: RA is not legally recognised nor referenced in CAP implementation documents. Without such recognition, farmers have limited access to targeted funding or performance-based incentives.
- Limited technical support: Agricultural advisors and consultants often lack training in regenerative principles. Research institutions are only beginning to collect long-term soil data under RA systems, and few publicly funded pilot sites exist.
- Perceived economic risks: Farmers are cautious about investing in unfamiliar machinery (e.g. no-till drills) or switching rotations without guarantees of profitability or yield stability.
- Fragmentation of initiatives: Current efforts are mostly project-based, with weak coordination between stakeholders. No national network, demonstration farm system, or central advisory hub exists to aggregate knowledge or facilitate transitions.
- Cultural and communication gaps: Many farmers associate RA with organic farming or environmental activism, leading to scepticism. Terminological inconsistency further complicates public and institutional understanding.

The Ekopolis report (Čaja et al., 2021), also stresses that transition requires both technical and institutional adaptation. For instance, rotational planning with cover crops and intercropping demands agronomic flexibility, while acquiring no-till or strip-till equipment represents a substantial investment. The absence of targeted financial support, a legal framework for regenerative practices, or a national strategy further complicates farm-level decisions.

Rovný (2023) highlights several economic and institutional barriers hindering adoption. These include outdated legislation, a lack of CAP support tailored to regenerative methods, and high upfront costs. Nevertheless, on-farm trials suggest that after an initial dip in yields, regenerative farming can become more profitable than conventional methods due to lower input costs and participation in carbon compensation schemes. In a 2022 case study from southern Slovakia, regenerative wheat production showed higher profit per hectare (€517 vs. €480) despite lower yields.

Still, the growing number of active farms and research initiatives signals increasing momentum. Cross-border collaboration (e.g. Soil4Nature), peer exchange (e.g. EIT Food workshops), and applied research offer a foundation for scaling regenerative practices—especially in regions most affected by soil degradation and climate stress.

# 5. Regenerative Agriculture in Hungary

The preceding chapter has shown that while regenerative agriculture in Slovakia remains in its early stages, a growing number of farms are testing and adapting soil-focused practices within project-based frameworks. Despite institutional and financial challenges, on-farm experimentation and peer exchange have proven to be valuable entry points for transition.

In order to deepen the regional perspective, the next chapter turns to Hungary — a neighbouring country with a similarly diverse farming landscape but different research infrastructure and policy support. By comparing Slovak and Hungarian experiences, we aim to explore how context-specific conditions shape the adoption of regenerative practices, and what cross-border lessons may be drawn for enhancing soil health across the Pannonian region.

Regenerative agriculture in Hungary is being adopted by a growing number of farmers and cooperatives, supported by research projects and regional partnerships. This chapter summarises the current state of adoption, key practices, field-level experiences and observed impacts on soil quality.

## 5.1. Introduction

Soil health is crucial for sustainable agriculture, influencing crop productivity, environmental quality, and food security. Improving soil health is a global priority due to increased agricultural demands and climate change vulnerability. (Tahat et al.,2020; Omer et al.,2024). Healthy soils promote water retention and filtration, lower greenhouse gas emissions, increases agriculture yield, and improve the natural value of the soil (Singh Yadaf et al., 2023).

Hungary provides an interesting background for investigating the link between farming practices and soil health. As a country with a rich agricultural past, almost 60% of Hungary's land area is used for farming, making soil a critical national resource. The country's soils are diverse, including fertile chernozem in the Great Hungarian Plain, brown forest soils in Transdanubia, and sandy soils in other areas. However, decades of intensive farming, mechanization, monoculture practices, and chemical inputs have resulted in widespread difficulties such soil erosion, organic matter loss, compaction, and diminishing microbial activity. (Kovács et al., 2023; Nyárai, 2021).

In addition, Hungary has seen a rise in interest in conservation and organic farming, offering a diverse range of farming practices and their effects on soil quality.

This literature review aims to summarize the current state of knowledge regarding the effects of various farming practices on soil health in Hungary. With an emphasis on their effects on important soil health indicators such organic matter content, structure, microbial life, erosion rates, and nutrient availability, the scope encompasses conventional, organic, and conservation farming practices. The evaluation looks for trends, knowledge gaps, and chances to enhance soil management in Hungarian agriculture by examining national and regional studies. Considering contemporary environmental and policy concerns, this assessment also adds to larger conversations about sustainable land use in Central and Eastern Europe

### Context and Background

Most of the research studied focused on soil tillage and some adoption of the conversation tillage, with a few scientific articles focused on substantiable practices and soil management were published in Hungary.

