EU CAP NETWORK

Focus Group – Regenerative agriculture for soil health

Final report

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Executive summary

In 2023-24, 20 experts from the EU CAP Network Focus Group 'Regenerative agriculture for soil health' worked on the question: '**How can regenerative agriculture practices help farmers restore, protect, and improve soil health and productivity?'** For the purpose of this Focus group, Regenerative Agriculture (RA) was defined as an outcomes- and principles-based approach to agriculture that prioritises **soil health restoration and enhancement**. It involves implementing **practice** systems **adapted to local contexts**. By restoring soil health, regenerative agriculture also aims to: (1) reverse **biodiversity** losses; (2) restore well-functioning **water cycles**; (3) adapt to and mitigate **climate change,** and; (4) increase **economic profitability**. Given that restoration is a process, there are no 'regenerative farms' per se, but rather farms at various stages of the restoration process.

The degradation of soil health, including wind and water erosion and loss of soil organic matter, **necessitates RA**. RA employs a combination of diverse **farming practices**: managed grazing, improved manure management, agroforestry, minimal tillage, permanent soil cover, crop diversification, soil amendment, and biostimulation, tailored to specific contexts. Systems such as regenerative market gardening in vegetable production, or organic no-till arable production, emerge from these combinations. To scale RA in Europe, advocates must overcome several **challenges.** They need to ensure farmers have access to relevant knowledge, tools and machinery, foster a mindset change in the food and agriculture sectors and beyond, provide financial support for farmers' transitions, and address new climate conditions.

To aid in overcoming these challenges, the focus group explored **five critical areas for RA success** in Europe: (1) the role of animal husbandry in RA, (2) education reform and knowledge dissemination, (3) outcomes and indicators for RA, (4) value creation through RA, and (5) systemic integration of practices. The Focus Group identified several **research needs** from practice, such as developing a practical soil health indicator set responsive to management practices, and production performances in different contexts. Other suggestions included assessing RA's impact on climate, integrating effects on the micro-climate and small water cycles, plant protection through soil health management, plant microbiome and mineral nutrition management, and optimising and evaluating cover crop management practices. The Focus group also proposed **innovative ideas** to further develop RA through **Operational Groups**, such as characterizing which sets of practices perform well in specific contexts, or developing minimal or no-till systems that perform well without herbicides. Other suggestions included developing tools to monitor soil health indicators on farms, developing high-performing intercropping systems in different contexts, and creating easy-to-use solutions to integrate grazers into crop-producing farms.

Introduction

The aim of the Focus Group "Regenerative Agriculture for Soil Health and Sustainable Agricultural Production' was to answer the main question: '**How can regenerative agriculture practices help farmers restore, protect, and improve soil health and productivity?'**

The tasks of the focus group were to

- identify regenerative agricultural practices, highlighting their benefits, challenges and opportunities from an environmental, economic and societal perspective
- identify, discuss and propose solutions to the identified challenges
- collect and present success stories of regenerative agricultural practices in different regions and cropping systems across Europe
- identify and collect practitioners' needs for technical knowledge and advice for the successful implementation of regenerative agricultural practices
- identify innovative ways for knowledge exchange and dissemination related to regenerative agriculture
- identify research needs from practice and possible knowledge gaps on regenerative agriculture, and propose directions for further research
- suggest innovative ideas for EIP-AGRI Operational Groups and other innovative projects on regenerative agriculture.

In the first meeting, 18 experts out of 20 were present from 11 EU countries and with different professional backgrounds. The group included six farmers, three farm advisors, seven researchers and four NGO representatives (see Annex 1 for more details). The meeting took place on November 28th-29th 2023 in Bratislava, Slovakia. The first day was dedicated to exchanging good practices, their benefits, success factors, and challenges. The second day focused on identifying solutions to the challenges and initiating further work on key topics related to RA implementation.

The following sections present the results of the first part of the experts' work, combining survey results, posters, and workshop discussions. It builds on and complements the starting paper with the focus group expertise.

1. Setting the scene

1.1. Regenerative agriculture and soil health: definitions

The European Commission´s Proposal for a Directive on Soil Monitoring and Resilience (July 2023) defines 'soil health' as 'the physical, chemical and biological condition of the soil determining its capacity to function as a vital living system and to provide ecosystem services'.

Coined by the Rodale Institute in 1983, the use of the term 'regenerative agriculture' has seen a dramatic increase in use since 2016, with no clear consensus on its definition. **In this report, regenerative agriculture will be defined as** "an outcomes- and principles-based approach to agriculture that focuses on restoring and enhancing soil health. It promotes the implementation of a system of practices adapted to the local context. By restoring soil health, regenerative agriculture also aims to

a) adapt to and mitigate climate change

b) restore well-functioning water cycles

c) reverse biodiversity losses

d) increase economic profitability.

Five **principles** underpin regenerative agriculture: minimise soil disturbance, maximise crop diversity, keep the soil covered, maintain living roots year-round, and integrate livestock." These principles aim to maximise the capture and conversion efficiency of light into energy forms usable by plants and their microbiome. Regenerative agricultural practices seek to valorise ecological processes and ecosystem services by integrating them as fundamental elements in the development of these practices. In this regard, they are similar to so-called 'agroecological practices' and nature-based solutions (Wezel et al. 2014).

We acknowledge that regenerative agriculture should also contribute to the restoration of well-being and prosperity on farms and in rural areas. It was not included in the definition above, to maintain a focus on soil health.

1.2. Why do we need regenerative agriculture in Europe?

Today, the health of Europe's soils is a major source of concern. According to the Joint Research Centre (JRC), 61% of EU soils are considered unhealthy (2020, 2023). Erosion rates are estimated to be 1.6 times higher than soil formation rates in the agricultural lands of the EU (Panagos et al., 2015). About 23 % of soils in the EU have critically high soil density levels, likely indicating deep compaction (Schjønning et al., 2015). The species richness of earthworms has overall decreased (Tsiafouli et al., 2015).

Water erosion.

Copyright: Knud Bay-Smidt, Denmark.

Wind erosion.

Copyright: Knud Bay-Smidt, Denmark.

Experts were asked to explain which problems in their geographical area of expertise required the implementation of regenerative agriculture. By far the most cited issues were **soil, wind, and water erosion** and **loss of Soil Organic Carbon (SOC) and Soil Organic Matter (SOM),** mentioned by experts from 11 different EU countries. Experts also highlighted other soil physical degradations, such as soil compaction and lack of soil aggregate stability leading to poor water infiltration and soil sealing. They mentioned soil chemical degradation such as soil salinisation, soil acidification, contamination with pesticide residues in soil and groundwater, and nutrient losses. Experts pointed out the degradation of soil biological quality, including soil biodiversity loss, particularly soil microbiota and low microbial and fungal activity. They emphasised the need for climate change mitigation and adaptation, e.g., coping with unpredictable hot or wet climatic events, recurring spring droughts, desertification, and aridification. Social issues were also noted, such as unhappy farmers, younger generations not attracted to farming, and consumers dissatisfied with current farming practices. Additionally, other issues like the loss of above-ground biodiversity, dependency on non-renewable resources, and negative externalities of current agriculture in other parts of the world were highlighted.

2. Good regenerative (systems of) practices

To address the issues described above, the experts experimented with or observed several good regenerative practices or systems of practices, which they shared before and during the Focus Group meetings. An agricultural practice is a single crop or livestock management operation on a farm, such as tillage, grazing or fertiliser application. A system of practices combines different interrelated practices the implementation and/or results of which depend on the implementation of the other practices in the system, e.g., direct seeding combined with cover cropping is a key system of practices in RA (section 2.2.6).

The following sections summarise these (systems of) practices, their benefits for soil health, success factors and limitations, starting with animal production (section 2.1.), followed by plant production (section 2.2.). For each (system of) practices, more details on the benefits, success factors, limitations, and links to more information can be found in Annexes 2 & 3. Challenges to their implementation and solutions proposed by the experts are presented in section 3. These sections are based on the inputs from the experts, except for the practice introductions, limits and footnotes.

2.1. Practices in regenerative animal husbandry systems

2.1.1. Managed grazing

Managed grazing involves the intentional movement of livestock between enclosed areas with recurring grazing and resting periods (Baronti et al., 2022; Gosnell et al., 2020; Leach et al., 2014). Stocking density, the time the herd remains in each paddock, and resting period are adapted to the type of forage grown and local growing conditions.

According to the experts, these practices stimulate root growth and nutrient cycling, thereby increasing soil fertility, especially SOM, as well as productivity per hectare. It introduces beneficial soil microbiota from the animal's gut. This minimises soil erosion, prevents soil compaction, increases soil water percolation and retention, and stimulates soil life. Ultimately, it enhances overall ecosystem multifunctionality. As cows feed on more productive grasslands, labour dedicated to feed production, distribution, and animal care can be significantly reduced. More benefits are presented in Annex 3 (Table 1).

The main success factor is understanding how the system works, and following the rhythms of nature and the microclimate of each area annually. This requires flexibility in adjusting stocking density and grazing time to the conditions of the place and year.

The main limitation is the slight increase in working time due to fencing and visits. This should be weighed against the time savings mentioned above. The transition to this new management also requires time to master it.

Illustrated below are different managed grazing approaches.

Adaptative multi-paddock rotational grazing

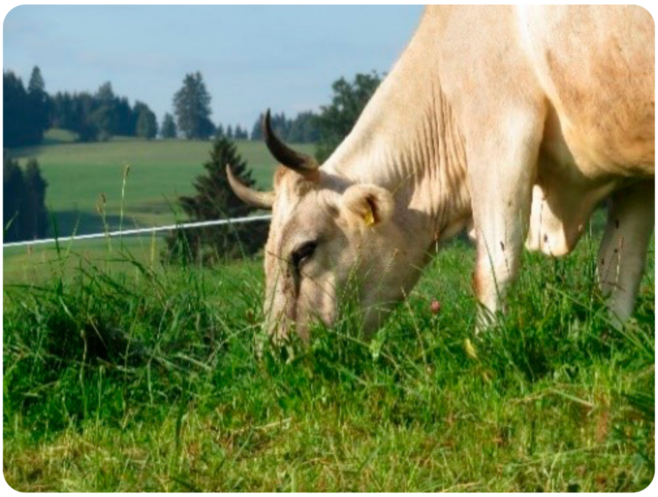
Adaptive multi-paddock rotational grazing.

Copyright: Airi Külvet, Estonia.

In **Estonia** our expert moves her cows to a new portion of land every one to three days, ensuring a rest period of 21 to 90 days before the next grazing round.

In **Denmark**, a similar practice is applied with sheep, keeping the animals on the same spot for a few hours to a few days. This is applied on permanent grasslands and temporary grasslands integrated into cropping cycles.

From holistic planned grazing to holistic management



Holistic planned grazing. In the foreground the grass from the previous plot can be seen.

Copyright: Christine Bajohr, Bavaria, Germany.

In **Bavaria, Germany**, a group of eight farmers are testing holistic management [1] and holistic planned grazing as part of the KuhproKlima project.

In **Portugal**, farmers use holistic planned grazing in cover crops within orchards or vineyard systems, mimicking natural grazing patterns.

Winter bale grazing

Winter bale grazing.

Copyright: Airi Külvet, Estonia

In **Estonia**, an expert uses rotational grazing (see above) in winter. Winter forage bales are unrolled daily in a new location, and the animals evenly cover the area with nutrients.

2.1.2. Improving forage management

Ley farming consists of introducing temporary grass or grass-clover crops into the crop rotation. Multi-year ley farming results in covering the soil for a long period with a permanent crop, which develops a large and deep rooting system and produces biomass and exudates throughout the entire vegetative period. No-tillage occurs during that period. As a consequence, according to the experts, this increases SOM, virtually suppresses soil erosion, actively protects and feeds soil life, and increases water retention in the landscape. It may also bind nitrogen through legumes. The presence of livestock on the farm, or from a collaborating farm to make use of the fodder, is the key success factor. The productivity and economic benefits depend on the alternative crops that could be produced on the farm.

Multi-year ley farming

Multi-year ley farming.

Copyright: Claudia Nielsen, Denmark.

Our Danish expert introduced us to a 3-5 year grass crop within her crop rotation system. This temporary grassland is grazed in a rotational way.

2.1.3. Silvopasture

As a farming practice, **silvopasture** is the intentional combination of pasture and **trees or shrubs** on or around the same plot. In most cases, these are **fruit** and/or **timber** trees. They may also be **fodder trees**.

In the example of grazing-based viticulture and orchard below, silvopasture brings soil cover and plant diversity in monocropping systems with bare inter-rows. In that way, it increases SOM, stabilises soil structure (hence minimising erosion), actively protects and feeds soil life and overall biodiversity, prevents pest and disease outbreaks, and improves nutrient cycles. According to the experts, the key success factor is the presence of animals on the farm or collaborating farms, and the adaptation of pruning and trellising systems.

[1] Holistic management is defined by the Savory institute as 'a framework for making decisions amidst the ever-changing conditions of the living world. Specifically, it includes (1) a decision-making framework for defining your north star, finding alignment amongst decision-makers, and ensuring your actions move you in the right direction.' It also includes '(2) planning procedures [...] specifically for those managing land and livestock, to help you plan in a simple and step-by-step manner'. Holistic planned grazing is one of these planning procedures.

Grazing-based viticulture and orchard

Grazing-based viticulture and orchard.

Copyright: Claudia Nielsen, Denmark.

Farmers in **England, Germany, France, Austria, Switzerland, and Italy** graze vineyards and orchards most often with sheep but also occasionally with cattle and pigs. They graze between the vine and tree rows, often grass, but also diverse types of cover crops.

2.1.4. Manure management

Manure management consists of transforming raw manure into a form that provides a beneficial microbiome for the soil and crops, plant nutrients, and soil organic matter. The experts focused on **composting** as a way to manage manure along with other organic farm residues (e.g., vegetable scraps, pruning material). **Composting** is a traditional practice consisting of 'the controlled biological decomposition of organic material in the presence of air to form a humus-like material' (EEA, n.d.). The composting process can be tuned based on the organic material, physico-chemical conditions, and additives. The application of compost as an amendment is detailed in section 2.2.5.

Composting produces an organic soil amendment with several beneficial properties, depending on the type of composting process. The thermophilic composting process prevents the reintroduction of plant and human pathogens as well as weed seeds in the soil. Vermicomposting, on the other hand, creates a biodiverse, numerous, and active soil life, with inoculants increasing soil life activity and biodiversity (see below).

According to the experts, the key success factors are: the know-how on production; the availability of organic resources in quantity and quality, e.g., good balance of N and C; and the necessary investments in machinery. The main limitations are (1) the additional workforce needed to compost directly on farms, and (2) the costs of large volumes of compost when bought from a commercial producer.

Composting

Composting.

Copyright: Karme Petrutis, Estonia.

In **Austria**, our expert and his colleagues produce and sell compost made through a thermophilic process, which reaches temperatures up to 70°C. This is enabled by regular turning to homogenise it, check conditions, and prevent overheating and anaerobic conditions within the system. Because of the high temperatures, weed seeds can be killed, and plant pathogens and human pathogens can be destroyed or inactivated.

In **Estonia**, market gardeners produce compost on a small-scale for their farms.

Vermicomposting

Vermicomposting.

Copyright: Alfred Grand, Austria.

In **Austria**, our expert and his colleagues produce and sell compost made with the help of epigeic earthworms and other species. As it is produced at a moderate temperature, the end product contains a more diverse range of microbes (bacteria, archaea, fungi, protozoa, mesofauna and macrofauna).

2.2. Regenerative plant production systems

The following regenerative practices are implemented in arable, vegetable and orchard systems.

2.2.1. Minimal tillage

Minimal or reduced tillage includes a variety of practices without ploughing (Labreuche et al., 2014). According to experts, it benefits soil health by reducing soil disturbances. This results in fewer SOM losses through mineralisation and more SOM at the top of the soil, hence preventing soil surface crusting, protecting soil life through the mulch and by minimising soil disturbance, and more stable soil aggregates, which drastically reduce soil erosion. It also increases soil water percolation and retention in the landscape, reducing runoff.

According to experts, the success factors for minimum tillage are good cover crop development, access to machinery, good timing of application, and system understanding. These factors are key to reducing soil tilling and glyphosate use. Although minimum tillage generally leads to a significant increase in glyphosate use, some pioneering farmers are managing to reduce both at the same time. They combine the use of dense cover crops, superficial tillage ('scalping'), and roller crimping to keep total glyphosate use below 300 g/ha/year, i.e., 1 L of the classic 360 g/L formulation (Brun et al., 2021).

The main limitations are the difficult control of pests such as voles and slugs, and temporary higher soil compaction before soil organisms and roots take over the soil structure. It also tends to reduce the options for controlling perennial weeds and relies on total herbicides such as glyphosate. Soil warming and mineralisation tend to be slower in spring, which can negatively affect the crop development. Finally, productivity tends to be lower in wet years.

Below are various illustrated minimal tillage techniques.

Strip-till

Strip-till consists of tilling the soil with a tine at a depth of 15 - 20 cm, in strips covering less than 30 % of the field surface. The rest of the field is typically covered by crop or cover crop residue.

Strip-till.

Source: E. Trefeu, France

Practice applied in **Normandy, France** for maize production. Strip tillage, sowing, and underfoot fertilisation are done simultaneously. The strip-till is done after a cover crop, participating in preparing a good soil structure.

No-till

No-till farming involves direct seeding without disturbing the soil through tilling. At least 30 % of the field should be covered by plant residues right after crop establishment. A way of implementing no-till is to use no-till drills. Both minimal tillage, and no-till, require proper management of cover crops and successful termination before seeding.

No-till. Copyright: ECAF, Spain.

Source: ECAF, Spain.

Experiments are being conducted in **Czechia** at two sites using no-till machinery with parallelograms, in combination with rich cover crops (more than nine species), compost and biochar application, as well as intercropping. No-till sowing is used for both cover crops and main crops.

An advisory company in **Slovakia** is supporting farmers in developing no-till systems in both conventional and organic farming. For example, no-till seeding of soybeans in cover crop residues in April is followed by no-till seeding of hard wheat and winter pea mixtures in September after harvest.

Organic No-till using roller-crimper

Crops can be terminated mechanically using a **roller-crimper,** rolling down and crimping a cover crop when it starts flowering. Rolling and sowing can be done simultaneously. According to experts, roller-crimpers combined with direct sowing avoid high soil temperatures in summer, reduce evapotranspiration and weed germination, and maximise the time when roots are present in the soil and when soil is covered. The use of a roller-crimper to manage weeds requires water availability in spring and low weed pressure. Its success highly depends on weather conditions and is not adapted to all crops.

Roller crimper.

Copyright: Alfred Grand, Austria.

Experiments are being conducted in **Greece** using a roller-crimper to terminate the cover crops before direct seeding the following crop into the resulting residue mulch for spring-summer crops.

Our expert in **Austria** used a roller-crimper combined with a direct seeder, both in spring on a rye cover crop, and in autumn on a fava bean cover crop, with satisfying results (see Annex 4).

2.2.2. Permanent soil cover

Permanent soil cover means that the soil is always covered either by living plants or dead plant residues. Living cover crops (also known as catch crops or green manure) cover the soil during the time in between two main crops. Cover crops can also be applied continuously over several years, resulting in **permanent living mulch**. In this case, commercial crops are sown within the cover crop. Residues of commercial or cover crops cover the soil during the initial phase of crop growth when it has been sown with no-till or minimal tillage techniques. These practices can be found in both arable cropping systems and orchard systems.

According to the experts, permanent soil cover drastically reduces soil erosion and prevents soil surface crusting. It also actively protects and feeds soil life, and provides organic material to the soil, often resulting in a higher SOM. Furthermore, it increases soil water-holding capacity as well as soil water percolation. While crop residues left on the surface only reduce the impact of water and wind on the soil, permanent cover crops preserve the soil structure through their living rooting systems. They also protect soil fertility by reducing leaching and providing additional nitrogen, suppressing some pests and diseases, preventing soil compaction, and creating ecological corridors and landscape continuity.

Among the main success factors cited by the experts are: (1) understanding how the new system works, (2) sowing the right mix of cover crops early enough, and (3) having the appropriate machinery to sow and terminate the cover crops.

Leaving crop residues

Leaving crop residues.

Copyright: Julio Roman-Vasquez, Spain.

See minimum tillage above.

Cover crops in arable cropping systems

Cover crop - arable.

Copyright: Karel Klem, Czechia.

In **Czechia**, at two sites, cover crop mixes with more than nine species are tested, combining different functional groups (legumes, deep rooting species, grasses, Brassicaceae). The cover crop is terminated mechanically.

In **Austria**, two agri-environmental measures of the CAP finance the implementation of mixes of cover crops and permanent soil coverage with the use of cover crops (single species or mixes).

Cover crop in orchards

Cover crop – orchard in the Mediterranean context.

Copyright: Julio Roman-Vasquez, Spain.

In **Spain and Portugal,** farmers use cover crops in orchards such as olives and almonds, between the tree rows on at least 30 % of the surface. The cover crop is sown once and then maintained throughout the season.

In **Spain,** cover crops are grown as green manure in rain-fed almond orchards. A mix of leguminous and Gramineae species is sown and incorporated into the soil by shallow tillage in mid-spring.

Perennial living mulch

Alfalfa as a perennial living mulch – arable.

Copyright: Fredrik V Larsen, Denmark.

In **Denmark**, a farmer is experimenting with alfalfa as a perennial living mulch. Each year, main crops are sown within the alfalfa cover. After the main crop is harvested, the alfalfa continues to grow and can itself be harvested. Alfalfa is managed through mowing and herbicides and is expected to last up to five years. This perennial mulch provides significant nitrogen to the main crop and helps rebuild soil organic matter. The alfalfa's long tap root also improves the structure of the deeper soil layers. However, managing competition between the crops can be challenging, and farmers need to find ways to utilise the forage effectively.

2.2.3. Crop diversification

Diversifying crop succession involves **introducing new crops**, often from different families. **Intercropping is a form** of crop diversification at the field level, and is defined as 'a system of multiple cropping in space' (Whitmore and Schröder, 2007). This can involve two commercial crops, such as oats and peas, or a commercial crop and a service crop, such as oilseed rape and frost-sensitive legumes. **Undersowing** is a type of intercropping where the main crop (e.g., pumpkin, soy, sunflower, etc.) is sown first, and then grasses or legumes are spread over the top (e.g., Picard et al., 2010).

Crop succession diversification.

Source: Piet Levering

Intercropping

Intercropping with cereals and legumes.

Source: Karel Klem, Czechia

Intercropping with cereals and legumes is being experimented in **Czechia**.

Undersowing

Undersowing. Buckwheat in Sunflower.

Source: Willi Peszt

- Undersowing is financially supported in **Austria** as part of the Agri-Environmental program against soil erosion.
- It is also experimented with annual cover in **Czechia**.

2.2.4. Agroforestry

Agroforestry in crop production systems is mostly implemented in **alley cropping** with timber, fruit and/or nut trees. The orientation and spacing of tree lines influence light distribution, (wind) erosion reduction potential, and water dynamics in the system. **Hedgerows** are lines of different types of bushes and small trees growing very close together along the sides of the fields. A **food forest** is a highly diverse agroforestry system. It consists of planting a wide variety of complementary perennial species in a planned manner to optimize the use of light and water resources, and offer food and shelter to pollinators and natural pest enemies. The perennial crop produces either food or services to the staple crops.

Alley cropping agroforestry

Agroforestry.

Source: Piet Levering, Netherlands.

In the **Netherlands**, the collective vegetable farm De Biesterhof has planted 8 ha. of ryegrass pasture with rows of fruit trees and bushes: plums, apples, and hazels spaced by 36m of organic crops (Link).

Hedgerows are financially supported in **Austria** as part of the Agri-Environmental program of the CAP.

Food forest

Food forest.

Source: Yann Boulestreau, Ketelbroek Netherlands.

In the **Netherlands**, the collective vegetable farm *De Biesterhof* plan to plant a 5 ha. food forest.

2.2.5. Soil amendment and biostimulants

Soil amendments aim to change long-term soil properties through the addition of specific inputs such as compost (see section 2.1.4), biochar, or lime. **Soil biostimulants** are compounds applied to the soil with specific microbial communities to perform a specific function in the soil, such as nitrogen-fixing bacteria.

Use of compost as a soil amendment

Application of compost as a soil amendment.

Source: Zrno Rrganic Farm, Croatia.

Cereal and vegetable farmers in **Estonia** apply organic compost to build up their soil.

Market gardeners in **central and northern Croatia** use Deep Compost Mulch to support organic no-till vegetable systems, both in terms of nutrient fertility levels and maintaining the soil free of perennial weeds.

Use of compost extract as biostimulant

Application of compost extract as biostimulant.

Source: Alfred Grand, Austria.

Our expert in **Bavaria, Germany** is using compost extract applications in combination with holistic planned grazing to influence soil life networks and plant communities.

A farmer in **Austria** is using vermicomposting extract to coat the seeds of their crop to enhance the microbiome in the rhizosphere, thereby supporting several functions such as nutrient uptake. This reduces their need for fertilisation.

2.2.6. Integrating the practices in a farming system

More than the use of individual practices, regenerative agriculture consists of the combination of practices that work synergistically. For instance, no-till must be combined with the use of cover crops, as seen in conservation agriculture cropping systems. Regenerative farming systems, such as most market gardening systems, combine numerous practices at the field level (e.g. minimal tillage, cover crops, soil amendments, diversification), the farm level (e.g. landscape structure and diversity) and the food system level (e.g. direct selling) to regenerate soil, biodiversity and rural livelihoods.

Market gardening

Market gardening.

Source: Alfred Grand, Austria.

In **Austria,** our expert combines the application of compost and mulch with a highly diverse crop rotation and the use of cover crops. No heavy machinery, pesticides, or mineral fertilisers are used, relying instead on small-scale hand labour. The products are sold directly to local customers and businesses, fostering a strong connection between farmer and consumer and ensuring good revenue.

In **Croatia**, the oldest organic farm *Zrno* produces organic vegetables on no-till compost beds with an approximately 1.5-metre deep compost layer (see Supplementary Table 9). They cover the soil permanently with living plants, using cover crops (including green manure) and a diverse commercial crop rotation, biodiversity strips (e.g. flower strips), and minimal tillage.

Conservation agriculture in arable cropping and orchards

Conservation agriculture.

Source: Karel Klem, Czechia.

In **Hungary** the Soil Restoration Farmers Association (TMG) promotes the combination of no-till or strip-till, cover crop use, and crop diversification across the country.

In **Czechia** researchers experiment with farming systems that combine species-rich cover crops (more than nine species) with no-till, intercropping, and the application of compost and biochar. The cover crop mixes are designed to include different functional groups such as legumes, deep-rooting species, grasses, and Brassicaceae. Intercropping is done with spring triticale and fava bean, or between winter wheat and winter peas.

In **Spain**, rain-fed almond farms have experimented with reduced tillage combined with green manure. The reduced tillage is performed twice a year (in autumn and spring) at a depth of 15cm using a chisel cultivator to control weeds. The green manure is produced by seeding a mixture of common vetch (*Vicia sativa* L.) and oat (*Avena sativa* L.) at 150 kg ha.$^{-1}$ in early autumn to provide a cover crop during winter.

Organic no-till systems in arable crops

Organic no-till.

Source: Christos Vasilikiotis, Greece.

In **Macedonia, Greece**, cover crop mixtures are tested in combination with a no-till system without herbicide use. A roller-crimper is used to terminate the cover crop. Spring crops are then directly sown into the resulting cover crops.

See our example in Austria in section 2.2.1.

Integrating livestock into organic no-till systems for arable crops and vineyards

(Organic) no-till with grazing animals.

Source: Francisca Reis, Portugal.

Our expert in **Basque Country, France**, implemented organic no-till in arable crops while integrating cows for meat purposes, in a rotational grazing system. This combination enables him to graze the cover crops and also to utilise failed experiments as fodder for the animals.

In **Portugal**, orchard and wine farmers are combining cover crops between tree rows and no-till to control their growth.

3. Challenges and solutions

During the first meeting, the main challenges to implementing a diverse range of regenerative farming practices and systems in various European contexts were highlighted. Subsequently existing or novel solutions to address these challenges were proposed. This section summarises these challenges and the proposed solutions.

3.1. Technical

Table 1. Technical challenges and solutions in regenerative agriculture

Challenges	Solutions
Integration of practices Practices (partially) incompatible or presenting dis-synergies. E.g., no-till combined with organic fertilisation reduces nutrient availability in early spring and might increase N_2O emissions.	**Integration of practices** Experiment with combinations of practices to reveal possible synergies between them and couple the results with remote-sensing observations and big data analysis. This would allow for developing better RA decision support tools and defining context-specific and measurable RA outcomes.
Managing weeds Weed control in minimum to no-till systems, especially with no or reduced use of herbicide such as glyphosate (e.g., organic no-till).	**Managing weeds** Combining technical solutions, e.g., crop rotation breaking weed cycles, mulching with (cover) crop residues or compost, using a frost-sensitive or knife-roller-sensitive cover crop mix sown directly after harvest.
Managing voles and slugs Vole and slug damage in strip-till and no-till systems.	**Managing voles and slugs** Sowing spring crops in late winter.
Lack of adequate inputs or machines Existing inputs or machines not adapted to new regenerative (systems of) practices, e.g., cover crop varieties are not adapted to permanent living mulch. Lack of access to specific inputs such as compost or high-quality organic fertiliser free of plastic or toxic components. Lack of access to existing specialized machinery: no or few local test, rental or service options, high cost to purchase a new machine, few used machines available, e.g., direct seeding machines.	**Lack of adequate inputs or machines** Closer collaboration with the agricultural industry to develop appropriate machines and inputs. Development of vermicomposting production in Europe to increase availability to farmers at a reasonable price. Development of adapted varieties, such as dwarf alfalfa, e.g., by non-profit or public institutions to support the initial market development. Farmer machine cooperative, where farmers share equipment (e.g., CUMA in France). Public support to machine cooperatives.
Market specifications Market specifications incompatible with certain regenerative practices, e.g., intercropping systems tend to produce mixed-grain harvest, incompatible with industry standards for human consumption.	**Market specifications** New compromises with the industries on specifications or on processes to enable on-farm regenerative practices.
Integrating animals Integrating animals in plant production operations represents high costs, e.g., for new equipment, building, and knowledge. Fencing, providing water and shade in rotational grazing systems.	**Integrating animals** Animals sharing among farmers. High quality planning and organization.
Effective biostimulation Inconsistent field results from commercial biostimulant applications.	**Effective biostimulation** Biostimulants produced based on local organic sources, e.g., local forest floor, could increase efficiency and reduce costs.

Source: European Commission

Additional information on the practitioners' needs for technical knowledge and advice can be found in section 5.1.

3.1.1. Climate change adaptation

Table 2. Climate change adaptation challenges and solutions in regenerative agriculture

Challenges	Solutions
Some key regenerative agriculture principles are being challenged by climate change. For instance, maintaining living roots year-round is becoming increasingly difficult in regions where summers are drier and hotter, such as the Mediterranean regions and Brandenburg in Germany.	› adapting the crop varieties to new climate conditions › constantly adapting crop and husbandry systems to the ever-changing climate

Source: European Commission

3.1.2. Knowledge

In the solution section below, we present the innovative ways for knowledge exchange and dissemination identified by the focus group.

Table 3. Knowledge transfer challenges and solutions in regenerative agriculture

Challenges	Solutions
Farmer and farm advisor Lack of knowledge about regenerative practices and system understanding among farmers and farm advisors	**Farmer and farm advisor** › development of an 'inter-rail program' for young farmers and agriculture students where they visit pioneers of RA in Europe › provision of subsidies to advisors based on their results in terms of practice change › initial and lifelong training of advisors and farmers in RA › development of decision support tools for regenerative practices › development of advisory services independent from input companies, as the latter do not foster knowledge acquisition on systems relying less on pesticides and synthetic fertilisers › developing and profiting from local, national, and European networks fostering peer exchange, e.g., the national Hungarian association for RA (TMG), the European network (EARA), and the EU CAP Network › working with cooperatives to support more farmers › development of a platform to share knowledge about failures › systematic education exchange programs in the EU to benefit from the knowledge of the most advanced countries
Context-based knowledge RA is context-specific. We lack knowledge on the best regenerative system(s) for each European context.	**Context-based knowledge** › funding on-farm experiments led by farmers (e.g., through eco-schemes) across farm networks and capitalising on them › funding multi-stakeholder platforms to develop knowledge and innovations adapted to their local context, e.g., EIP OG projects, EU Mission Soil living labs › highlighting pioneer farmers, especially at the local leveldevelopment of an open-source database on context-specific knowledgeestablishment of more demonstration farms and demo days

Source: European Commission

3.1.3. Mindset and culture

Table 4. Challenges and solutions in mindset and culture

Challenges	Solutions
Clear RA definition The lack of a clear and common definition of regenerative principles, outcomes and ways to measure them opens the way to greenwashing.	**Clear RA definition** Agreeing on a European-wide common definition.
Changing farmers' mind-set Experienced farmers or advisors evaluate performance at the crop level solely in terms of yield or 'cleanliness of the field' (e.g., no weed, no pest damage, no crop residues). Social pressures from neighbouring farmers criticising new ideas or new images of the field.	**Changing farmers' mind-set** Teaching innovative thinking in agriculture curriculum for farmers and advisors, e.g., using biomimicry and taking the point of view of keystone species such as earthworms. Development of contests on the best RA farms and practices instead of ploughing contests.
Knowledge in society Lack of understanding on the need and challenges for RA in society, impeding social support to it. Lack of understanding in society for the positive role grazing animals play in ecosystems.	**Knowledge in society** › teaching in schools › teaching policymakers › building multi-stakeholder platforms to support co-creation, testing of solutions and knowledge exchange, e.g., EU Mission Soil living labs and lighthouses › popularising the concepts of one health: soil, plants, animals, food, and humans

Source: European Commission

3.2. Economic and financial

Table 5. Economical and financial challenges and solutions in regenerative agriculture

Challenges	Solutions
RA as the best economic option for European FARMERS Moving away from non-regenerative practices that perform well economically at the farm level. The economic superiority of regenerative farming practices is not always clear nor guaranteed (see section 2.)	**RA as the best economic option for European farmers** › environmental services payment, including setting up an EU-wide regulatory standard for measurements and funding and training analytical labs › price premium guaranteed through participatory guaranteed systems › introducing resilience in the financial assessment of farming systems, e.g., yield stability across years › supporting RA (system of) practices through the eco-schemes
Capital to transform farming systems Regenerative practices often require changes in machinery, e.g., direct sowing machines. Agroforestry requires initial capital to invest in planning and planting materials.	**Capital to transform farming systems** Subsidising the acquisition of specialised equipment for RA or the development of machine cooperatives.

Source: European Commission

4. Deep dive into five critical areas for the success of regenerative agriculture

From the challenges collectively identified, five critical areas emerged for the successful contribution of regenerative agriculture to European soil health. Each of these areas was addressed by a group of experts in the form of a Mini Paper, the results of which are summarised below. Each paper concludes by highlighting research needs from the field and ideas for practical innovation projects (e.g., EIP Operational Group projects) related to its topic.

4.1. The role of animal husbandry in regenerative agriculture and the potential of livestock grazing to restore soil and ecosystem functioning

Integrating animals is considered one of the principles of regenerative agriculture, while animal production is under scrutiny from many critics in European society. One of the main criticisms is the emission of greenhouse gases from animal production, especially from ruminants, leading to environmental degradation. These criticisms, together with the uncertain economic perspective and the hardship of animal care, tend to limit the reintegration of animal production in a regenerative way. In response, this Mini Paper aims to explain the principles of regenerative livestock production, particularly grazing management, and the expected impacts on soil and ecosystem health.

4.2. Reaching hearts and minds: how education reform and more effective dissemination of knowledge can support the mainstreaming of regenerative agriculture in Europe

Although there is already extensive knowledge about regenerative agricultural systems, this knowledge is still poorly represented in European farms, within their advisory services, and in agricultural and agronomic schools or universities. This paper focuses on practical approaches to (co)produce and disseminate knowledge on regenerative agriculture, and the mind and heart conditions conducive to the implementation of RA in European farms. These approaches are illustrated with a rich panel of European examples, such as the state-funded farm innovation groups in France, or the Northern Roots forum organised in Estonia.

4.3. Outcomes and indicators for regenerative agriculture across Europe

To date, there is a lack of widely accepted and benchmarked indicators of soil health and methods to measure them. One of the reasons for this is the difficulty in finding the right trade-off between the scientific relevance of the indicators and the cost of the associated measurement methods. Expensive but precise methods can be used for scientific research aimed at producing generic knowledge and recommendations. However, farmers need access to cost-effective and time-efficient measurements that allow them to generate context-specific knowledge to support their decisions on how to manage soil health on their farms. This paper proposes a list of indicators to measure six key outcomes of RA on soil health at the field level: (1) increased infiltration and water holding capacity, (2) reduced erosion, (3) increased soil biodiversity, (4) increased carbon sequestration, (5) increased nutrient cycling, (6) pest and disease suppression. For each of these indicators, the authors propose one or more measurement methods for scientific studies and on-farm decision support.

4.4. Value creation through regenerative agriculture

A key lever to support the implementation of RA in Europe is to convince the different stakeholders that they will benefit from it. In particular, it is crucial to show farmers that they will benefit economically from the transition to this new approach to farming. This paper aims to show the direct impact of the transition to RA on farm profits, and where support may be needed during the transition. It also aims to detail the public goods provided by RA and how they could be remunerated to farmers (and value chain actors) through private initiatives, e.g., carbon markets and supply chain approaches, or public initiatives, e.g., action and result-based payments.

4.5. Systemic integration of regenerative practices

The use of a single practice labelled as regenerative (e.g., cover crops, no-till) is rarely sufficient to achieve the outcomes sought by RA (see definition). Rather than a list of individual practices to be applied, RA relies on systems of practices that are implemented in a way that produces the desired outcomes in a given context. This system of practices generally evolves over time, growing with farmer experience and changes in the agro-socioecosystem, such as changes in rainfall patterns, farm gate prices, or consumer perceptions. This paper aims to present different combinations of practices that achieve the desired regenerative outcomes in different contexts, from southern to northern Europe.

5. Needs and recommendations

5.1. Practitioners' needs for technical knowledge and advice

The experts identified practitioners' needs for technical knowledge and advice on: (1) service crops with emphasis on (permanent) cover crop and intercropping, (2) crop diversification, e.g., with legumes, (3) methods to phase out herbicides, (4) knowledge about soil biology and how to monitor its changes with simple and practical methods on the farm, (5) fertility management in regenerative agriculture systems, (6) the effective use of biostimulants, (7) the implementation of regenerative grazing, (8) the advantages and disadvantages of the different machines adapted to RA, in a given context, as well as how to build them on the farm, (9) pest management using crop diversity and natural enemies, (10) other technical topics such as agroforestry, water management and the prevention of soil compaction.

Detailed information can be found in Table 7 in Annex 5: Practitioners' needs for technical knowledge.

The experts also shared what they think the advice should look like. If you are interested in this topic, please consult Annex 4 and/or the corresponding Mini Paper (see 4.2).

5.2. Research needs from practice

The Focus Group experts identified and refined five key ideas for future research projects valid all across Europe, although the implementation should be adapted to the local context.

1. **Scaling up RA through better consumer engagement**
   There is no clearly shared definition of regenerative agriculture in Europe. There is a need to understand how to engage consumers as broadly and quickly as possible, in order to scale up regenerative agriculture.

2. **Developing and defining soil health indicators usable in practice**
   Many soil health indicators exist, but they are often not designed for practical use, or it is not well understood how they reflect the impact of soil management practices (in this case, sets of RA practices). They also need to be fine-tuned for specific combinations of climate-soil-crop rotations. They should also indicate the side effects of practices (nutrient use efficiency, N losses, GHG emission). How can this information be made easily accessible to farmers? One example is the Food4Sustainability database, which is applicable across the EU and very relevant to RA, but also to other agricultural systems.