The ability of soil to remain a living ecosystem that supports humans, animals, and plants is referred to as soil health. Soil health includes physical, chemical, and biological characteristics that support the soil's capacity to support agricultural productivity while preserving ecological balance and environmental quality, in contrast to the more traditional notion of soil fertility, which focuses primarily on the supply of nutrients for crops. Soil health takes a comprehensive approach to soil health, including its critical role in water filtering, nutrient cycling, carbon storage, greenhouse gas regulation, and biodiversity support.

## 5.2. Farming systems in Hungary

Hungary's farming systems witnessed considerable modifications between 1990 and 2020, affected by historical, economic, and environmental variables. The move from collectivized agriculture to a market-oriented system has resulted in increased landownership and a change in production patterns (Lennert & Zsolt, 2020). Large-scale farms increasingly dominate the agricultural landscape, despite rising realization of the need for more family-run farms to increase diversity and resilience (Juhász, 1991). Crop production accounts for the majority of Hungary's agricultural output, with crop yields recovering significantly after 2000 and approaching communist-era levels. However, livestock production has suffered long-term challenges, highlighting a need for targeted initiatives to reinvigorate the sector (Lennert & Zsolt, 2020). This overview will look at structural changes, contemporary agricultural methods, and sustainability challenges in Hungarian agriculture.

### Tillage system in Hungary

The historical evolution, present situation, and prospects for soil tillage practices in Hungary are examined by Kovács et al. (2023), who highlight the advantages of conservation tillage for crop productivity and soil quality. Hungary has been interested in conservation agriculture for more than a century, but the last 50 years have seen the most notable adoption. Traditional plough-based systems, which dominated for centuries, frequently resulted in soil deterioration, compaction, and decreased fertility. Modern conservation tillage practices, such as no-till, strip-till, subsoiling, and tine tillage, have been introduced and tested through long-term studies and field monitoring. These strategies have been shown to improve soil physical properties, moisture retention, organic matter content, earthworm abundance, and overall crop yield, particularly in the face of growing climate extremes. The review emphasizes the importance of site-specific, adaptive tillage techniques tailored to Hungary's different soils and climatic circumstances in maintaining agricultural productivity while avoiding climate-related risks. Despite progress, ploughing is still widely used, though its future use may decrease due to environmental concerns and governmental demands.

### Organic Farming in Hungary

Organic farming in Hungary has increased dramatically since the 1980s, with 3929 growers currently cultivating on 209.382 ha of land. Since more than half of the land is utilized for grazing pastures and meadows, animal husbandry is decreasing even if organic farms only make up 4% of the overall agricultural land area. Organic plant agriculture is growing, yet it confronts logistical, processing, finance, and organizational obstacles. Hungarian organic agriculture could profit from an emphasis on organic stores, markets, and e-commerce. As societal demand for sustainable solutions grows worldwide, organic farming poses both obstacles and opportunity for Hungarian agriculture.

### Regenerative Agriculture in Hungary

Hungary's agricultural sector has undergone significant transformations over the past few decades to regenerative farming, a process he began few years ago. This shift involves the use of practices such as minimum tillage, cover crops, and precise soil management supported by digital tools. According to recent studies, these methods have significantly improved soil health, enhanced crop performance, and reduced input costs.

## 5.3. Methodology of the review

The literature review was conducted using a structured and systematic approach to identify, select, and analyze relevant academic sources focusing on the effects of farming practices on soil health in Hungary. The primary aim was to gather empirical data and conceptual insights from existing research to evaluate how different agricultural methods influence various soil properties. Data were primarily derived from published, peer-reviewed research publications and academic literature. Literature was collected using several online databases and search engines, including Google Scholar, Scopus, and Google Search Engine. The keywords included in the search were "soil health Hungary," "farming practices and soil properties," "organic farming Hungary," "conservation tillage Hungary," and "effects of agriculture on soil quality." English-language studies were reviewed to provide a broad regional perspective.

### Selection Criteria

The selection criteria for studies include being conducted in Hungary, evaluating the impact of a farming practice on soil health indicators, being peer-reviewed, and prioritizing quantitative data on soil properties. Exclusions include studies solely on crop yield, lacking clear methodology, or lacking original data.

### Data Extraction and Organization

After initial screening, the selected articles were reviewed in detail. Relevant data were extracted and compiled into a structured Excel database for further analysis. The database included the following fields:

- Article ID, Title, Date of entry
- Treatment Category (e.g. tillage, fertilizer, cover crop, crop rotation, aerometry, etc.)
- Treatment description
- Location of the study, soil type and soil sample depth

- Studied soil properties (e.g. SOM, SOC, pH, bulk density microbial activity…etc.)
- Effect (direction of change), and the effect size (quantitative measure where available).