3. **Assessment of regenerative agriculture impact on climate**
   What is the impact of regenerative agriculture on the microclimate, particularly on the water cycle and clouds (link between vegetation, photosynthesis and biomass, and climate)? This could be assessed across Europe or in pilot projects in different regional contexts.

4. **Best way of linking agricultural actors for the further development of regenerative agriculture**
   Currently, farmers are not sufficiently connected with advisors, scientists, and decision-makers. Understanding the language of scientific knowledge is often a challenge for farmers. Advisors and the farm advisory system could provide a bridge between science and farming practice. Additionally, farmers' needs do not always reach decision-makers. Therefore, there is a need to develop and assess methodologies to engage multi-stakeholders in the further development of regenerative agriculture Europe-wide.

5. **Optimisation of cover crop management**
   There is limited knowledge on the design of cover crop-based systems: what species, seeding timing, termination timing and methods are adapted to different soils, climatic conditions and farmer objectives (weed control, pest management, soil building). There is a lack of overall understanding of the effects of cover crops on soil quality, biology, water management, and nutrient cycling. Methods for integrating livestock into cover crop management need to be developed. This is important for arable crops, tree crops, vegetables, and livestock.

Additional ideas are to be found in the Mini Papers.

5.3. Recommendations for Operational Groups

The Focus Group experts identified and refined six key ideas for Operational Groups valid all across Europe, although the implementation should be adapted to the local context. We sum them up in the table below (RA= Regenerative Agriculture).

Table 6. Recommendations for regenerative agriculture Operational Groups

Titles	Challenges	Recommended activities
Optimise cover crop systems for RA.	There is limited know-how on which cover crops to use in various farming systems, and how to manage them for soil quality, fertility and nutrient management.	Help farmers choose the right type and management of cover crops for a given challenge (nutrient management, soil quality, water management). Determine the challenges facing farmers in the region and test cover crop types, timing of seeding and termination.
No/Min-tillage without herbicides in RA.	In RA many farms use herbicides (e.g., glyphosate) for cover crop removal and weed control. Without the use of herbicides, farmers would return to deep tillage. Methods and practices are needed that eliminate herbicide application in no/min-tillage systems without the disadvantages of destroying soil health through deep tillage.	Development of no/min-tillage weed control strategies without herbicides. Create guidelines for implementing successful solutions for no/min-tillage without use of herbicides (machinery, practices, etc.) Research, field trials, peer-exchange and dissemination activities.
Practical tools to measure soil (biological) quality indicators at the farm level and evaluate the effects of specific RA practices	Farmers need to be able to use easy, practical and inexpensive tools to evaluate the effects of specific RA practices on soil health. It is essential is that a farmer can see the evolution of soil quality as influenced by specific RA practices. More general beneficial effects of specific RA practices could then be derived and extrapolated to other regions.	Inventory of existing easy-to-use tools and apply them with specific RA practices; monitor the evolution over time. Use or develop apps to assess and interpret the soil quality.
Intercropping management.	Numerous technical questions remain unsolved, such as the species/genotype selection, time of sowing (simultaneous or relay), weed management, harvest technology, and the equipment needed.	Provide decision support for the technical points described in the previous cell. Field trials, microbiome analyses, machinery development, species and genotypes screening, cost-benefit analysis, development in the food chain of products from crop mixtures.
Integrating grazing animals into the crop system.	Integrating animals in a crop farm operation is challenging. Cover crop mixtures need to be adapted as well as the animal specie(s) used.	Support cooperation between dairy, beef, sheep, and goat farmers and crop farmers to improve soil health. Build contracts between different farmers to introduce animals into regenerative agriculture cropping systems. For example, agreements to allow animals from one farm to graze the cover crops of another farm. Organise Field days. Measure the impact on soil health, animal health and performance, and canopy cover.

Source: European Commission

Additional ideas are to be found in the Mini Papers.

6. Conclusion

The Focus Group on 'Regenerative Agriculture for Soil Health' defined regenerative agriculture as an outcome- and principle-based approach that emphasises restoring and improving soil health. It also aims to reverse biodiversity loss, restore water cycles, adapt to and mitigate climate change, and increase economic viability. The expert identified a variety of agroecological practices that can be combined in a context-specific manner to achieve these outcomes, such as managed grazing, minimum tillage, permanent cover, and agroforestry.

Main findings and challenges

1. **Productivity & economic benefits**
   - increase in crop yield through improved organic matter and grassland recovery
   - higher yield of livestock-related products (milk, meat) due to increased forage yield and pasture-carrying capacity
   - higher income per unit of land through double production
   - reduced machinery, fuel, and labour costs
   - increased opportunities for tourism and recreational activities
2. **Economic & time savings**
   - lower application of inputs such as organic fertilisers, additional animal feed, and fuel
   - lower veterinary costs and reduced machinery costs for weed control in orchards
   - significant reduction of time required for field operations and higher flexibility with less dependency on weather conditions
3. **Social and environmental impact**
   - drastically reduced soil erosion and CO_2 emissions
   - alternatives to total herbicides like glyphosate, leading to reduced surface water pollution and sedimentation in reservoirs
   - increased animal health
4. **Challenges identified**
   - technical challenges, such as implementing no-till without glyphosate
   - climatic challenges affecting the transition
   - knowledge dissemination issues
   - economic and financial barriers
   - inappropriate mindsets and cultural resistance
5. **Solutions and recommendations**
   - overcoming these challenges requires a combination of targeted solutions suggested in five focused Mini Papers
   - recommendations include enhanced advisory services, new research projects, and the formation of operational groups

Final Note

The Focus Group hopes that its work will inspire and help stakeholders to support the transition of the European food system towards regenerative agriculture, thereby significantly improving the health of our precious soils.

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Annex 1: List of Focus Group experts

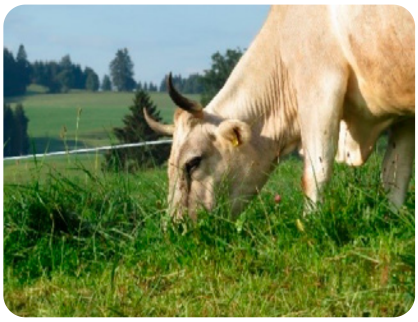
Family name	First name	Country	Profession
Almagro	María	Spain	Researcher
Bajohr	Christine	Germany	Farmer
Bay-Smidt	Knud	Denmark	Farmer
De Neve	Stefaan	Belgium	Researcher
Félix	Noblia	West Normandy - France	Farmer
Fortino	Gabriele	West Normandy - France	Farm advisor
Grand	Alfred	Austria	Farmer
Klem	Karel	Czechia	Researcher
Koster	Howard	Netherlands	Farmer & Researcher
Külvet	Airi	Estonia	Farmer
Marhavy	Lubomir	Slovak Republic	Farm advisor
Nielsen	Claudia	Denmark	Farmer & Researcher
Nyárai	Orsolya	Hungary	NGO representative
Petrutis	Karme	Estonia	NGO representative
Pinto-Correia	Teresa	Portugal	Researcher
Reis	Francisca	Portugal	NGO representative
Román-Vázquez	Julio	Spain	NGO representative
Trstenjak	Magdalena	Croatia	Farm advisor
Vasilikiotis	Christos	Greece and Italy	Researcher
Weber	Thomas	Austria	Farm advisor

Facilitation team

Boulestreau	Yann	Coordinating expert	France
Ulm	Liina	Task manager	Estonia
Verwimp	Bavo	Co-task manager	Belgium

Annex 2: Regenerative animal husbandry practices: benefits, success factors, limitations and links

Supplementary Table 1. Managed Grazing

 *Adaptive multi-paddock rotational grazing* Source: Airi Külvet.	 *Holistic planned grazing. In the foreground the grass from the previous plot can be seen* Source: Christine Bajohr	 *Winter bale grazing* Source: Airi Külvet.

Benefits for soil health mentioned by the experts

- increase soil fertility, especially SOC & SOM by enhancing root growth and nutrient cycling
- minimise soil erosion
- prevent soil compaction
- balance soil chemical composition
- (re)introduce beneficial organisms
- increase soil biodiversity, especially soil microbiota partly inoculated through the animal's gut
- increase soil life
- increase soil water percolation
- increase water retention in the landscape
- increase overall ecosystem multifunctionality

Other benefits mentioned by the experts

Productivity

- increases crop yield, through the increase of organic matter and, in the case of forage, by letting the grassland recover after grazing
- increase yield of livestock-related products (milk, meat), through higher forage yield and higher carrying capacity of pastures
- increases animal health

Economic

- lower application of inputs such as organic fertiliser, additional animal feed (including on-farm produced forage, e.g., for the winter), and fuel
- lower veterinary costs
- reduced machine cost for weed control in orchards

Ecological

- also favours above-ground biodiversity

Social

- prevent damage to infrastructure and building due to flood and soil erosion
- restore ecosystems with high recreational value, including above-ground biodiversity
- wildfire prevention in Mediterranean countries by controlling excessive vegetation which can serve as fuel

Time

- less work for feeding and managing manure

Success factors mentioned by the experts

- be flexible
- understanding how the system works and follow the rhythms of nature and the microclimate of each area, every year
- consider the ratio between the number of animals versus the area of ground

Limitations

- no time gain or slight loss
- may require a few years of transition to get used to the new system
- when done on cover crops, it is not compatible with all species

More information		
› Youtube video › Nielsen et al., 2021 (doi: 10.3389/fenvs.2021.785531) › Diaz de Otalora et al., 2021 (doi: 10.1016/j.ecolind. 2021.107484) › Fernandez-Guisuraga et al., 2022 (doi: 10.3389/fevo .2022.861611) › https://sandcountyfoundation.org/news/2023/soil-health-rotational-grazing › https://www.soils.org/news/science-news/crop-rotation-grazing-rebuilds-soil-health/ › https://orgprints.org/id/eprint/49879/	› Best-practice guide: Leitfaden (kuhproklima.de)	› Youtube video
› Mini Paper 'The role of animal husbandry in regenerative agriculture _ outline_v2'		

Supplementary Table 2. Multi-year ley farming

Multi-year ley farming

Source: Claudia Nielsen.

Benefits for soil health mentioned by the experts

- minimise soil organic matter losses
- minimise soil erosion
- provide organic material to the soil
- actively protect and feed soil life
- balance soil chemical composition
- minimise soil life disturbance
- increase water retention in the landscape

Other benefits mentioned by the experts

Productivity & Economic

- higher yield resulting in higher income

Ecological

- also favours above-ground biodiversity

Social

- prevent damages to infrastructure and building due to flood and soil erosion
- reduced drinking water pollution due to leaching of nutrients

Success factors mentioned by the experts

- livestock present on the farm or from a collaborating farm

Limitations

- more time-consuming if no animals on the farm beforehand
- the productivity and economic benefits depend on the alternative crops which could be produced on the given farm

Supplementary Table 3. Grazing-based viticulture & orchard

Grazing-based viticulture & orchard

Source: Claudia Nielsen.

Benefits for soil health mentioned by the experts

- minimise soil organic matter losses
- minimise soil erosion by stabilizing soil structure
- provide organic material to the soil
- balance soil chemical composition
- minimise soil life disturbance
- actively protect and feed soil life
- (re)introduce beneficial organisms
- shelter and feed biodiversity, especially natural enemies
- prevention of pests and diseases
- reduction of pesticides/herbicides use
- increase and improve nutrient cycles

Other benefits mentioned by the experts

Social

- higher landscape aesthetical value

Productivity & economic

- grass cover between orchard rows in combination with grazing allows for a double production on the same area, increasing the income per unit of land
- reduce machinery, fuel and labour costs
- increases opportunities for tourism and recreational activities

Time

- reduce time requirements for weeding, mowing, trimming, spraying

Success factors mentioned by the experts

- understanding of animal husbandry
- adapted pruning and trellising systems

Limitations

- additional stables and fodder might be needed in winter

More information

- AGFORWARD project
- https://www.mdpi.com/2071-1050/13/22/12340
- 'Win-win im Weinberg' project

Supplementary Table 4. Manure management

Composting

Source: Karme Petrutis.

Vermicomposting. Installation from Alfred Grand

Source: Alfred Grand.

Benefits for soil health mentioned by the experts

- prevent the reintroduction of plant and human pathogens in the soil compared to direct application of fresh manure (or plant residues)
- prevent the reintroduction of weed seeds in the soil compared to direct application of fresh manure (or plant residues)
- create a biodiverse, numerous and active soil life with inoculants increasing soil life activity and biodiversity

Other benefits mentioned by the experts

- substitute synthetic fertiliser
- might be sold to local gardeners

Success factors mentioned by the experts

- know-how on production
- available resources (especially composting) quantity and quality, e.g., good balance of N and Cinvestments in machinery

Limitations

- composting on the farm is time-consuming and can be costly

More information

- https://www.best4soil.eu/videos
- https://betterorganix.com/
- https://noura.hable.ee/#
- https://www.matogard.ee/en/
- https://www.mdpi.com/2073-4395/11/10/1952
- https://www.best4soil.eu/videos

Annex 3: Regenerative plant production practices: benefits, success factors, limitations and links

Supplementary Table 5. Minimal tillage

Strip-till	No-till	Roller-crimper
 *Strip-till* Source: E. TREFEU	 *No-till* Source: ECAF	 *Roller-crimper* Source: Alfred Grand
Benefits for soil health mentioned by the experts		
› minimise soil organic matter losses › minimise soil erosion › minimise soil life disturbance › increase water retention in the landscape (when residues left on the surface for no-till)		
	› prevent soil surface crusting › actively protect soil life › increase soil water percolation	› increase soil water percolation › prevent soil compaction › actively protect and feed soil life › prevent soil surface crusting › provide organic material to the soil › shelter and feed biodiversity, especially natural enemies › avoid high temperatures in summer › reduce water evaporation › reduce invasive species (at least in that area) › maximise timespan of soil coverage and living root systems in the soil

<table>
<tr><th colspan="3">Other benefits mentioned by the experts</th></tr>
<tr>
<td>Economic
› higher income due to lower costs (machinery, fuel, labour)
Time
› save time as tilling and sowing is done simultaneously
Social
› less soil erosion</td>
<td>Productivity
› from −20 % to +10 %. Negative effects are linked with perennial weeds, field voles and compacted soil. Positive effects are linked with increased resilience to droughts (better water availability during dry years) and later also with improved soil structure (after 3 years of application). In general, the positive effects are most visible after 3 to 5 years transition period
Economic
› in orchard: helps with pest control.
› generally positive due to reduced input costs (fuel) and labour cost overbalancing eventual yield reduction. In Mediterranean climates and arable crops, no-till reduces fuel consumption by around 50 % and increases crop profitability by around 15 %.
› decrease irrigation needs.
Time/organisational
› significant reduction of time required due to fewer passages on the field. In Mediterranean conditions, under no-till, working time reduction around 40 % much higher flexibility and less dependency on the weather conditions
Social
› soil erosion by water is very drastically reduced → less surface water pollution, less sedimentation of reservoirs. Fewer CO_2 emissions</td>
<td>Economic & Time
› if the cover crop is properly destroyed and rolling and sowing are done simultaneously, it reduces the machinery costs and time
Social
› alternative to total herbicides such as glyphosate</td>
</tr>
<tr><th colspan="3">Success factors mentioned by the experts</th></tr>
<tr>
<td>› successful cover crop development and termination
› good timing of the strip-tillage: soil humidity and temperature, air temperature forecast</td>
<td>› being patient to overcome the 3-5 years transition period
› change in mindset: accepting another image of the field
› system understanding
› access to direct seeders
› thinking in the medium/long term</td>
<td>› well-developed cover crop with >7 tDM, ideally in flowering stage
› appropriate direct seeder
› low weed pressure
› water availability in spring</td>
</tr>
</table>

Limitations		
› can favour pests such as voles	› higher soil compaction may occur temporarily › in the initial phase, growers often use higher rates of herbicides and rely on total herbicides such as glyphosate in the long term › slower soil warming, which negatively impacts spring crops such as maize (see strip-till) › reduced options for the control of perennial weeds › difficult management of field voles › slower N mineralisation in spring › reduced productivity in wet years › GHG emission balance is unclear, linked to potentially temporarily higher N_2O emissions	› success is highly variable depending on weather conditions › late seeding time for cash crop › not adapted to all crops › vole and slug management › perennial weed management
More information		
› CAPISOL project webpage (in French)	› Gonzalez-Sanchez et al., 2015 (Link) › Kassam et al., 2018 (Link) › Gertsis A. C. et Vasilikiotis C. (2018) (Link) › https://biopratex.sk/ › https://www.facebook.com/zdravapuda.cz/	› spring application [2] (Link) › autumn application [3] (Link)

2 Please download the videos first, before you play them, otherwise the resolution is poor.
3 Same comment.

Supplementary Table 6. Permanent soil cover

 *Leaving crop residues* Source: Julio Roman-Vasquez, Spain	 *Cover crop – arable* Source: Karel Klem, Czechia	 *Cover crop – Orchard in the Mediterranean context* Source : Julio Roman-Vasquez, Spain	 *Perennial living Mulch - Arable* Source: Fredrik V Larsen, Denmark
Benefits for soil health mentioned by the experts			
› minimise soil organic matter losses › minimise soil erosion › prevent soil surface crusting › provide organic material to the soil › actively protect and feed soil life › shelter and feed biodiversity › increase soil water percolation › increase water retention in the landscape	› increase the soil fertility by retaining nutrients such as nitrogen in the soil › prevent soil erosion › increase the carbon sequestration and humus content › suppress some pests and diseases › prevent soil compaction › prevent soil surface crusting › actively protect and feed soil life, **especially soil microbiome** › shelter and feed biodiversity › increase soil water percolation › increase water retention in the landscape	› minimise soil erosion › prevent soil compaction › prevent soil surface crusting › provide organic material to the soil › retain nutrients and provide additional N › minimise soil life disturbance › actively protect and feed soil life › increases soil organic matter › reduce fragmentation of the landscape by providing shelter and feed for biodiversity › increase water retention in the landscape › reduce run-off to about 65 % and erosion to 95 %	› the living mulch (e.g., alfalfa) and to the rebuilding of the SOM › the alfalfa's long tap root improves the structure in the deeper soil layers

Other benefits mentioned by the experts			
Productivity › by leaving crop residue on the soil surface, soil erosion and nutrient loss can be reduced and soil moisture can be retained, overall leading to a potential increase in productivity and yield **Economic** › potential reduction in irrigation costs › **Social** › reduced soil erosion › increased water availability for other uses	**Productivity** › if implemented well, increased productivity due to better soil fertility and weed suppression **Economic** › well-developed catch crop and timely termination reduces costs for fertiliser and increases productivity › supported by the CAP and carbon credits **Time** › cover cropping time is equivalent to alternative intercrop management (e.g., ploughing, false seedbed, herbicide use) **Social** › protect ground and surface water › reduced soil erosion (wind, water) › aesthetic value › good image for the farmer › increased biodiversity, especially pollinators	**Productivity** › increased biodiversity → reduces the need for pest control through pesticides **Economic** › may reduce irrigation needs hence irrigation costs › herbicide or tillage costs may be higher than vegetation maintenance **Social** › less herbicide use › climate change mitigation › landscape improvement › desertification risk reduction	**Economic** › the living mulch (e.g., alfalfa) can contribute with a larger amount of nitrogen to the main crop, hence reducing fertiliser costs

Success factors mentioned by the experts			
› understanding how different elements of the system affect each other (e.g., soil cover → soil moisture) › ability to ignore potential negative comments by peers or neighbouring farmers › developing a novel approach to what healthy soils need and how healthy land looks like. (e.g., 'tidy' ≠ 'healthy')	› sowing early enough › mix composition › sufficient water › good rotation design › appropriate machinery to sow and terminate the cover crop › access to information on locally adapted cover crops › understanding the role of different plant functional groups in cover crop mixtures	› access to information on locally adapted cover crops	› establishment of alfalfa › choice of herbicides › control of competition › value of the forages
Limitations			
› need for the crop residues for animal husbandry (feed, bedding)	› cover crop termination and fertilisation should be adapted to avoid competition for water and nutrients with the next commercial crop and/or mechanical issues during sowing	› the competition for nutrients and water may initially influence the orchard's productivity but seems to be compensated by positive effects after a few years	› competition between the living mulch and the main crop often occurs, leading to reduced yield › broadleaf weeds are difficult to manage › reliance on herbicide use to control the Alfalfa › slug and vole management is difficult

More information

- https://science.ku.dk/english/press/news/2021/researchers-let-crop-residues-rot-in-the-field--its-a-climate-win/
- https://talajbakterium.hu/kozos-kincseink-a-tarlo-szarmaradvanyai/ (in Hungarian)
- https://ktn.lko.at/zwischenfr%C3%BCchte-ein-schl%C3%BCssel-zum-erfolg+2400+3235185 (In German)
- https://www.pikk.ee/vahekultuuride-infopaeva-jarelkaja/ (in Estonian)
- https://germinal.ie/knowledge-hub/catch-crops-and-cover-crops-guide/
- www.ecaf.org
- The story of catch crops in Denmark, Nanna Hellum Kristensen PlanteInnovation, SEGES, Denmark
- González-Sánchez, et al., 2015 (Link)
- Evaluation of cover crop mixtures for weed management and soil fertility improvement in organic agriculture, Vasilikiotis, C, 2018 (Link)
- Vasilikiotis, C. et al. 2015 (Link)
- Gertsis A. C. et Vasilikiotis C. (2018) (Link)
- https://www.agromanual.cz/cz/clanky/technologie/regenerativni-zemedelstvi-1-hlavni-cile-predpoklady-a-zasady (in Czech)
- https://www.agromanual.cz/cz/clanky/technologie/regenerativni-zemedelstvi-2-hlavni-prinosy-a-rizika (in Czech)
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- Vasilikiotis, C. et al. 2020 (Link)
- http://www.diverfarming.eu/index.php/es/
- https://soilhealthbenchmarks.eu/
- Almagro et al., 2016 (Link)
- Almagro et al., 2017 (Link)
- https://agroganic.com/the-benefits-of-lucerne-as-a-perennial-living-mulch/

Supplementary Table 7. Crop diversification

 *Crop succession diversification* Source: Piet Levering	 *Intercropping* Source: Karem Klem	 *Undersowing. Buckwheat in Sunflower* Source: Willi Peszt
Benefits for soil health mentioned by the experts		
› balance soil chemical composition › minimise soil life disturbance › shelter and feed biodiversity	› provide organic material to the soil › balance soil chemical composition › actively protect and feed soil life › shelter and feed biodiversity, especially natural enemies	› minimise soil organic matter losses › minimise soil erosion › provide organic material to the soil › increase water retention in the landscape
Other benefits mentioned by the experts		
Productivity › when crop life cycles are not correlated, it decreases vulnerability to weather **Economic** › may reduce the need for fertiliser, herbicide, irrigation, and pesticides › when crop prices and life cycles are not correlated, it decreases vulnerability to weather and price variation **Social** › reduced pesticides use › increased local adaptive capacity › market access for local crop varieties › increased resource use efficiency › reduced financial risks associated with unfavourable weather or market shocks	**Productivity** › tends to slightly decrease yield (maximum 10 % loss in root crops) but may be positive, especially where nitrogen is limiting **Economic** › reduce the need for fertilisers **Social** › biodiversity in the field	**Economic** › reduced need for fertilisers and plant production products › possibility to produce two crops in one year (relay-cropping) **Time** › if only one crop is produced, then requires more time pro unit of production **Social** › reduction of soil erosion

Success factors mentioned by the experts		
› understanding the system and how its elements affect each other and the overall production › available up-to-date knowledge from the farm advisory system and agricultural education/training › access to funding and seeds › peer learning opportunities or demonstration farms › market for different types of crops › access to easy-to-understand, science-based information	› synchronisation of growth and harvest between the two crops	› date and plants used for under-sowing optimised for the commercial crop › supportive weather conditions › proper machinery › organic farming systems
Limitations		
› crops available for diversification often have a lower economic margin	› little machinery available to separate and clean grains after harvest › limited plant protection solutions available, especially for weed control	› tends to slightly decrease yield (maximum 10 % loss in root crops)
More information		
1. DiverImpacts project (Link)		2. Untersaat unter Sonnenblumen (Link – In German)

Supplementary Table 8. Agroforestry

Agroforestry

Source: Piet Levering, Netherlands

Food forest

Source: Yann Boulestreau, Ketelbroek Netherlands.

Benefits for soil health mentioned by the experts

- actively protect and feed soil life
- shelter and feed biodiversity
- increase soil water percolation
- increase water retention in the landscape
- limit water evaporation
- limit wind and water erosion

Other benefits mentioned by the experts

Productivity

- increase productivity per unit of surface

Social

- increase above-ground biodiversity
- create an attractive landscape
- offer a diversity of locally produced products
- provide water retention and a cool microclimate
- increase structural diversity of landscapes
- reduce wind erosion and dust potential

Success factors mentioned by the experts

- knowledge for correct local design, implementation, and management
- financing, especially for planting
- farm/landowner motivation
- local value chains
- access to adequate machinery
- landscape approach instead of single farm approach

Limitations

- economic benefits depend on the prices of the products
- takes 2-15 years before the first significant sales, depending on the species used
- higher complexity of the system leads to higher investment and operational costs

More information

- European Agroforestry Federation
- EIP Focus group – Agroforestry
- Veldkamp, E. et al., 2023 (Link)
- Wageningen research group
- http://www.unserboden.at/711-0-Bodenschutzanlagen.htm
- Windschutzhecken, Mehrnutzenhecken (Link - German)

Supplementary Table 9. Soil amendment and biostimulants

Application of compost as an amendment

Source: Zrno organic farm, Croatia.

Application of compost extract as biostimulant. Vermicompost

Source: Alfred Grand.

Benefits for soil health mentioned by the experts

- (re)introduce beneficial organisms
- shelter and feed biodiversity
- actively protect and feed soil life, increasing soil microbial activity
- increase in soil organic matter SOM which will bind soil particles, making them less sensitive to compaction
- better release of nutrients, improved soil fertility and crop development
- prevent soil compaction
- balance soil chemical composition
- prevent soil surface crusting
- reduce soil erosion
- increase soil water percolation
- create larger pores in the soil, leading to better structure
- increase water retention in the landscape

<table>
<tr><th colspan="2">Other benefits mentioned by the experts</th></tr>
<tr><td>

Productivity & quality

- higher productivity and vegetable quality (taste, storability)

Economic

- might be beneficial depending on the conditions (balance between amount, price and effect on productivity)

Social

- reduced soil erosion

</td><td>

Productivity

- higher productivity

Economic

- low cost, especially for seed coating. Higher productivity leads to higher profitability

Time

- the reduction in input needed (fertiliser, pesticides) might compensate for the biostimulant application

Social

- less pesticide application

</td></tr>
<tr><th colspan="2">Success factors mentioned by the experts</th></tr>
<tr><td>

- use of catch crops after the main crop to retain nutrients
- good application timing
- access to suitable machinery
- access to good quality compost
- good knowledge of compost and its use

</td><td>

- access to suitable machinery
- access to good quality compost/compost extract
- good knowledge of compost extract (e.g., compost tea) and its use

</td></tr>
<tr><th colspan="2">Limitations</th></tr>
<tr><td>

- high volumes of compost application might lead to leaching
- compost can be contaminated with pollutants such as heavy metals, plastics, weed seeds, or pathogens
- composting on the farm requires proper equipment, knowledge and is time-intensive
- buying compost for a large operation is expensive

</td><td>

- commercial biostimulants often do not perform consistently across a variety of contexts

</td></tr>
<tr><th colspan="2">More information</th></tr>
<tr><td>

- https://www.best4soil.eu/videos
- https://betterorganix.com/
- https://noura.hable.ee/#
- https://www.matogard.ee/en/
- https://zrno.hr/en/
- https://www.greenthingsfarm.com/farmer-resources/deep-compost-mulching
- https://www.notillgrowers.com/blog/2019/2/13/deep-mulch-system-step-by-step

</td><td>

- https://www.mdpi.com/2073-4395/11/10/1952
- https://www.best4soil.eu/videos

</td></tr>
</table>

Supplementary Table 10. Integrating the practices in a farming system

	Synergy benefits on soil health	Other synergy benefits	Success factors	Limitations	More information
 *Market gardening* Source: Alfred Grand	Rapid increase in soil biodiversity and soil life activity. Rapid increase in soil water holding capacity and water infiltration. Rapid improvement of soil structure. Rapid increase in soil organic matter (SOM) and soil organic carbon (SOC). Rapid increase in soil fertility.	**High productivity.** **Fair profitability** when combined with direct selling. Increased **food security** for villages and cities. **Connect producers and consumers**, serving as an education hub.	Know-how. Awareness. Small-scale hand labour. Hard work. Community building. Long-term approach and mindset.	Highly labour-intensive and physical, yet also attractive for young generations in Western Europe.	GRAND GARTEN - Videos ERASMUS+ project trAEce Erasmus+ project AGRETAIN OG Austria - Marktgärtnerei Relaviso YouTube
 *Conservation agriculture* Source: Karel Klem.	Rapid increase soil biodiversity and soil life activity, incl. microbial activity. Rapid increase of soil water holding capacity and water infiltration. Rapid improvement of soil structure. Rapid increase in soil fertility. Rapid increase of soil organic matter (SOM) and soil morganic carbon (SOC).	Increased above-ground biodiversity. Profitability increases through stable yield with lower overall costs (input, machinery). Working time is saved, especially at peak season making it easier to attract a workforce all year round. No soil erosion, reduced nutrient leaching and buffering of high precipitation events.	Knowledge and understanding of how soil biology works. Knowing what to do and particularly what not to do. Ready to accept a 3-5 year transition period with potential yield and economic losses.	Reliance on total herbicides such as glyphosate to guarantee a reliable performance. Perennial weeds and field voles are problematic.	**Arable** ECAF TMG website Cover crops **Orchard** Ecological production of almonds and olives using green manure (Link) FAO, Recarbonizing global soils: A technical manual Alvelal organization (in Spanish)

	Synergy benefits on soil health	Other synergy benefits	Success factors	Limitations	More information
 *Organic no-till.* Source: Christos Vasilikiotis	Same as conservation agriculture. Mulch protects the soil from the sun, heavy rain and wind. It buffers soil temperature in summer.	No herbicide use, especially no glyphosate. Reduction of water evaporation, hence reduced water needs.	Same as conservation agriculture. Grow a cover crop with high biomass so that it is sensitive to the roller-crimper (in Austria and France, around 7t DM/ha). Low weed pressure. The seeding technology needs to enable sowing in the mulch.	Perennial weeds and field voles are problematic. Late sowing not possible for each and every crop. Water competition between cover crop and next cash crop in spring.	Video Spring Video Autumn
 *(Organic) no-till with grazing animals.* Source: Francisca Reis.	Same as organic no-till, with quicker results on soil fertility, carbon sequestration and soil life.	Resource use efficiency. Increased profitability, especially through reducing costs. Lower input use. More stable productivity.	Observation. Experimentation. Knowledge sharing and learning. Agronomic support. Not having economic pressure on the results.	Labour intensive due to animal management.	Video 1 Video 2 Video 3 Video 4

Annex 4: How to provide technical knowledge and advice

Advisory services should have the following characteristics:

- offer technical support independent from the sales of products
- **high up-to-date knowledge about RA practices**
- be soil-focused
- be science-based
- **Practical**
  - speak the farmer's language
  - be farm-specific
  - be reliable
  - use a system/holistic approach: take the whole farm system into consideration in the advisory approach
  - adapt to the local context, e.g., right practice for the right place/conditions/purposes, practice timing, adapted machines
  - support farmers to build their own strategy based on a deep understanding of their context, i.e., soil, climate and plant dynamics, and market dynamics

Knowledge could be provided in several ways:

- specialised knowledge exchange database
- study/farmers-working groups on regenerative agriculture: peer exchange
- demonstration of crop techniques and machinery
- lecturing
- hands-on courses
- thematic festivals
- online/offline resources
- open-source database shared across Europe

Annex 5: Practitioners' needs for technical knowledge

Supplementary Table 11. Practitioners' needs for technical knowledge

Technical topic	Knowledge and advice needs

Service crops	**General**
	› benefits and challenges of using legumes
	› which crop cultivar is related to the specific nutrient dynamic of a regenerative system
	Intercropping
	› managing intercropping in different contexts
	› especially undersowing in root crops and maize
	› answering questions such as:
	  › what is it? Why is it good? What are the different types?
	  › what species?
	  › how and when to sow and harvest?
	  › how to control weeds?
	Cover crops
	› cover crop mixtures (species, varieties)cover crop termination: early-warning indicators to recommend the termination date at the regional scale would assist farmers
	› what is the best cover crop for a given main crop (and context)how to support water retention through cover crops
	Permanent cover crops
	› variety choice
	› management across the rotation
	› how to avoid or limit the competition with the main crop

Crop diversification	› benefits and challenges of legumes › adaptation of crop rotation to no-ploughed systems
Herbicide-free	› controlling weed in organic low or no-tillage systems › how to phase out of herbicides
Soil biology knowledge and assessment	› link between practices, soil biology and crop performance › how to simply measure soil biology indicators on the farm and to adapt the practices accordingly, e.g. through visual assessment

Technical topic	Knowledge and advice needs
Fertiliser/Fertility management	› how to manage fertilisation in regenerative agriculture, where fertility cycles differ from conventional › how to combine organic and mineral fertilisation in a dynamic way › applications, time technical impacts of different composts › on-site good compost making and where and how to use it
Biostimulants	› more transparency on biostimulants and prebiotic application conditions to achieve full efficiency › supporting farmers in creating their own bioproducts
Grazing	› grazing cover crops › how to support soil biology with grazing animals › grazing practices in winter › impact of grazing animals on winter crops (Nordic regions)
Machinery	› which no-till seeders for what farm context › supporting farmers in self-construction of no-till equipment
Pest management	› pest management in regenerative agriculture systems: which thresholds for intervention in a context with high plant diversity and natural regulators › farmland biodiversity-based: support pesticide phase-out on regenerative farms through natural pest control
Others	› how to grow nutrient-dense food in practice › how to practice agroforestry and for what benefits › water management in RA systems › guidance to support adaptive/regenerative land management in a changing climate increases sustainable input & machinery management › high-value cash crops: how do we farm regeneratively? (e.g., potatoes) › which species/animal for the context › holistic management › soil compaction prevention

Source: European Commission

Mini Paper 1: The role of animal husbandry in regenerative agriculture and the potential of livestock grazing to restore soil and ecosystem functioning

Claudia Nielsen (Coord.), Christine Bajohr, Airi Külvet, Stefaan De Neve

Table of Content

Disclaimer

This Mini Paper has been developed within the frame of the EU CAP Network Focus Group 'Regenerative agriculture for soil health' with the purpose of providing input to the Focus Group discussions and final report.

The information and views set out in this Mini Paper are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this Mini Paper. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.

If you wish to cite this Mini Paper, please refer to it as 'Annex to the final report of the EU CAP Network Focus Group 'Regenerative agriculture for soil health', 2024'.

Introduction

The emergence of the animal kingdom approximately 500 million years ago marked a key juncture in Earth's ecosystem development, fostering countless symbiotic relationships essential for ecosystem stability and climate regulation, such as those between grasses and ruminants. However, human activity, particularly since the 19th century, has significantly altered ecosystems through industrialization, leading to intensive livestock farming practices focused primarily on food production. In this context, animals lost their traditional role in the landscape. Regenerative agriculture aims to restore this balance by redefining the role of animals, utilizing them not only for production but also as agents for restoring soil fertility and ecosystem functions. Achieving this transition requires a nuanced and context-specific approach tailored to individual farm businesses, necessitating a shift in mindset and the exploration of new insights and inspirations. However, the processes itself always starts with a different way of thinking which in turn requires new insights and inspirations which are discussed in this mini paper.

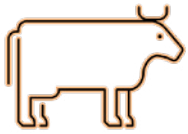
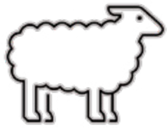
Black Alentejano pig breed grazing on a fodder beet field in Portugal. Here is used Adaptive Multi Paddock Grazing in which a high livestock density grazes for short durations between long periods of forage rest to catalyze accelerated grass growth and soil health enhancement. Photo: Monte Silveira farm (Portugal)

Source: Diogo Pinho

1. Animal husbandry in regenerative agriculture

Animals play essential roles in sustainable ecosystem management, particularly when managed through regenerative grazing practices. Livestock like cattle, sheep, and goats, when moved frequently across pastures, prevent overgrazing, promote grass growth, and enrich the soil with essential nutrients through manure and urine distribution. Moreover, animal manure serves as a valuable resource, enhancing soil structure and nutrient availability. Integrating animals with crop production further enhances sustainability by improving soil fertility, reducing erosion, and promoting carbon sequestration. Additionally, animals contribute to weed and pest control, foster biodiversity, and create diverse habitats within agricultural landscapes.

Mini Paper 1 Table 7. Overview of the most commonly found livestock in regenerative systems and their contribution and examples of regenerative farms

				
Due to their versatility, cattle are by far the most abundant livestock found in regenerative agricultural practices Cattle contribute significantly to soil health, biodiversity, and carbon sequestration, playing a key role in sustainable food production within regenerative systems.	Through responsible management, dairy cows provide a sustainable source of high-quality milk, supporting ecosystem health within regenerative systems. Examples of utilising dairy cows for building soil health in a way as with cattle are increasingly found if logistics allow.	Examples of Sheep and Goats in regenerative agriculture, either for dairy or meat production, are abundantly found in silvopastoral systems (e.g. vineyards, almond plantations or Christmas trees) but also in rotational grazing systems on grasslands. Due to their smaller body size as compared to cattle, small ruminants are aftersought in grazing cover crops during winter on heavy soils.	Traditionally a herded grazer, pigs contribute to soil health and nutrient cycling through natural behaviours such as rooting and scratching. By integrating pigs into these systems, farmers enhance ecosystem resilience and promote sustainable agriculture, leveraging their foraging habits to manage weeds, pests, and organic matter, fostering regenerative practices.	Poultry are prevalent in various agricultural systems such as free-range, integrated crop-livestock, agroforestry, and orchards. Their scratching and pecking behaviours are ideal for chemical-free control of pests and diseases (including fungi), weed management, and soil aeration.
https://liivimaalihaveis.ee/	https://www.kugelsüdhanghof.de	www.poetgaard.dk	https://freixodomeio.pt/	https://www.facebook.com/Appel.Eier

Source: European Commission

Regenerative Grazing (holistically planned) with two species

Source: Christine Bajohr

In landscapes re-integrated, grazing animals play crucial roles in sustainable food production, land restoration, and climate change mitigation. They serve as both habitat constructors and farm production sectors, contributing to healthier soils, increased biodiversity, and long-term agricultural sustainability. Contextual, site-specific pasture management is crucial to harnessing these services effectively, tailored to local needs and ecosystem functioning principles.

2. Regenerative grazing for ecosystem functioning in practice

Various grazing concepts like Rotational Grazing, Adaptive Multi Paddock Grazing (AMP), Mob Grazing, Management Intensive Grazing, and Holistic Planned Grazing (HPG) involve moving ruminant herds quickly between pastures. While they share similarities, differences exist in implementation and goals. Fixed rotational grazing lacks adaptability, unlike AMP and HPG, which tailor management to diverse contexts. Successful pasture management always depends on the manager's ability to adapt to environmental conditions, seasons, and growing periods. Converting to regenerative management typically starts with understanding living systems and assessing the farm environment. A successful pasture manager invests time in planning, monitoring, and flexibility. Gradual regeneration through targeted animal herd use can reduce the need for additional measures like reseeding or fertilizing. Positive development varies depending on the initial situation and objectives. Rapid yield increases may occur in desolate conditions, but restoring biodiversity in intensively used systems takes several years and requires comprehensive, coordinated measures across the entire farm.

Below listed are key criteria for successfully implementing regenerative grazing to improve soil health:

2.1. Successful planning

Creating a comprehensive long-term plan that considers social, ecological, and economic aspects is crucial for successful regenerative grazing practices. Seasonally adapted grazing plans within this framework cater to individual needs and circumstances. Effective planning, considering factors like weather extremes and invasive species, is essential for buffering unexpected events and achieving anticipated goals like soil cover and biodiversity. Detailed goal setting, including baseline assessment of soil properties and farm events, is critical. Plant growth rates and recovery phases between grazing vary with weather and season, affecting grazing management. Site factors ultimately dictate the rate and pattern of change, influencing successional developments. With experience and knowledge, optimizing pasture utilization, promoting soil and pasture health, and ensuring long-term agricultural sustainability become attainable goals.