## 5.4. Main findings on soil health impacts

The literature summarized in this report focuses on how these soil properties are affected by farming practices. Some treatments appear in the literature more than others as seen in Figure 1, illustrate the distribution of various farming practices included in the literature being collected. Each section represents a specific treatment or practice category used in soil-related studies in Hungary.

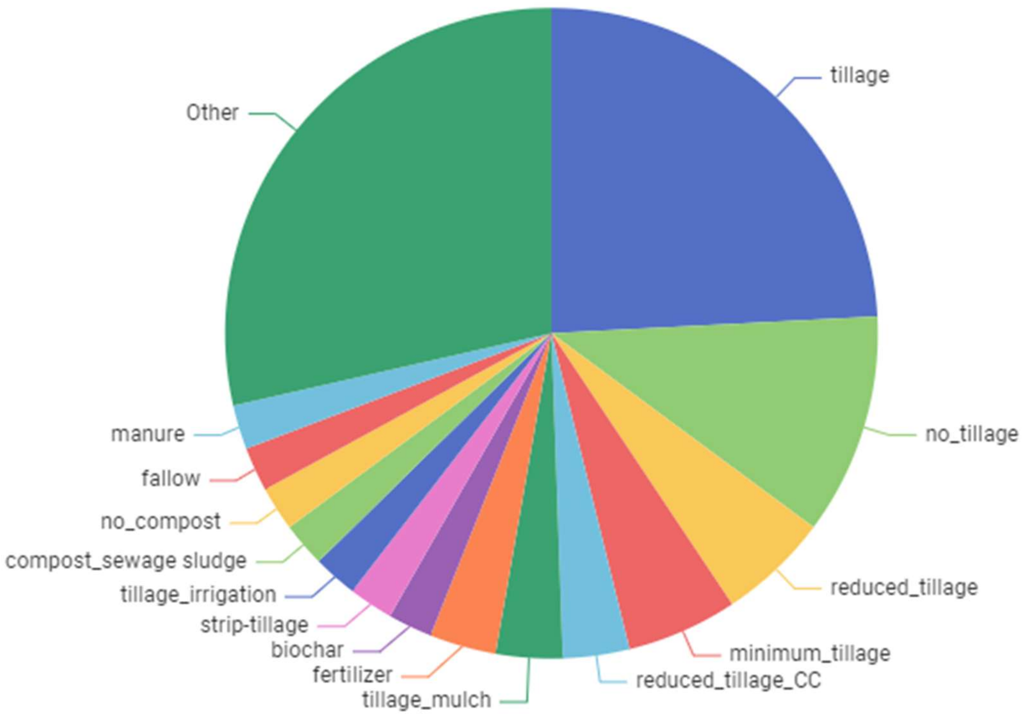


*Figure.1 Studied treatments that found in the literature*

The chart shows that tillage is the most studied practice in Hungarian agriculture, with no-tillage and reduced tillage being prominent. Alternative and soil-amending practices include manure, compost, sewage sludge, biochar, fertilizer treatments, strip-tillage, and tillage combined with mulch or irrigation. The "Other" category includes less common or less easily grouped treatments. The imbalance suggests areas for further studies, particularly for underrepresented methods like cover cropping, organic amendments, and biochar.

The distribution of the soil properties analyzed across various studies is shown in Figur2, which provides information on available data and research priorities related to agricultural practices and soil health.