2.2. Adaptation to non-growing seasons and harsh weather conditions

Bale grazing during winter is an option to keep livestock outside

Source: Airi Külvet

In regions with suitable climate and geography, winter grazing or bale grazing systems are viable options for livestock management. Bale grazing involves strategically placing hay or silage bales in pastures, allowing animals to consume feed while depositing manure, enriching soil fertility and pasture health. This method, often integrated into rotational grazing systems, provides supplemental feed during limited forage availability, such as droughts, while enhancing soil and pasture quality. Winter pasture grazing requires careful planning, including rotation, water supply, and shelter considerations, to ensure livestock welfare and sustainable land management.

2.3. Adapting the production to site conditions

From a regenerative perspective, adapting the agricultural system to local conditions is more sustainable and economically promising. This involves selecting suitable animal species and breeds that thrive in the given environment while considering animal welfare. For instance, high-performance dairy breeds may not be ideal for year-round grazing due to their energy requirements. Herd adaptability to varying weather conditions and feed quality in pasture systems is essential.

Planning must account for the herd's impact and needs, including grazing behavior, feed intake, excrement concentration, and interactions with the environment. Incorporating additional species like poultry or horses can enhance impact by leveraging diverse needs. Diverse age groups within the herd can influence soil impact and grazing outcomes positively. Herd size and stocking density should align with available forage, preventing underuse, overuse, or soil damage. Adjustments in herd size may be necessary based on seasonal forage changes, market demands, or pasture health considerations.

2.4. Adaptation to environmental challenges and needs

Planning to be at the right time at the right place with the right behaviour of the herd

Source: Christine Bajohr

Effective grazing management relies on precise timing, duration, and adequate recovery periods. Timing is crucial for carbon sequestration, aiming to sustain vegetative growth. Rapid regrowth phases necessitate swift herd movement to prevent plant population weakening, while slower growth or drought requires extended rest periods. Planning must consider factors like season, temperature, soil quality, and precipitation.

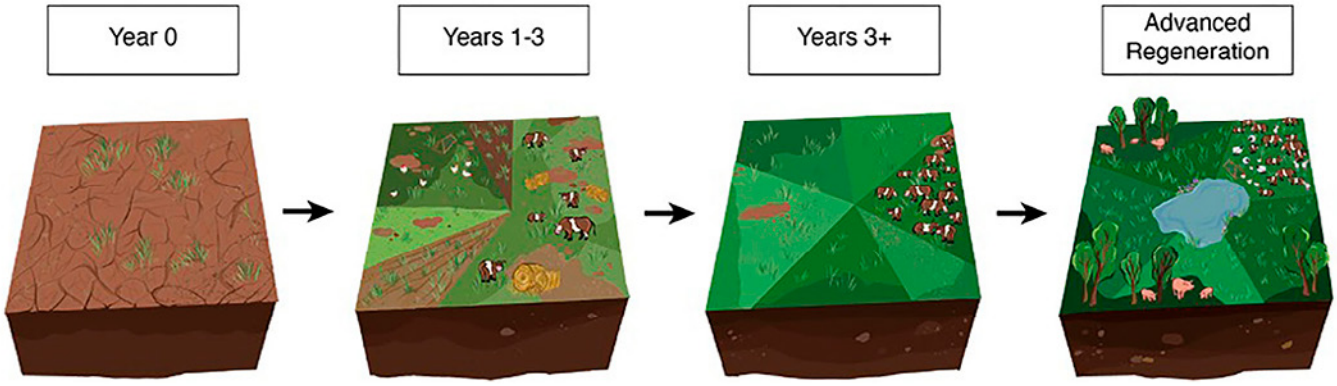
The length of stay on a pasture decreases with higher stocking density. Overgrazing or rapid return to grazed areas risks ecosystem degradation, soil decline, and reduced water holding capacity. Attention to timing is vital, considering the needs and reproductive cycles of plants, soil life, insects, and wildlife.

However, exceptions exist. Disruptive events, like temporary overgrazing, can reset systems stuck on the regenerative pathway, fostering greater species diversity. Flexibility in grazing management allows for adaptive responses to changing environmental conditions, promoting resilient ecosystems.

Find more information in an informative video on regenerative grazing in Estonian conditions.

3. Effects of best grazing practices on soil health and biodiversity

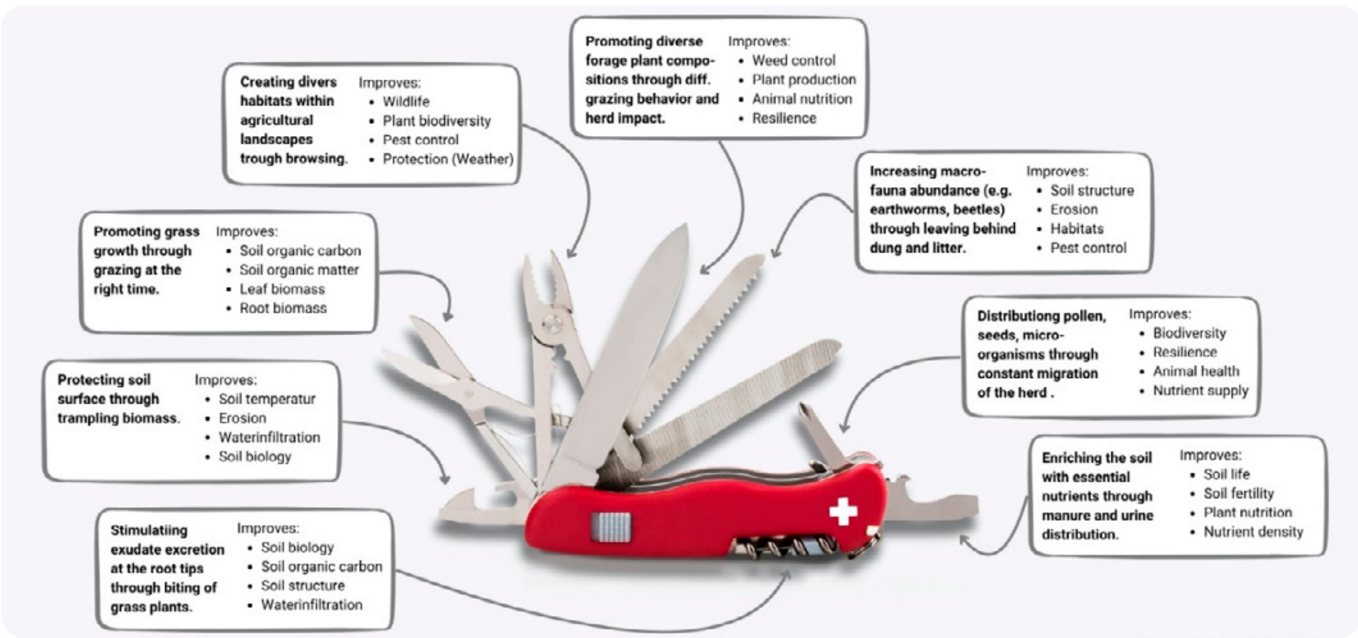
Figure 1. The regeneration process employed by White Oak Pastures, USA, illustrating the effects of rotational grazing on degraded cropland



Source: Rowntree et al., 2020

In principle, grazing is possible in all agricultural systems if care is taken to match the appropriate livestock for the task. Thus, for the desired effects to be achieved, it is critical to use livestock according to the current needs of the existing ecosystem in coexistence with production requirements. If farm animals are seen as tools for regenerating ecosystems, a ruminant herd could be compared to the famous «Swiss army knife» due to its multifunctional use in grasslands.

Figure 2. Allegoric depiction of ruminants as multi-functional tools in restoring, boosting, and maintaining soil health and ecosystem functioning



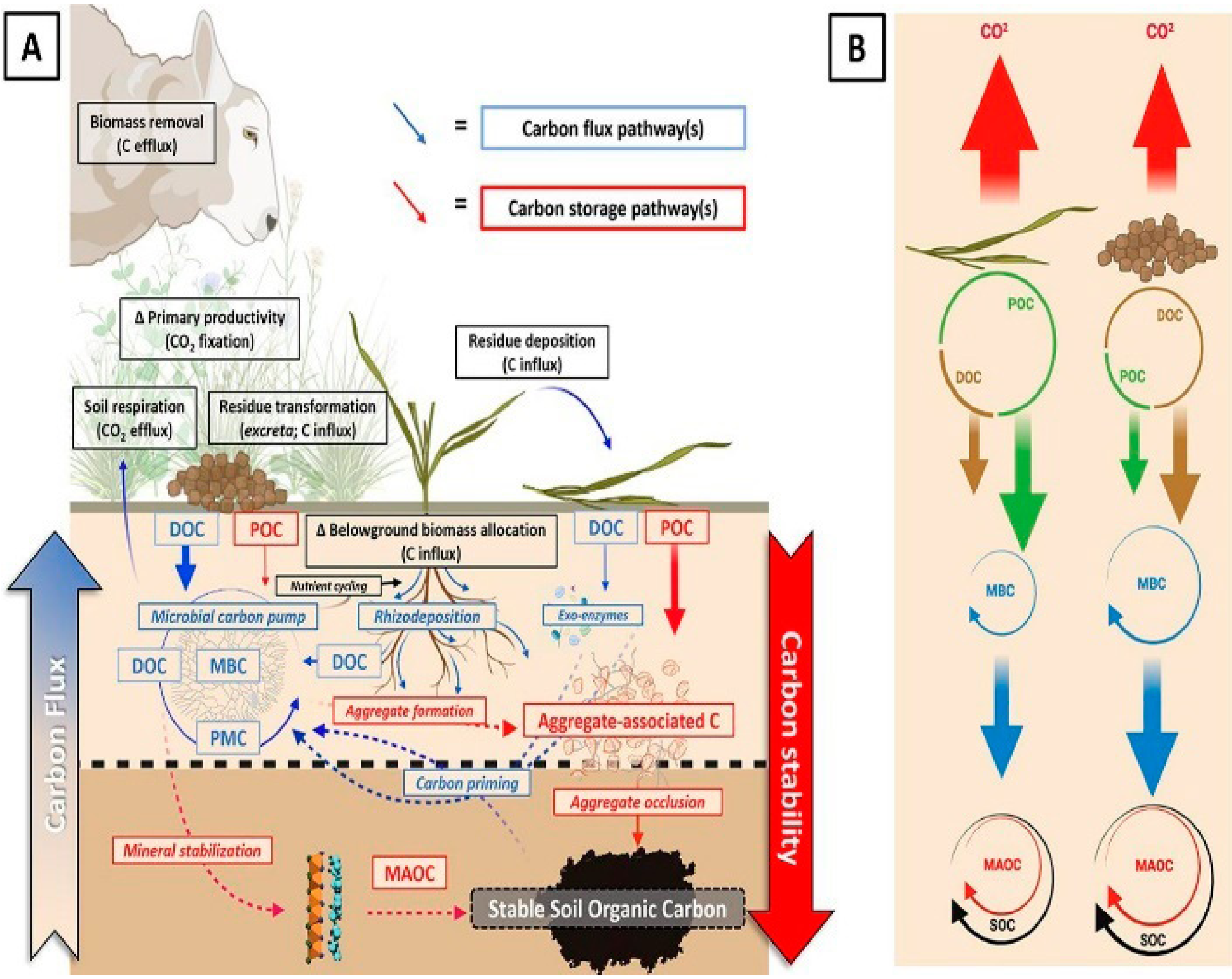
Source: Christine Bajohr

Grazing, and in particular rotational regenerative grazing has a variety of effects on soil health and biodiversity-related aspects. Those can be assessed individually, or in the context of holistic ecosystem multifunctionality, giving insights into the complexity of ecosystem-related interactions, thereby acknowledging differences resulting from spatio-temporal variation. In the following subsections, we introduce some of the scientifically reported direct effects of grazing on soil health and biodiversity

3.1. Direct effects of regenerative grazing on soil health

3.1.1. Above- and belowground biomass

Figure 3. Pathways for carbon storage and decomposition under intensive regenerative grazing



Source: Brewer et al., 2023

Regenerative grazing impacts both above- and below-ground biomass in grasses, with plants prioritizing new aboveground growth for photosynthesis or more root biomass during drought or nutrient scarcity. This approach has shown a reported 30% increase in forage production (Díaz de Otálora et al., 2021), but differences in biomass yields depend on various factors, with limited studies quantifying these differences. Additionally, regenerative grazing promotes diverse forage plant compositions, including tap-rooted plants like plantain, which aid in nitrous oxide reduction, soil aeration, water infiltration, carbon retention, nutrient retention, and erosion prevention (Pijlman et al., 2019; Kell, 2011; Vannoppen et al., 2017).

3.1.2. Soil organic matter input

Grazing, unlike mowing, returns carbon and nutrients to the soil through animal excreta by about 50-70% (Gilmullina et al., 2020). This input includes altered compounds and lower carbon-to-nutrient ratios. Also, leaf litter after senescence adds organic matter to the soil through trampling or bioturbation. Intensive defoliation with long rest periods increases root growth, further enhancing organic matter input into the soil through various root processes (Nielsen et al., 2021; van Veelen et al., 2018; Sanaullah et al., 2009).

3.1.3. Soil carbon stabilisation and storage

In general, soil organic carbon (SOC) is preserved through three primary processes: protection from decomposition under low-oxygen conditions, binding to stable minerals like iron or aluminum oxides, and microbial remains, which constitute 50-80% of the stable soil carbon pool (Buckeridge et al., 2020). Regenerative grazing has been shown to increase stable SOC levels in surface soil by up to 12% over the mid to long term (Hewins et al., 2018; Díaz de Otálora et al., 2021) and enhance physico-chemically stabilized mineral-associated organic carbon in the subsoil layer (Brewer et al., 2023). However, the efficacy of SOC retention depends on climate, soil type, and the presence of stress or disturbances (Abdalla et al., 2018; Zhao et al., 2020; Yang et al., 2020). Overgrazing in conventional systems, for instance, can disrupt carbon sequestration in soil, affecting its long-term carbon storage capacity.

3.1.4. Soil microbial community structure

In healthy soil, diverse microbial communities, including archaea, bacteria, and fungi, play a crucial role in carbon and nutrient cycling, mediating approximately 90% of soil functions (Mhuireach et al., 2022). Grazing has consistently shown positive effects on soil microbial diversity and communities across various biomes and climates. It enhances soil productivity and functions by increasing microbial diversity compared to non-grazed ecosystems (Xun et al., 2018). Grazing animals also promote the presence of endophytic microbes, which benefit plants by aiding in nutrient mobilisation and uptake, ultimately promoting plant growth (Yang et al., 2021; Rana et al., 2020). Particularly, endophytic microorganisms are crucial for successful agriculture. Regenerative and multi-species rotational grazing hold significant potential for positively impacting soil microbial communities and enhancing soil health and functioning.

3.1.5. Physicochemical traits

Rotational regenerative grazing significantly impacts physico-chemical soil properties. Teutscherová et al. (2021) observed lower bulk density, improved soil aggregation, and higher water retention on rotationally grazed farms compared to continuous grazing. These improvements were linked to increased macrofauna abundance, particularly earthworms and beetles, which enhance soil structure through bioturbation. Additionally, Galindo et al. (2020) found that rotational grazing enhances soil quality by increasing ß-glucosidase activity, available nutrients, soil pH, carbon content, sulphur content, and microbial decomposition, thereby improving nutrient cycling and productivity.

3.2. Direct effect on biodiversity

Naturally developed mixture of grasses, herbs, and clover following rotational grazing

Source: Claudia Nielsen

Biodiversity, including species richness and diversity indices, is a key metric for assessing the effectiveness of Regenerative Grazing Management (ReGM), according to the Savory Institute (2019). Regenerative farmers prioritise biodiversity for the ecological and economic sustainability of their farms (Stinner et al., 1997). However, comprehensive data on the impacts of intensive, infrequent grazing on various organisms are lacking (Carter et al., 2014). Achieving high livestock production and biodiversity conservation simultaneously may entail trade-offs (Lawrence, 2019). Morris et al. (2021) found higher soil microbiota diversity under regenerative rotational grazing, but vegetation responses varied. Grazing-induced structural changes benefited certain bird species, providing better foraging and nesting sites, but intensive stocking practices could reduce food resources for some birds during winter and drought (Morris et al., 2021). Despite mixed findings, European studies have generally shown positive impacts on plant biodiversity under regenerative grazing (Enri et al., 2017; Austrheim et al., 2001; Bugalho et al., 2011; DeGabriel et al., 2011).

3.3. Additional direct effects and benefits

Regenerative rotational grazing practices offer numerous environmental and non-environmental benefits, including improved soil and water management, enhanced animal welfare, and biodiversity conservation, ultimately contributing to agricultural sustainability. These practices can mitigate soil erosion and runoff, increase water availability for plants, and promote soil structure improvement. They also contribute to livestock health and welfare by reducing stress levels, improving body condition scores, and providing access to diverse forage species. Additionally, managed intensive grazing reduces the risk of accidents and injuries for farmers and agricultural workers. Rotational grazing further enhances positive landscape-level impacts. Furthermore, integrating livestock into grazing rotations promotes nutrient cycling, enhances soil fertility, and reduces reliance on synthetic fertilizers, thereby minimizing nutrient runoff into water bodies.

4. Economic performance

The economic performance of every production system is dependent on a plethora of direct and indirect effects. This is not different for regenerative grazing practices. Until now, only few studies have examined the economic performance of regenerative grazing as compared to no-livestock regenerative systems, or traditional cut and carry forage systems with up to 5 annual cuts and synthetic fertilisers or manure return.

Shropshire sheep in the vineyard

Source: Nikolas Schoof

A study on the economic performance of marginal livestock farms in the UK (Clark and Scanlon, 2019) revealed that, reducing output to a level where stock is sustained solely on naturally available grass, without artificial fertilisers, can increase profits or reduce losses due to significant savings in variable costs. This approach not only benefits financially but also alleviates environmental pressure on the land, especially in cases of overgrazing. The findings challenge the common belief among marginal farmers that increasing production leads to greater profitability, which was found across all farms examined, regardless of ownership, location within protected landscapes, or size.

In another study, using a life cycle analysis to compare regenerative to conventional sheep farming in Australia (Colley et al., 2019), it was found that regenerative grazing had the potential to improve their performance by offsetting fossil fuels.

Further, in another long-term study (Ogilvy et al., 2018) it was found that the average profit levels of the regenerative graziers were consistently higher (12 out of 14 years) compared to average conventional livestock (sheep and beef) farms and showed less variability over the study period. In particular, the economic performance was significantly better in years with adverse environmental conditions, like drought.

Thus, since less can be more, boosting the economic performance in livestock systems applying regenerative grazing practices is based on the following pillars:

- Reducing variable costs (including synthetic fertilisers and fossil fuels) by adjusting output levels to match the farm's natural grass availability.
- Streamlining fixed costs by maximising the utilisation of fixed assets, such as machinery sharing and resource cooperation with neighbouring farmers.
- Enhancing the value of meat products to improve price received. Integrating environmental stewardship into farm management, potentially increasing product value and eligibility for public payments tied to delivering public goods.
- Exploring diversification opportunities to expand the business portfolio. This shift entails moving from a production-focused model to one centred on profit margins. Case studies underscore the importance of exploring diverse options to boost farm business viability and profitability, necessitating a heightened emphasis on comprehensive business planning.

5. Challenges

Primarily, economic valuation and political trends present challenges for farmers applying regenerative livestock grazing. Traditional economic metrics may not fully capture its long-term benefits, hindering its economic viability. Additionally, political priorities often favour short-term gains over long-term sustainability, leading to policies that discourage livestock farming in general, including regenerative practices. In this context, subsidies and support systems until now tended to favour either classical conventional or certified organic agriculture, creating financial barriers for farmers interested in adopting regenerative approaches without additional certification and audit. Overcoming these challenges requires broader recognition of the benefits related to regenerative livestock grazing and policy frameworks that incentivise sustainable land management.

1. Valuation: Despite producing sustainable, high-quality products with added ecosystem service benefits, primary producers often receive inadequate remuneration due to insufficient valuation of regenerative practices.
2. Implementation: The diverse environmental variables across different farm settings make it challenging to offer standardized guidance, requiring a nuanced approach tailored to each farm's unique context. Understanding the delayed effects of management measures further complicates implementation, demanding a shift in mindset and the development of skills to balance ecological, social, and economic needs.
3. Workload: While sustainable management practices and diversification efforts improve landscape health and farm viability, they can also entail increased paperwork, establishment costs, and workload. Additionally, the initial investment in fencing may appear daunting, although modern fencing systems offer efficient solutions that require minimal time investment.

Livestock: production or tool?

The dual role of livestock in regenerative grazing, serving both production and habitat construction, poses challenges. Balancing grazing intensity for habitat diversity and production goals is complex. Managing livestock to avoid negative impacts on sensitive habitats requires careful planning and monitoring. Integrating livestock into habitat construction efforts may demand additional resources and expertise, posing logistical and financial hurdles for farmers. Thus, while livestock are valuable for habitat creation, their dual role presents management challenges in regenerative grazing systems.

6. Conclusion

Ecosystems are now under unprecedented pressure, with climate change probably being the most worrying. Regenerative grazing can be an instrument for adapting to climate change by strengthening the resilience of ecosystems. In particular, the improvement of carbon and water cycles, the promotion of soil fungi and grass stands with a deeper root system are practical examples that can make a positive contribution to adaptation in agricultural systems.

Regenerating an agricultural system is a dynamic and ongoing process in which no final state can be achieved. There are no universal or single regenerative practices. Instead, there are different approaches and methods, some of which are combined in different ways to initiate regeneration within a specific context. Both the goals and the results are always context-dependent in terms of climatic, ecological, economic and similar conditions.

To effectively utilise the potential of regenerative strategies, it is helpful to look into the original concept of nature and favour the use of animals, especially if less or even no fossil fuels are to be used in agriculture in the future. Where livestock farming has already been abandoned, cooperation could be entered into with livestock farming partners or livestock could be rented during the summer.

7. Research Needs

While the regenerative agricultural concept gains popularity globally, only few data exist on its spread in Europe. Currently, neither EUROSTAT nor FADN datasets give insights into the geographical distribution of regenerative grazing practices. More on-farm research is needed:

1. Understanding the complex interaction between grazers and grasslands requires comprehensive research efforts. Grazing outcomes vary greatly based on initial conditions, implementation methods, and subsequent feedback mechanisms, influencing management decisions. With climate change exacerbating weather extremes and seasonal shifts, there is a pressing need for studies investigating grazing effects across diverse climatic contexts.
2. Furthermore, research should delve into the impacts on resources and ecosystem processes, including carbon sequestration, biodiversity, soil fertility, and water storage capacity. Long-term studies are crucial to validate the positive effects of regenerative grazing, informing future climate assessments.
3. Additionally, assessing nutrient use efficiencies, nutrient losses, and greenhouse gas emissions from regenerative grazing systems compared to traditional husbandry practices is essential for a comprehensive understanding of their potential.
4. Further, understanding the full scope of regenerative grazing requires assessing its economic performance, alongside environmental impacts. Conducting life cycle assessments (LCAs) can provide insights into the overall sustainability of regenerative grazing systems, considering factors such as resource use, emissions, and economic viability. By integrating economic analyses with environmental assessments, researchers can better evaluate the holistic benefits and trade-offs associated with regenerative grazing practices.
5. In this context, assessing the enviro-economic performance of regenerative grazing systems is essential for informing stakeholders and policymakers, thus encouraging adoption by farmers in the case of incentivisation.
6. Additionally, assessing the farm-specific work distribution over the year (e.g., Madelrieux et Dedieu, 2007), is key to identify bottlenecks in the transition to regenerative grazing systems and solutions.
7. Assessing the occurrence and distribution of practices regenerative grazing in Europe, e.g. via Citizen Science.

8. Ideas for innovation

1. Affordable monitoring apps with integrated satellite-supported recording of biomass, biodiversity, energy flow, humidity/precipitation, and other data.
2. Techniques and methods to extend the grazing period in different regions (Baltic countries, Nordic countries, arid regions).
3. Easier access to knowledge and valuable information's in one's native language.
4. Regenerative peer-to-peer exchange networks and support from experienced mentors over the first 1-3 years of the transformation process to facilitate the transformation process towards regenerative management.
5. Livestock-pooling platforms and networks.

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Mini Paper 2: Reaching hearts and minds: how education reform and more effective dissemination of knowledge can support the mainstreaming of regenerative agriculture in Europe

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Disclaimer

This Mini Paper has been developed within the frame of the EU CAP Network Focus Group 'Regenerative agriculture for soil health' with the purpose of providing input to the Focus Group discussions and final report.

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1. Introduction

Increasing number of farmers have improved the sustainability of their production systems by implementing certain practices of regenerative agriculture, but this is often a long-term process and the majority of farmers are, at best, still at the initial stages.

Besides agronomic or economic difficulties, changing the farming system is often a matter of changing the 'culture', the paradigm. In many cases, regenerative farming has been developed by pioneer farmers, aligned with their local context, with their own resources and taking their own risks, instead of following a top-down approach. Peer to peer access to information on regenerative agriculture is often easier than before, especially with social networks, therefore a flow of new ideas is continuously tested by farmers, who need to cope with an ever-changing context (economic, regulatory, climate etc.), as well. However, knowledge is still mostly scattered and not yet well structured. Accessing reliable and clear information is difficult not only for farmers but also for advisors.

Regenerative agriculture is an outcome- and principle-based approach to agriculture that focuses on restoring and enhancing soil health. In addition to restoring soil health, regenerative agriculture also aims to reverse biodiversity loss, restore well-functioning water cycles, adapt to and mitigate climate change and increase economic profitability. The practices that regenerative agriculture promotes to implement should be adapted to the local context.

Grand Farm in Austria. Grand Farm (2021)

Source: Alfred Grand

Beyond a change of mindset, introducing new practices on a farm also requires acquiring the relevant know-how. This should be provided not only by progressive farmers, but also by the AKIS (Agricultural Knowledge and Innovation System) that each EU Member State has set up.

Sharing up-to-date knowledge, practical solutions and guidance on regenerative agriculture with farmers through effective platforms, a reformed educational system and credible advisors could contribute to a long-term change in beliefs, attitudes and ultimately, in behaviour. The wider adoption of a holistic regenerative approach, as well as single regenerative practices among farmers could not only increase their and their farms' resilience but it could also help address the pressing issues of our time, such as climate change, biodiversity loss and food security.

2. Objectives

This mini paper aims to increase public awareness and understanding of the importance and key issues of mainstreaming regenerative agriculture, to inform readers - farmers, advisors, consumers, policymakers - about potential ways and existing best practices to address these issues and to explore how regenerative agriculture and regenerative practices could become more visible and how they could gain increased support from both farmers and the wider society.

Changing a whole system needs not only a new mindset but a change of heart, as well, both from the farmer and the surrounding community. This mini paper aims to provide thoughts, ideas and inspiration on how to create a more resilient and regenerative way of farming. All over Europe, this should be achieved through a reformed, up-to-date education based on the highest scientific standards and a more effective dissemination of knowledge for today`s farmers, as well as for the generations to come.

3. Context and key issues

Currently, the institutional education of future farmers is often based on material that excludes or insufficiently integrates the principles and practical examples of regenerative agriculture. At the same time, the national farm advisory systems are not based on up-to-date systematic knowledge either when it comes to regenerative agriculture, often because there is not enough science-based knowledge available to advisors. Motivating farmers to undertake more initiatives, fostering not only their own improvement but also the enhancement of other critical factors, especially environmental and economical ones, often prove to be challenging. During the 'information gathering' phase, farmers actively seek evidence to support their decisions, evaluate advantages and disadvantages, identify potential drawbacks and risks, and ultimately decide whether to implement these decisions in their specific circumstances or not.

Many farmers are willing to follow regenerative practices, but since knowledgeable and accessible scientists and advisors are often missing, farmers are forced to become researchers themselves. This takes a lot of resources: finances, labour and time. On the other hand, lack of sufficient awareness of the benefits and potential impact of regenerative agriculture can also result in farmers' perceived lack of need for knowledge on it and therefore, their lack of willingness to pay for it. Already at the level of education, this may create a barrier to the implementation of regenerative agriculture based on, to a large extent, false paradigms regarding, for example, humus and the stability of organic matter in the soil, the role of delivered dead biomass versus the role of exudates from living plants, or the role of soil microorganisms primarily as decomposers of organic matter.

The relationships between the elements of a socio-technical system, like values, knowledge, organisations, and technologies, can create strong interdependencies and self-reinforcing mechanisms, which can result in a lock-in, and may discourage stakeholders from adopting alternative production systems and practices. There should be more initiatives and projects focused on knowledge and practice transfer among regenerative farmers. At present, there is a noticeable lack of investment in knowledge transfer implementation, such as research and demonstration farms, pilot projects (lighthouse farms), and similar practical solutions. This is particularly pronounced in less developed countries. In the EU, between 2019 and 2021 only 6.1% of the total financial support allocated to the agricultural sector was dedicated to agricultural knowledge and innovation (OECD, 2023).

According to Eurostat, the number of young farmers below the age of 35 is only 6.5%, compared to 57.8% who are older than 55. This can have serious implications to the mainstreaming of regenerative practices. It reinforces the need to go beyond reforming the educational programme and teaching material merely in schools and at universities and focus on and also invest in reforming adult learning and advisory services on regenerative practices for a greater and faster impact.

In relation to the wider society, there is often widespread confusion about the difference between concepts like organic farming, regenerative farming, integrated management and agroecology. Educating consumers about the benefits and environmental impact of non-conventional farming practices could eventually affect their expectations, judgement, consumer demand and willingness to pay for products coming from regenerative farming.

4. State-of-the-art of research and practice

Educational programmes

In France, elements of regenerative farming have been taught in agricultural Vocational Education and Training (VET) schools since 2014 by including them in the agroecology framework. The national plan *Enseigner à produire autrement* (teach to produce differently) led to the renewal of many curricula. In this framework, the next generations of farmers and advisors are trained to better take into account the environmental impact of farming and to use the ecosystem services approach for a 'greener' production. Students are taught to focus on farming systems as a set of practices that needs to be adapted to different objectives and contexts taking into account ecosystems and climatic risks. The general idea is not acting on the environment but interacting with it. Thus, students have to learn technical knowledge but also show that they are capable of adapting to the environment and to evolve with it.

Enseigner à produire autrement, L'Institut Agro Montpellier (2023)

Source: L'Institut Agro Montpellier.

There is still great confusion regarding terms and definitions, for example, about what the difference is between agroecology and regenerative agriculture. While agroecology builds on ancestral practices and studies whole ecosystems - that is, the social, cultural, economic, and political dimensions as well in addition to their biology and ecology -, regenerative agriculture on the other hand focuses on restoring and enhancing soil health by rehabilitating organic matter and microbial activity in the soil.

Pilot farms and lighthouse farms

On-farm experimentation is considered to have a great potential, especially because of its systemic scale and adaptability to different contexts. This approach, that seems very appropriate to soil regenerative farming, is slowly spreading across the world, but it is still a minority compared to conventional, analytic experimentation (Lacoste et al. 2021). Based on co-learning, it is: (i) generally implemented at field scale, (ii) takes into account private interests of farmers and other stakeholders, (iii) creates value with interaction of different fields of expertise. These factors are very relevant to ensuring an effective dissemination of knowledge. Finally, giving the farmer a central role in the process, it can highlight the adaptation process to complex issues in a changing context.

In Estonia, there are a number of agroecological research projects on, for example, annual and long-term catch crops (Vaher, 2024; Ess and Vetemaa, 2022) and no-till farming (Lõhmuste, 2023) conducted at university level or by private companies in cooperation with farmers. In addition, a lot of research is done mainly by farmers themselves, including in cooperation with international actors and specialists.

In France the national action plan for pesticide use reduction has created and funded a national network of 'reference farms' that aims at reducing pesticide use according to the specificity of the local context and production system. These farms commit to testing new practices, implementing them at the farm scale, and disseminate their experience. The involved farmers work with advisors that have the role of facilitators linking them to the rest of the national network and to research. One advisor manages around ten farms at local scale that share knowledge and define common actions (French Ministry of Agriculture, 2010).

The Lighthouse farms from the Global Network of Lighthouse Farms, initiated by Wageningen University. This is a network of 13 farms, which are pioneers in their specific production system, eager to accept students on the farm and closely working together with scientists to develop their production systems further. One of these farms is GRAND FARM, which is an Austrian regenerative, organic (ROC certified) arable field, agroforestry, grassland and vegetable farm. Alfred Grand (co-author of this mini paper) developed the farm into a research and demonstration farm for regenerative practices with a focus on Soil Health, Agroforestry and Market Gardening. GRAND FARM is participating in Horizon Europe, Erasmus+ and EIP-Agri focus groups, as well as EIP-Agri operational groups. Approximately 2000 visitors per year are welcomed, trained or demonstrated on the activity at the farm.

The incorporation of the EU Mission Soil`s bottom-up, multi-actor approach into Living Labs, that are being established under the EU Soil Mission, marks a significant development, promising to facilitate the adoption of regenerative practices. By directly involving a broad spectrum of stakeholders in both project design and implementation, this methodology ensures active engagement throughout the program.

One such example is a newly approved project on Carbon Farming by a consortium in Southern Europe. The project will develop five Living Labs (LLs), with partners that include researchers, end users (farmers) and policy actors. The core partners will identify complementary regional agricultural stakeholders to be directly involved in the definition of the LLs and their activities through a co-creation process, ensuring the adaptation to the regional needs and challenges faced by the primary sector. Each LL will also establish Lighthouse farms, where regenerative practices will be highlighted and demonstrated to regional farmers.

Farm advisory services and training tools

EU regulations mandate that all Member States establish a farm advisory system, aimed at assisting producers in aligning with the standards outlined in the Common Agricultural Policy (CAP). However, the effectiveness of Farm Advisory Services in the EU is constrained by the commercialisation of advisory services and the limited training of advisers, which poses further challenges to promoting regenerative practices. Increasingly, advisory services in the EU are becoming privatised, with many advisory services offered by commercial agronomists tied to farm input sales (Sutherland and Labarthe, 2022). There are very few independent commercial advisers, partly because farmers have historically relied on free advice from input providers. Consequently, the transition to regenerative practices faces significant hurdles due to this reliance on commercially-driven advice.

In France since 2022, advice and pesticide sales have been officially separated in order to guarantee the independence of advice given to farmers and prevent conflict of interest that could result from the coexistence of these activities within the same organisation. Nevertheless, advising change of practices, such as adopting regenerative farming, is not straightforward. In many cases, advisors can choose the 'safest' solution in order to protect crop yields and thus their relationship with the farmer. As they are often solicited to 'do the right thing', they are not willing to take the burden of a risk. Risks should be assessed and shared with the farmer and advisors should help them minimise them, including helping them in on-farm tests.

A tool that is more and more used for system or practice change is serious games. Even though entertainment is a part of it, serious games serve other purposes, which the players may or may not be aware of. The design and use of serious games for farming has boomed in recent periods. Seen as tools for social innovation, they are used for teaching, scientific mediation and awareness-raising, as well as for action (decision support, foresight, design of new practices, simulations, etc.). Playing is part of the concept, as it allows us to escape from reality, thus allowing us to take risks that we would not take in reality and thus enabling creativity and openness. It is also a process of decisions made by the player or players together or against each other. These decisions are made according to the rules of the game, which can be challenged to a greater or lesser extent. This creates a balance in the uncertainty of the course of the game, but also of its outcome.

- Key to soil is a free serious game, available in French or English. It is a role-playing game developed by INRAE for use in introductory agronomic and environmental training courses at high school, bachelor's and master's levels. This game reproduces the barriers faced by the various actors involved in south-east France vegetable production as they make the transition to agroecological practices. It is based on the case of soil pest management. By simulating complex interactions between the actors in the agri-food system (R&D, advisory, production and marketing actors), it helps to understand the processes that prevent the development of agroecological practices for managing the health of soils in vegetable farms. The game facilitates the assimilation of generic knowledge on agroecological transition. It also encourages the exploration of multi-actor coupled innovations in response to the problems encountered during the game.
- Another example is Interplay, a board game also developed by INRAE, designed to support practitioners in assessing the ecosystem services provided by a large range of cereal-legume intercropping options. It was created during a ReMIX project and is now improved and further developed with the contribution of the IntercropVALUES project.
- Serious games can also be used for raising awareness targeting the general public. The Soil game is such an example.

In Greece, the EU-mandated Farm Advisory System has faced delays and was only recently initiated. Farm Advisory organisations must undergo state certification, in order to receive state support for delivering free advice to producers. An essential criterion for certification is the exclusion of any commercial activity in farm inputs, allowing certified advisors to focus on improving farm profitability and reducing inputs. This restriction presents a great opportunity to facilitate the promotion of regenerative agriculture practices in other Member States, as well.

In Austria, some activities in research towards regenerative agriculture came up with implementing EIP-AGRI operational groups together with regenerative farmers (e.g. BIOBO, KLIWA, Agroforestry, Market Gardening, etc.). The NGO Verein Boden Leben initiated research together with BOKU University, accompanying farmers (Soil.Pioneers/Boden.Pioniere) in their on farm soil regenerative activities. At GRAND FARM, a private research and demonstration farm, co-creation of research questions from different stakeholders has led to research and demonstration activities on regenerative farming topics (soil health, biodiversity, agroforestry, market gardening, composting, vermicomposting, etc.). The research activities are conducted by national and international research institutions and projects.

Existing best practices

Regenerative agriculture has been integrated to varying degrees in European countries' educational curricula. It is increasingly the focus of research projects, courses, training, and thematic events. In countries, where institutionalised education is still lagging behind on teaching about regenerative practices, different bottom-up, independent, often farmer-led initiatives and platforms take up the mission of sharing knowledge and experience on regenerative farming.

The below table provides a collection of best practices and existing tools and platforms from selected European countries, demonstrating how regenerative agriculture is currently featured in national agricultural education and what other forms, networks, and initiatives exist for enabling knowledge-exchange and practical development on regenerative agriculture.

Table 1. Existing tools and best practices for mainstreaming regenerative agriculture in selected European countries.

Country	Agricultural education	Knowledge-sharing
Austria	Bio Austria offers the Soil practitioners training which is a practice-oriented training aiming to give farmers a better understanding of the soil ecosystem and providing them concrete advice on soil management. In the training programme, soil practitioners act as multipliers by passing on their knowledge and experience on soils to their fellow farmers in lectures, working groups, field days, etc. Specific courses of the Rural Institute for Further Education (LFI) are provided with some level of focus on regenerative practices as part of AKIS. Some academic courses at the University of Natural Resources and Life Sciences (BOKU) in Vienna, as well as the curricula of some agricultural schools touch upon regenerative agriculture but they do not focus on it specifically.	There are multiple initiatives and groups working on sharing knowledge on regenerative agriculture in Austria, among them is 1. the Relawi student group at BOKU University, a think tank with the aim to connect interested students and other stakeholders and learn from each other about economically, ecologically and socially sustainable agro-ecosystems, which revive the desire to work and live in harmony with nature in the countryside; 2. the NGO Verein Bodenleben, an association with the goal to gather knowledge about soil-improving and erosion-reducing cultivation methods and to put this knowledge into practice through practice-oriented research work, awareness raising and knowledge transfer; 3. and several other smaller (farmer-led) organisations promoting carbon sequestration and soil health through demonstration and training, e.g. GRAND FARM.
Croatia	Regenerative agriculture is included in mandatory courses and modules at certain universities in Croatia. The main learning outcomes are focused on the application of environmentally friendly plant protection systems, determining the applicability of acquired knowledge, etc.	Generally, the majority of knowledge transfer among farmers occurs through their internal communication, methods like «train the trainer,» and similar approaches. Additionally, advisors, both private and governmental, play a role in knowledge dissemination. In recent years, private advisors have regularly conducted workshops for farmers but primarily focused on EU funding opportunities. State advisors primarily transmit knowledge through organising mandatory education for farmers, such as eco-scheme programs. 'Platforms' for knowledge transfer such as the National Rural Network have not emphasised regenerative agriculture and related examples of good practices in their previous work.