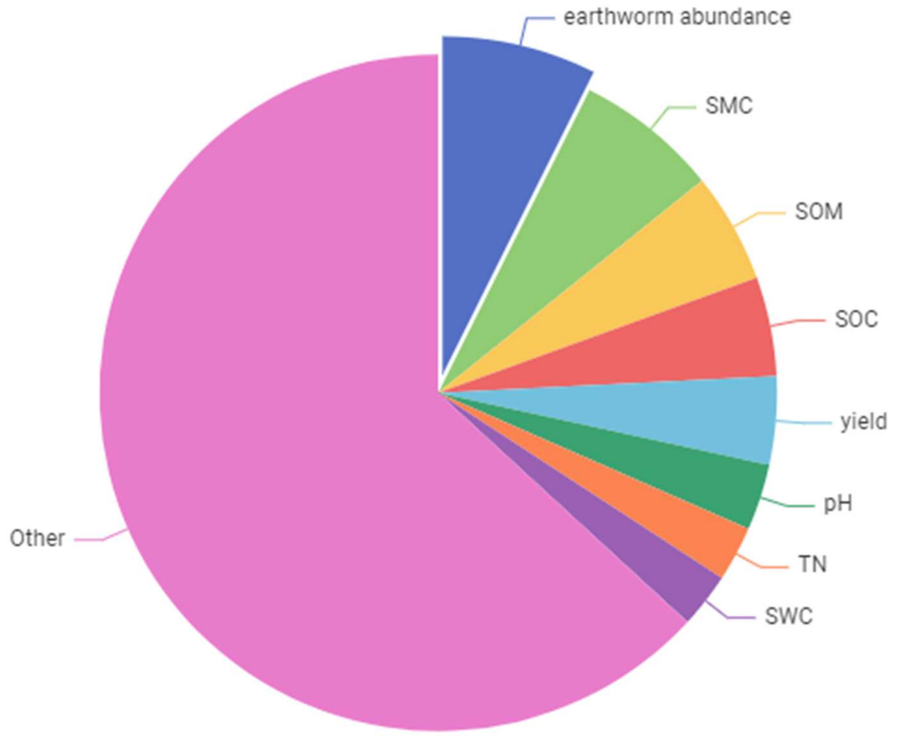


*Figure.2 The most studied soil properties found in the literature database*

Earthworm abundance is the most commonly studied biological indicator in soil health research in Hungary. It provides insight into the impact of tillage, organic amendments, and pesticide use on biodiversity and ecosystem function. Other key indicators include soil moisture content (SMC), soil organic matter (SOM), soil organic carbon (SOC), crop yield, soil pH, total nitrogen, and soil water content. These properties are crucial for maintaining soil structure, fertility, and resilience to drought, and are used to compare conventional and conservation-oriented farming systems.

*Table 2 Most studied treatment and their impacts on soil properties*

| Treatment | Studied Property | Negative Effects | Neutral Effects | Positive Effects |
|---|---|---|---|---|
| Reduced tillage | earthworm abundance | | 0 | |
| | SMC | | 0 | + |
| | soil penetration resistance | | 0 | |
| Reduced tillage_C | SMC | | 0 | + |
| | infiltration | | 0 | + |
| Tillage | SOM | | | + |
| | SOC | - | | |
| | earthworm abundance | | 0 | + |
| | infiltration | | 0 | + |
| | Water stable aggregate | | | + |
| | runoff | | 0 | + |
| | soil loss | | 0 | + |
| Crop rotation | Water stable aggregate | | 0 | |
| | TC | | 0 | + |
| | TN | | | + |
| | pH | - | | + |
| Biochar | enzyme activates | - | | |
| | SWC | - | | |
| | enzyme activity | | | + |
| Cover crop | SOM | | | + |
| | microbial activity | | | + |
| | aboveground biomass | | | + |
| | grain yield | | | + |
| Fertilizer | soil NH4-N | | 0 | |
| | soil NO3-N | - | | + |
| | soil extractable K | | 0 | + |
| | soil extractable P | | 0 | + |
| | water holding capacity | | 0 | + |
| No tillage | SOC | - | | |
| | earthworm abundance | | 0 | |

## 5.5. Conclusion and implications

Based on results from the literature, the table presents an overview of the observed effects of different agricultural practices on significant soil health indices. In general, the findings indicate that most sustainable practices, such as reduced tillage, crop rotation, biochar application, cover cropping, and no-tillage, have neutral or positive effects on soil characteristics. Reduced tillage and no-tillage were consistently related with increased soil moisture content (SMC), infiltration, and earthworm abundance, with only a few studies reporting neutral or even negative impacts on soil organic carbon. Conventional tillage, which is still commonly performed and studied, produced mixed effects. It generally improved soil structure-related properties (e.g., infiltration, water-stable aggregates), but it was often associated with decreases in SOC, highlighting the long-term hazards of intensive soil disturbance.

Crop rotation was largely positive, increasing total carbon (TC) and total nitrogen (TN) levels while improving aggregate stability, demonstrating its importance in nutrient management and erosion control. Biochar and cover crops have also been proven to improve soil biological activity and enzyme function, while biochar can have neutral or slightly negative impacts on parameters such as pH and soil water content (SWC), depending on the application.

Finally, the application of fertilizers yielded more variable results. Although soil nitrate ($NO_3^-$) and extractable phosphorus (P) levels increased, other research found detrimental effects (e.g., on pH), emphasizing the need for balanced fertilization. In conclusion, the evidence supports the benefits of conservation-oriented and integrated soil fertility approaches, which generally improve or maintain soil health while reducing degradation risks. These findings highlight the importance of promoting sustainable management alternative options customized to various soil types and agroecological conditions in Hungary.

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