<table>
<tr><th>Country</th><th>Agricultural education</th><th>Knowledge-sharing</th></tr>
<tr><td>Estonia</td><td>The Centre of Estonian Rural Research and Knowledge (METK) long-term (since 2003) scientific agrotechnological (also crop rotation, green manure, catch/cover crops etc) research in METK field testing station, including observations regarding the effect to soil microorganisms, nutrient balance, the use of pesticides etc.

Estonian University of Life Sciences have several research projects related to different regenerative practices (catch crops, cover crops, composting, no-till, use of digestive from biogas stations etc).

Environmental and climate-change related courses are given by the Estonian University of Life Sciences, but a special course or curriculum for regenerative agriculture is missing.</td><td>Regenerative agriculture is currently a very hot topic for the last couple of years, both amongst younger farmers, but also scientists and policy-makers. Numerous different field-days, conferences and other initiatives have been organised by different stakeholders. For example, in 2021 a large conference was held at the Estonian Ministry of Regional Affairs and Agriculture.

In 2023, eAgronom held a demo-day on catch crops: Vahekultuuride põllupäev 2023 ettekanded - YouTube

In 2023, METK organised a Network to Innovate seminar on innovative solutions regarding regenerative agriculture.

In 2024, The Northern Roots Forum organised by EST enthusiastic young farmers. It was an initiative with foreign experts and a lot of participants in Tallinn.</td></tr>
<tr><td>Finland</td><td>In Finland, a special e-course for regenerative farming is available in Finnish and Swedish language.

In Finland a special course for advisors has been developed: 'Mainstreaming regenerative agriculture by training agricultural advisors in soil health – experiences from Finland', developed by the Baltic Sea Action Group.</td><td>In Finland, a regenerative farming criteria has been developed by the Baltic Sea Action Group.</td></tr>
<tr><td>France</td><td>In France, regenerative agriculture and agroecology have both been featured in the curricula of various educational institutions, programmes and projects, among them:

› Enseigner à produire autrement and CEGA-TANGGO projects aiming at reinforcing links between VET schools and agroecology farmers groups;

› GAMAE: a platform for choosing among many serious games available that can be used with students or farmers for farming practice changes;

› the University of Pau offers an 'agroecology, agroforestry and soil conservation' degree;

› Institut Agro Montpellier offers a 'biodiversity, soil, climate and environmental assessment' degree; and finally;

› Agroparistech offers a degree in 'Soil management and ecosystem services'.

Along with the renewal of agricultural VET schools' curricula in France, teachers need to create learning situations that allow the students to develop their toolbox and learn to cooperate in problem solving.</td><td>There are various groups, networks and platforms in France enabling the sharing of knowledge on regenerative agriculture, among them:

› State-funded GIEE groups and network;

› the BASE network and APAD network, two associations farmers pioneers of soil conservation farming;

› the knowledge platform 'Ver de Terre Production' especially videos on their YouTube channel; 'Triple performance' is an open-source website listing agro-ecological practices and feedback from farmers;

› CAPISOL a webpage capitalising knowledge issued from agricultural Chambers on soil conservation farming.</td></tr>
</table>

Country	Agricultural education	Knowledge-sharing
Hungary	In the Hungarian agricultural university curriculum, 'conservation agriculture' is still the dominant name used for teaching regenerative practices. Most elements of regenerative agriculture are being taught as part of the agricultural university programmes, with an increased focus on no-till farming and the use of cover crops. What seems to be missing is the integration of a more systemic and holistic approach and understanding of regenerative agriculture, incorporating all its principles. In January 2023, MATE, the Hungarian University of Agriculture and Life Sciences, organised a conference, Organic Producers' Second Winter Meeting, with the theme 'Regenerative farming in focus', discussing the main principles of regenerative agriculture, the importance of a landscape approach, and applying regenerative practices in market gardens and family farms.	Independent, bottom-up, farmer-led initiatives, like the Regenerative Farmers Association Hungary, play a significant role in sharing up-to-date, practical knowledge and experience with Hungarian farmers, as well as creating platforms and opportunities for knowledge exchange among conventional and regenerative farmers. The Association organises the annual Soil Life Conference, regular Farmers Forums focusing on a specific topic relevant to a specific region, farming method or soil type, and offers an online regenerative scoring system, allowing transitioning farmers to assess their own farms along specific regenerative principles. The Hungarian Research Institute of Organic Agriculture (ÖMKi) organises regular events focused on regenerative agriculture, including the EIT Food-financed regular trainings, leads regenerative farming-focused research and farm visits (e.g. to the Grand Farm in Austria).
Slovakia	While regenerative agriculture is not yet visibly integrated in the agricultural education curriculum of Slovakia, there are notable bottom-up, farmer-led initiatives actively advocating regenerative practices. The agricultural cooperative Krakovany-Stráže, based in Trnava region, regularly shares its experiences, celebrates soil health and promotes education about regenerative farming. They welcome school visits and organise information days. Among the vision and objectives of the cooperative we can furthermore find their commitment to give university students and professors a platform for research and to influence the country's agricultural university to allow the teaching of no-till practices and to change the content of its teaching programmes.	Agricultural cooperative Krakovany - Stráže, as a well-known lively example of regenerative agriculture, organises awareness raising events for citizens and the wider public. Since September 2020 the cooperative had over 2000 people participating in farm activities, from farmers, gardeners, to students and researchers, as well as policymakers. Once a week, on Wednesdays, the cooperative is open to anybody willing to better understand the work and practices adopted on the farm. Every September, an annual gathering called Living Soil Day is organised. This regular event engages more than 100 people who participate in the event activities. Other on-site events are also organised throughout the year. (For more information on the cooperative in English.)

Source: European Commission

The role of national CAP networks to promote regenerative agriculture

National CAP networks should play a more active role in the process of mainstreaming regenerative agriculture as they have the right contacts, and they serve as platforms to disseminate, share knowledge and information, but also facilitate networking. So far, national CAP networks have mainly supported rural communities/ regional LEADER initiatives and groups in some countries. The new CAP has widened their network and added tasks (including environmental-friendly farming), which takes time to get familiar with and be effective (identify needs, find their specific role, reach out to stakeholders and develop networks).

The channels of dissemination must be tailored to farmers, which means it is necessary to explore the most effective ways through which news, knowledge, exemplary practices, or methods can reach them. Simply publishing on websites alone is not sufficient because farmers often do not even read those pages. Involving various media such as TV, radio, podcast-series specifically designed for farmers could yield greater success.

Practical farm demonstrations, farmers` forum and knowledge-sharing examples on regenerative agriculture from Ireland, France, Hungary and Austria.

Source: (1) Thomas Alföldi, (2) Marie-Christine Fort (CRAN), (3) TMG Association, (4) Alfred Grand.

European and global initiatives promoting regenerative agriculture

Sharing knowledge and information about sustainable agricultural practices and approaches is supported by various European and global initiatives and fora. The EU CAP Network plays a crucial role in innovation and knowledge exchange and it also hosts the Focus Group 'Regenerative agriculture for soil health' which enabled the publication of this mini paper. A new approach to the communication on regenerative agriculture is e.g. the Regenerative Organic Certificate. This is a global initiative, which has three pillars, Soil Health, Animal Welfare and Social Fairness for Farmers and Workers. The certificate builds up on organic standards and offers three different levels of certification, which are controlled by external audits from certified companies (similar to organic certification). Such certificates offer farmers the possibility not only to claim their regenerative work to their customers, but also to prove it.

Even if this initiative is only starting in Europe, globally, already 2.4 million hectares of land are certified. It enables certified farmers to communicate more effectively about regenerative farming to the consumers.

Other best practice examples are:

- Various EU-wide projects:
  1. Climate Farm Demo. The project aims to increase, speed-up and disseminate the adoption of climate smart farming practices and tools in the EU. The project will set-up a network of pilot farms across Europe and associated countries to reach this goal.
  2. Climate Smart Advisors. The research approach is to strengthen the capacity of the advisory community in the EU, an EU-wide network of 260 advisory communities (CoPs) is being established. The CoPs will be supported with training activities as well as an interactive database of knowledge and methods. Links will be established with national innovation projects and actors.
  3. NBSOIL. The EU-funded project offers a blended learning programme to mainstream knowledge on Nature-based Solutions for soil management and help soil advisors implement a holistic vision of soil health. The project focuses on six multifunctional practices: organic fertilisers from locally available biowastes, cover crops, paludiculture, forest diversification, bioremediation, and blue and green infrastructure in urban and periurban areas.
  4. LOESS. This Horizon Europe project aims to increase soil literacy by mapping, connecting and engaging relevant actors, target groups and other stakeholders. It will co-create tailored courses and modules, including the application of virtual reality, to address educational needs across different levels.
  5. CURIOSOIL. The EU co-funded project aims to enhance soil literacy in society through multi-sensorial soil experiences, educational products, course materials and training programmes for educators.

- The EU Mission: 'A Soil Deal for Europe' (the Mission Soil) and its 'multi-actor' approach: applying the 'multi-actor' approach is required across most research calls within the EU Mission Soil. This approach allows for the co-creation of knowledge and encourages the exchange of best practices and innovative solutions among a diverse group of participants, including scientists, advisers, enterprises, and farmers. Embracing a bottom-up approach, the multi-actor method transcends conventional involvement of end-users solely through result dissemination or stakeholder surveys.

- EIP-AGRI Operational Groups support smaller-scale practice-oriented innovative projects that aim to co-create practical solutions for agriculture, forestry and rural communities. Currently, there are 15 EIP-AGRI Operational Group projects with relevance for regenerative agriculture, ranging in focus from regenerative grazing, viticulture, soil regeneration and climate-adapted regenerative agriculture.

- EIT Food has an active programme on Regenerative Agriculture, with a series of funded activities, which include Regenerative Agriculture Workshops for farmers, advisory programmes mentored by experienced regenerative practitioners and the creation of specific resources, the Regenerative Agriculture Guidebook to help build a European regenerative farming community.

- The European Alliance for Regenerative Agriculture (EARA) is an independent farmer-led coordination and political advocacy organisation taking an active role in the movement of regenerative agriculture at the European level. The Alliance aims to make the voices of farming pioneers central in relevant political discourses both on an EU and Member State-level.

- The European R&I partnership on agroecology living labs and research infrastructures started out from an initiative by the European Commission aiming to accelerate farming systems transition towards agroecology. The Partnership is committed to provide spaces for long-term, site-specific, multi-stakeholder and real-life experimentation, and direction for research activities on agroecology at the European and national levels.

Moreover, farmers who are the end-users of regenerative practices developed under these projects, will be more motivated to use the results, having contributed to planning, implementation, result dissemination, and potential demonstration of regenerative practices in the newly established Living Labs. By fostering a sense of co-ownership, farmers will perceive themselves as contributors to the solutions, having actively participated in project design and contributed valuable ideas and views.

5. Conclusions and recommendations

The majority of farmers are still in the initial stages of adopting regenerative agriculture, highlighting the challenges of transitioning to a more sustainable farming system. Changing farming systems is not just an agronomic or economic challenge; it involves a cultural shift and paradigm change, often driven by pioneer farmers rather than a top-down approach. Currently, access to information on regenerative agriculture is often facilitated by social networks, while the institutional education of future farmers often lacks up-to-date information on regenerative practices, leaving a significant gap in knowledge transfer and implementation.

Changing old farming practices requires a change of mindset, which should be facilitated not only by progressive farmers but also supported by well-functioning Agricultural Knowledge and Innovation Systems (AKIS). Effective platforms, reformed education, and credible advisors are crucial for disseminating up-to-date knowledge and practical solutions on regenerative agriculture. The wider adoption of regenerative practices could enhance farmers' resilience and address critical issues like climate change, biodiversity loss, and food security.

There is a need for a change of heart in farming communities, involving farmers, families, and surrounding communities, to create a more resilient and regenerative way of farming. The low percentage of young farmers below 35 reinforces the need for educational reform and investment in adult learning to mainstream regenerative practices. Widespread confusion still exists in society regarding the differences between organic farming, regenerative farming, integrated management, and agroecology, highlighting the importance of consumer education.

In our mini paper, best practices from Austria, Croatia, Estonia, Finland, France and Hungary showcase various approaches to integrating regenerative agriculture into education, research, and on-farm activities. National CAP networks should play a more active role in promoting regenerative agriculture by serving as platforms for knowledge dissemination and networking. EU-wide projects like Climate Farm Demo and Climate Smart Advisors, along with the multi-actor approach under the EU Mission Soil, hold promise for accelerating the adoption of regenerative practices by actively involving stakeholders and fostering co-ownership among farmers.

For the advancement of regenerative agriculture and for mainstreaming regenerative practices in Europe, authors of this mini paper have formulated the below general recommendations:

- Strengthen contacts between agricultural students, conventional farmers and regenerative farmers through e.g. practical on-field visits which should focus not only on techniques, but also on the whole system, as well as farmers` motivation and reasoning behind adopting regenerative practices;
- Serious games can be relevant tools to open minds to new approaches and practices;
- An EU-level e-course (for farmers, advisors, students) could be a useful tool to learn from other farmers` experience;
- Encourage and incentivise farmer-to-farmer knowledge exchange and co-learning;
- Make science-based up-to-date information available to advisors and enable them to 'translate' this knowledge into practical guidance for farmers;
- Create initiatives that aim to improve communication, foster healthy relationships, and promote cooperation among farmers;
- Establish national-level databases or registries containing information about all regenerative farmers;
- Tailor channels of dissemination to farmers, consider involving various media such as TV, radio, podcast-series specifically designed for farmers.

6. Research needs from practice

Research is part of education as new solutions and knowledge are being developed through research and then new specialists are educated through university- or research-projects. Universities often get criticism over the lack of sufficient focus of their research on the real, everyday needs of farmers with the frequent consequence that students, farmers, advisors and politicians are not aware of the real environmental issues and available innovative solutions. Farmers often claim that they get very limited information regarding regenerative practices through universities, because they simply do not have knowledge, ongoing research or elements in the curriculum around this topic (especially on the importance and impact of animals in the farming system; but also on soil-related topics). Local context-specific research is rare, resulting in the lack of relevant and practical information and knowledge for different stakeholders. Due to these problems, young farmers, for example in Estonia, bring many foreign experts to their farms, because they have up-to-date and innovative knowledge and solutions. However, some claim that such knowledge is often not sufficiently validated under the local conditions.

Authors of this mini paper identified the below research needs from practice in the areas of education and knowledge-sharing:

1. Linking agricultural actors for the further development and mainstreaming of regenerative agriculture

Currently, farmers are not sufficiently connected with advisors, scientists and decision-makers. Understanding the language of scientific knowledge is often challenging for farmers. Furthermore, farmers' needs do not always reach decision-makers. Advisors and the farm advisory system could provide a bridge between science and farming practice. A more effective, trust-based relationship between agricultural actors could potentially contribute to more impactful on-farm research as well, resulting in successful on-farm trials for the advancement of regenerative practices. Further research and strategic development are needed to understand and improve the dynamics between agricultural actors, identifying existing obstacles and developing the most effective forms of collaboration for the advancement of regenerative agriculture.

This proposed research need could provide a solution to a Europe-wide challenge with relevance to both crop and animal production farms.

2. Connecting regenerative farmers with consumers and bringing regenerative products to the market benefiting farmers' efforts

At the moment, average consumers rarely have reliable knowledge about or access to products from regenerative farms which also results in the fact that regenerative farmers are not sufficiently recognised, their products do not have the deserved visibility and demand for. More research is needed on how to create a win-win situation in which both consumers and regenerative farmers benefit from an increased demand and improved access to high-quality regenerative products. This could potentially be achieved by better price offers and placement for such products, developing and incentivising short food supply chains, as well as by establishing a reliable and transparent certification system and labelling for regenerative products.

This proposed research need could provide a solution to a Europe-wide challenge with relevance to both crop and animal production farms.

3. Defining and measuring 'improved soil health' and 'more biodiversity'

While the potential positive impact of regenerative farming practices on soil health and biodiversity is well-known and widely advocated, farmers at various levels of transitioning to regenerative agriculture need clear, science-based, locally validated and measurable indicators to assess the impact of their farming practices on soils and biodiversity. Research is needed in order to define what exactly 'improved soil health' and 'more biodiversity' mean on a farm level, how much the identified indicators are country-, region- and farm type-specific, what user-friendly, accessible and reliable methods exist to monitor and measure farms` performance against these indicators and of course, how various practices impact soil health and biodiversity and how to make this impact positive for regenerative systems.

This proposed research need could provide a solution to a Europe-wide challenge with relevance to both crop and animal production farms.

7. Ideas for innovative actions

1. Public platform to share knowledge and experience on regenerative agriculture

The aim of the operational group would be to co-develop a publicly available platform and online decision-support tool with a multi-actor approach to provide access to common failures and successes in regenerative agriculture.

The proposed idea could provide a solution to Europe-wide challenge with relevance to both crop and animal production farms.

The main challenge is the lack of access to knowledge and practical experience on regenerative agriculture. The proposed platform would fill this gap and ensure its long-term sustainability through the multi-actor approach.

Proposed activities:

- Collection of existing best practices, common failures, tools, initiatives (e.g. FGs), practical tips and advice (with direct contact to experienced farmers and advisors);
- Development of an accessible, user-friendly platform;
- Identify potential networks (e.g. LEADER, EU & National CAP networks) and initiatives and develop a strategy to involve them in the dissemination, promotion and regular update of the new platform.

2. Enhancing the effectiveness and access of digital tools

Digital tools in general can be cost-effective and impactful media to reach, influence, educate and guide users. When it comes to reaching and supporting farmers on regenerative agriculture, the access and usability of digital tools varies a lot, depending on farmers` age, level of education, technological background, available capacities and of course, their perception and trust in such tools.

The aim of this operational group would be to identify current obstacles and reasons behind potential resistance towards digital tools in the farming community and how these could be overcome and utilised for the benefit of farmers, sustainable production and the environment. Digital tools, similarly to the formerly recommended public platform, could be effectively utilised to share knowledge, experience, successes and common failures, and to connect farmers on various levels of their transition to regenerative practices.

The proposed idea could provide a solution to a Europe-wide challenge with relevance to both crop and animal production farms.

3. Creating safeguards and incentives for independent, science-based, up-to-date and practice-focused national farm advisory systems

Today, a great share of farm advisors in Europe are in some way linked to commercial companies and interests, potentially putting the impartiality, science-based and effective nature of their advice to farmers at risk. In order to achieve the objectives set by the European Commission towards national farm advisory systems – namely, to improve the sustainable management and overall performance of farms by improving farmers` awareness of the relationship between farm and land management, as well as by delivering up-to-date technological and scientific information – Member State-level farm advisory systems need to become independent, science-based and practice-focused.

This operational group would focus on identifying existing obstacles and issues with the current advisory systems, collecting available best practices, safeguards and frameworks to achieve the overall objectives and to develop effective ways to integrate regenerative practices into the future farm advisory systems.

This proposed research need could provide a solution to a Europe-wide challenge with relevance to both crop and animal production farms.

Further innovative ideas:

- 'Interrail' for young people to visit and work on regenerative farms;
- Enabling young people to be ambassadors of regenerative agriculture (with social media tools etc.);
- 'Erasmus for farmers': incentivise farmers to participate in educational programmes and trainings (for life-long learning) - could be part of the national eco-schemes;
- Establishing and supporting a national networks of regenerative reference farms;
- Facilitate the creation of farmers' social networks for the implementation of regenerative agriculture practices.

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Mini Paper 3: Outcomes and indicators for regenerative agriculture across Europe

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Disclaimer

This Mini Paper has been developed within the frame of the EU CAP Network Focus Group 'Regenerative agriculture for soil health' with the purpose of providing input to the Focus Group discussions and final report.

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1. Introduction – Motivation

1.1. Context

According to the European Union Thematic Soil Strategy, soils worldwide are subject to several anthropogenic threats, such as erosion, sealing, pollution, loss of organic matter and biodiversity, compaction and degradation (EC, 2021; EC, 2021b). All these threats and associated negative on-site and off-site environmental impacts are largely attributed to land-use intensification and inadequate land management (Montanarella and Panagos, 2021). As a result, many important soil functions such as primary productivity provisioning, biodiversity maintenance, atmospheric CO_2 uptake, and nutrient and water cycling regulation are compromised, ultimately leading to a degenerative process with regional and global negative repercussions (FAO and ITPS, 2021; EC, 2006). These land degradation processes are further exacerbated by global change, notably extreme droughts and extreme precipitation events. Thus, there is an urgent need for land management practices and systems that have the capacity to stop and even revert this negative spiral.

1.2. Problem statement

Regenerative Agriculture (RA) is an outcomes- and principles-based approach to agriculture that has the potential to address these challenges by focusing on restoring and enhancing soil health and functioning. It promotes the implementation of a system of practices adapted to the local context. By restoring soil health, regenerative agriculture also aims to:

1. reverse biodiversity loss;
2. restore well-functioning water cycles;
3. adapt to and mitigate climate change;
4. increase economic profitability.

Currently, although there are many definitions in use for regenerative agriculture, a broad consensus of its practices, outcomes and criteria for measurement is lacking. This lack of consensus can be seen as problematic, given that it may prevent policymakers, practitioners and other relevant actors to unite behind the idea of regenerative agriculture and promote it, as well as leaving room for greenwashing. However, providing a definition that includes all practices and measures of RA may not be practical, as RA entails sets of very diverse practices that can be implemented to varying degrees, and trying to define precisely RA may lead to exclusion of specific sets of practices that do not fall under that definition. The fact that regenerative agriculture is by definition and necessity place and context specific further confounds this problem.

1.3. Content

In this Mini Paper the EIP-AGRI Focus Group on Regenerative Agriculture for soil health proposes generic outcomes that can and should be linked to RA and how to measure these stated outcomes.

Firstly, we will detail the contextual challenges and requirements for such a system, following which we will introduce the main desired outcomes for RA and suggest appropriate indicators that can be readily measured and interpreted in practice (lab and in-situ techniques). Furthermore, we will reflect on how to set this up in a flexible framework that allows for place and context specificity.

2. Dissertation

2.1. Challenges and requirements

We identify three main challenges that need to be addressed when designing an outcome-based indicator framework for RA: (1) Lack of widely accepted and benchmarked indicators for Soil Health; (2) Trade-offs between a generic and cost-efficient framework and the need for place and context specificity; (3) Operationalisation of already existing knowledge on RA.

1. Most scientific literature cites soil fertility, structure, biodiversity, resilience, and water dynamics as major aspects of soil health (Maurya et al., 2020, Bhaduri et al., 2022). Due to the complexity of soil systems, the scientific community has great difficulties establishing benchmarks on soil health. Chemical and physical soil indicators are well defined and benchmarked with large amounts of data, unlike for soil biological data, which are crucial for regenerative agriculture and its outcomes. Emerging technologies such as remote sensing, molecular biology, and precision agriculture offer new tools for soil assessment, monitoring, and verification, especially on soil biodiversity and organic carbon assessments.

2. A pan-European outcome/indicator framework for RA should be generic and cost efficient yet allow for place and context specificity to be effective. Current international systems for measuring soil health such as LUCAS SOIL are top down and rely on a minimum indicator set which is evaluated in a standardised manner regardless of place and context specific factors such as climate, soil type, and farming system (Orgiazzi et al., 2018). Moving towards a system that allows for customisation based on place and context however could lead to a prohibitively expensive and cumbersome system, as indicator measurements in such a diverse, complex environment would need to be done at field level throughout Europe (Wade et al., 2022). Establishment of easy to measure (proxy) indicators for the regenerative outcomes and setting place and context specific benchmarks along which the results could be evaluated could provide a solution to this, again with the drawback that it requires a large database of comparable samples that include the relevant information to be able to assess specific place and context parameters. Another approach is to monitor the applied regenerative practices rather than the outcomes themselves (Jeffery & Verheijen, 2020), as is currently done for Organic Agriculture and other certifications. The challenge here is that the same practice can lead to different outcomes, depending on where it is applied. Furthermore, while result based payments require more resources than practice-based payments, result based payments also produce higher awareness and interest for change among managers, side by side to the environmental or in this case soil health outcomes (Guimarães et al 2023; Pinto-Correia et al 2022).

3. Another paper on outcomes and indicators is of no added value if no attention is paid to the operationalisation of this knowledge. How can this paper help stakeholders including land managers adopt regenerative agriculture as well as measure its outcomes?

   For the wide practice linkage and practice effects of the knowledge on regenerative agriculture, efforts of a different kind than what has been experimented so far are needed. The first overarching goal is to increase the number of land managers which are impacted by the ongoing R&I projects and knowledge produced: they acquire new knowledge in relation to the soils they are dealing with, the possible practices and the expected outcomes and they may also, accordingly, change current management practices towards more regenerative practices to increase soil health.

   Understanding and describing RA outputs as accurately as possible is absolutely essential for enabling social learning by involving farmers and researchers in a joint pathway for participatory monitoring and evaluation of regenerative agriculture (Lujan-Soto et al 2021).

2.2. State-of-the-Art

From the previous section it becomes clear that for RA to become a mainstream success there is a need for a pan-European, outcome based, place and context specific indicator framework for Soil Health that not only focuses on scientific measurements but is co-developed with, and relevant for land managers.

Research

Ongoing research that is relevant towards this has been identified:

- The EU Soil Strategy aims to achieve healthy soils by 2050. The EU Mission 'A Soil Deal for Europe' (Mission Soil) aims to lead the transition towards healthy soils by 2030 and supports R&I on soil health, including soil health monitoring. The Mission project BENCHMARKS, one of the ongoing research projects monitoring this, 'collaborates with stakeholders in 24 European case studies to co-develop and evaluate a multi-scale and multi-user focused monitoring framework that is transparent, harmonised and cost-effective' (BENCHMARKS, 2022). It can be assumed that the output of this project will include an indicator framework that is very pertinent and applicable for the measurement of regenerative outcomes.
- ReGeNL is an EU 129 million Dutch RA program starting in 2024. Its goal is to kickstart the Dutch foods system transition towards RA. A core focus will be to develop context specific clusters of RA practices, scientifically linking these to outcomes (through measurements and modelling), as well as to payment schemes.
- There are many new innovations and technologies currently being developed to measure specifically as well as cost effectively. Promising examples range from remote sensing for monitoring soil plant cover to DNA sequencing for soil life. Also, the search is on for reliable, easy to measure and time sensitive (proxy) indicators that can be measured across contexts and systems. A good example of this is separating Soil Organic Matter (SOM) into fractions of Particulate Organic Matter (POM) and Mineral Associated Organic Matter (MAOM, (a very stable form of organic carbon in the soil) in order to assess and even predict soil carbon sequestration (Lavallee et al., 2020). If in the near future, this could be done accurately with NIR sensing methods, this could prove very valuable.

Simple aggregate stability test of soil in water using a coarse metal mesh

Source: Hatfield, J.L., Wacha, K. and Dold, C. (2018), "Why is SOIL ORGANIC MATTER so important?", *Crops & Soils*, 51: 4-55. https://doi.org/10.2134/cs2018.51.0205

Best Practices

Various programs are already in place to help land managers monitor their regenerative systems. A well-known example is the Savory Method, also known as Holistic Land Management, which not only helps farmers make management decisions, but also provides a set of easy-to-use indicator measurements to guide them over time. There are also certifying bodies such as the Rodale institute that have launched the Regenerative Organic certification. As with 'regular' organic, this is based on a set of practices rather than on the verifiable outcomes. From the industry side there is the SAI platform with their Regenerating Together program. This program includes an outcome assessment and progress reporting tool.

Recently, public and private laboratories have started going beyond common lab tests for nutrient levels in soil, by offering soil assessment services that include physical and especially biological soil parameters. One such example, is the Cornell University's Comprehensive Assessment of Soil Health test (CASH). Their lab offers commercial soil health tests that provide standardized information on soil biological and physical parameters. These services offer a scoring system for the measured indicators, which represent critical soil processes, helping farmers identify soil health problems and guide them to adopt improved and more sustainable soil and crop management practices.

For on-farm monitoring of soil quality, a soil kit has been developed by the USDA. The kit contains all tools and supplies needed to measure a set of selected physical, chemical, and biological properties of the soil, and can be used as a screening tool to allow the comparison of agricultural management practices, monitoring changes in soil quality over time, and for diagnosing possible soil health problems. The tests included in the kit can be easily conducted on the farm by either farm advisors or the farmers themselves to assess the quality of their soil (Seybold et al, 2001).

The Global Soil Partnership of the FAO has developed a soil educational field kit to train farmers, which is accompanied by a series of Training modules, where with the use of simple tools, farmers can learn to perform in-field assessment of physical, chemical, and biological conditions of their farm's soil (FAO, n.d.). Finally, the Visual Soil Assessment (VSA) Field Guides of the FAO provide easy to follow guidelines to assess soil quality with minimal tools (FAO, 2008).

2.3. Proposed Outcomes and Indicators

Desired outcomes of RA range from soil health and environmental to the social and economic domains. However, as soil health is the basis, and this MP cannot cover all outcomes, the focus of this section, as of the rest of the MP, is on the outcomes related to soil health.

Here we distinguish six main desired soil health outcomes, based on the main soil functions (Schulte et al., 2014) and widely established concepts of RA (Schreefel et al., 2020):

1. Increased infiltration and water holding capacity

'To receive, store and conduct water for subsequent use and as such to prevent droughts, flooding and erosion' (Wall et al., 2020). In many parts of Europe a direct effect of climate change is that rain falls in shorter, more intense periods interspersed with longer periods of drought. Important European rivers such as the Rhine, are increasingly dependent on rainfall rather than melting snow and ice, further compounding the challenge of water management and availability. Using RA methods to increase the infiltration and water holding capacity of agricultural soils can play a crucial role in building a system that is adapted to climate change.

Infiltrometer

Source: FAO

2. Reduced erosion

The main goal of RA is to protect the soil from erosion by increasing soil cover with cover crops, pruning residues and crop residues retention. It is important to bear in mind that soil erosion rates around Europe are higher than tolerable rates. In particular, in Mediterranean countries erosion rates in agricultural land range from 4-8 tonnes per hectare per year, or 1-2 cm of soil loss per year, if the soil is not protected with vegetation (Zhang et al., 2021). These erosion rates are unsustainable given that a century is needed for 3 mm of soil to be formed (Evans et al., 2019).

3. Increased biodiversity

Increase in soil biodiversity and abundance of organisms: although it is often very difficult to establish straightforward links between biodiversity and soil functions, in general increased biodiversity (and increasing abundance of soil life) are related to many other improved soil functions (aggregation, nutrient cycling, nutrient retention, disease suppressiveness).

4. Increased carbon sequestration

SOC is probably the key manageable variable, including in RA systems, given its enormous impact on nearly all biological, physical and chemical properties and processes. Increases in SOC will therefore increase production potential, resilience against soil degradation, resilience against climate change (droughts, flooding). Soil organic C (SOC) is found in two major pools: as particulate organic matter (POM; particulate organic residues mostly of plant origin) and mineral-associated organic matter (MAOM; a very stable form of organic carbon in the soil). RA practices such as no-till, cover crops and legumes contribute significantly to the formation of MAOM (Kauer et al., 2021).

5. Increased nutrient cycling

Nitrogen, a crucial nutrient for plant growth, exists mainly in crop residues, soil organic matter, and in manures and composts, in the form of complex organic compounds. These complex organic forms of nitrogen are inaccessible to plants as they cannot be directly absorbed by their roots, so plants rely on the process of nutrient cycling to convert this organic nitrogen into forms like aminoacids, ammonium and nitrate, which are readily uptaken by plant roots. The Soil N supplying potential is related to both the abundance and the metabolic activity of its microbial biomass. Soil biodiversity serves as a critical indicator of the potential for diverse nutrient cycles within the soil ecosystem.

6. Pest and Disease suppressiveness

Described by Creamer et al. (2022) as 'the capacity of soils to prevent the establishment and development of soil-borne plant pathogens (microorganisms and microfauna) and pests (meso- and macrofauna) despite their presence in the field, the availability of a susceptible host, and a suitable environment' this is a crucial outcome of RA in order for a resilient food system that produces healthy food and no longer relies heavily on artificial inputs for its productive capacity.

What indicator measurements can be linked to these outcomes? In the following table we distinguish between the indicators and the indicator measurements. We identify a selection of the 'best' indicators for each outcome, following which we attach two types of indicator measurements to these: (1) the scientific indicator measurement and (2) the farmer indicator measurement (Table 1). This aims to address the points made under sections 2.1 and 2.2 and bridge the gap between science and practice as well as place and context specificity.

Table 1. List of indicators for the assessment of Regenerative Agriculture Outcomes. Indicator measurements have hyperlinks to protocols or guide, while a list of all referenced guides can be found in the References section

RA Soil Health Outcome	Indicators	Indicator Measurements	
		Scientific	Farmer
Increased water holding and infiltration capacity	Water infiltration rate	Hydraulic conductivity, infiltration rate (soil infiltrometer, Fig 1),	Infiltration rate test Presence /absence of puddles and surface runoff several days after last rain
	Soil compaction	Penetrometer measurements, bulk density	Inspect compacted layers in a small profile pit and visual assessment of mottles, penetrometer measurements.
	Soil water content	Gravimetric/volumetric measurement	Soil water content: gravimetric method
	Water holding capacity	Pressure plate method (PF curve), funnel method	Funnel method
Reduced erosion	Soil cover	Quadrat method (% of plant cover)	Visual inspection: Bare soils or sparse green cover vs high density plant cover (or high residue cover) Canopeo app, measures % soil cover using the camera of a smartphone
	Soil structural stability (Aggregate stability)	Aggregate stability indices (Soil Survey Investigations Report No. 42, Version 6.0, Fig. 2), Glomalin content	Simple soil slake test in beaker with water using mesh (Fig. 3)
	Erosion rate	Erosion plots Estimation of the volume of soil lost after an erosive event by measuring the length, width and height of the gullies and rills observed in the field.	Visual inspection: Presence/absence of rills, gullies and visible erosion signs after a rainfall eventPorgand347
	Root proliferation (provide good structure and protect soils against erosion)	Analysis of soil cores	Visual inspection in a small profile pit

RA Soil Health Outcome	Indicators	Indicator Measurements	
		Scientific	Farmer
Increased biodiversity	Aboveground Functional biodiversity	Quadrat method/Shanon index	Indicator plants (e.g., leguminous), beneficial insects, pollinators
	Soil fauna	Earthworm numbers/diversity; nematodes	Earthworm numbers, earthworm burrowings, macro-arthropod numbers possibly through pitfall traps
	Microbial diversity and activity	Enzyme activities, C mineralization / respiration, Litterbag decomposition test, PLFA (Phospholipid Fatty Acids – quantification of main functional groups of soil microorganisms)	Soil decomposition rate – underpants (Fig. 4); teabags
Increased carbon sequestration	Soil Organic Carbon and Soil Organic Matter	Soil Total Carbon, SOC stocks, Particulate organic matter (POM) and Minerals Associated Organic Matter (MAOM)	Soil organic matter: reaction with hydrogen peroxide Soil organic matter: color observation
	Readily available C pool (microbial carbon food source)	Permanganate oxidizable C (POXC)	
Increased nutrient cycling	pH	pH-KCl or pH-H_2O	Soil pH: Indicator Strips
	Available organic N pool	Autoclaved citrate extractable (ACE) protein content	
	Soil microbial activity	Activities of enzymes involved in the C-, N-, P-, and S-cycles; basal respiration using a respirometer	Basal respiration field test (Solvita Soil Health Test) Soil decomposition rate – underpants (Fig. 4); teabags
Pest & Disease suppressiveness	Pathogen pressure or disease suppressiveness	Root Health Bio-assay (Cornell CASH), cellulolytic enzyme activity- e.g. β-glucosidase or cellobiohydrolase	

. Source: European Commission

Soil aggregate stability test

Source: Ristow et al. 2016

How can this address the challenge of place and context specificity?

Now that we have established indicators for each of the RA outcomes and proposed practical as well as scientific measurements for these indicators, the challenge for this framework remains the place and context specificity of RA. For the practical measurements the solution is relatively simple, as the goal here will nearly always be for the land-manager to observe change in soil health status over time and linked to changes in management practices. By measuring and observing periodically within the field/farm's own context, benchmarking can occur through a baseline measurement and the monitoring of change over time (and possibly space) from this baseline. Secondly, farmers in Europe widely indicate that they prefer peer-to-peer workshops and topical groups for knowledge exchange. Throughout Europe the Mission Soil is setting up regional Living Labs for the improvement of soil health. These could be the perfect organizing body for peer-to-peer groups of land managers that operate in similar systems and contexts, allowing them to share their experiences on RA practices and their links to the proposed soil health indicators.

At a scientific level the situation is slightly more complicated, where various solutions present themselves. In their paper Scheefel et al. present a flexible yet coherent framework, that allows for goalsetting based on place, context as well as scale and actor type and then proposes a set of indicators over time and scale (practice, result and outcome based) and the ways these can be measured (survey, stats, sample, space) (Scheefel et al., preprint). This framework offers the handholds for establishing a place and context specific system that is effective (measuring the relevant indicators for the relevant actors) and cost efficient (carefully assessing the scale and methods for measurements as well as using what is already there) for outcome-based measurements. The table presented in the previous paragraph can be fitted to this framework, whereby often the farmer indicator measurements are practice or result based and the scientific measurement lean towards result and outcome based. Farmer measurements rely on observation and sampling, whereas the scientific measurements can and should select from all available methods and only resort to sampling (due to costs) when no other reliable data at the required scale (field/farm/region/national/Europe) is available.

The final challenge here is the harmonisation of existing data and ongoing soil sampling efforts throughout Europe. For this there are already various large-scale projects within Europe and the Mission Soil. The most important of these is the BENCHMARKS project, that has as its stated purpose (amongst others) to derive local benchmarks through stratified normalization of monitoring data (BENCHMARKS, 2022). If this is a success this would allow for benchmarking indicators specifically within pedo-climatic regions and farming systems.

2.4. Conclusions

Six key RA outcomes for soil health have been described and indicators have been proposed for each. Indicator measurements are described for scientific as well as practical purposes. Allowing scientific, policy and value chain tracking of outcomes on the one side and enabling land managers to receive direct feedback from their soils regarding their management on the other side.

Peer-to-peer learning within already established Living Labs is suggested for farmer uptake of practices and monitoring, whereas a EU wide flexible yet coherent monitoring framework is proposed for effective and cost-efficient monitoring from a scientific perspective. The proposed table fits well within this framework.

3. Research needs for practice

3.1. Place and context specificity of practices and their soil health outcomes

Research needs for soil health indicators in Regenerative Agriculture emphasize understanding the specificities of agricultural practices and their outcomes in diverse contexts. This should be investigated across various climatic zones and soil types to determine optimal strategies for improving soil health, with a specific focus on collecting sufficient data for benchmarking of soil biological indicators. Additionally, assessing the relative relevance of regenerative practices for different agricultural systems, such perennial, annual and horticultural crops, is crucial.

Further development and validation is required for innovative tools such as soil test kits and visual assessment guides, for in-field monitoring of soil health, which can be performed by farmers or advisors to monitor improvement in soil health. Additionally, there is also a great need for research to identify indicators for assessing soil microbial diversity and activity and their efficiency in supporting nutrient cycling and carbon sequestration. These resources can empower farmers to conduct regular assessments of soil quality, enabling them to track progress over time and make informed decisions regarding land management practices. By incorporating these farmer-accessible and user-friendly soil quality monitoring techniques, we can enhance the efficiency and effectiveness of regenerative agriculture practices.

Development of complex indicators that reflect the contribution of soil to key ecosystem services or best describe soil health as a holistic parameter

Many soil health indicators exist, but they are often not directed towards practical use, or it is not well known how they really reflect soil management (in this case specifically sets of RA practices). They also need to be finetuned for specific combinations of climate-soil-crop rotation.

The main challenge is the ability to identify key parameters or a set of parameters, combined into a single aggregate indicator, that describe the contribution of soil to essential ecosystem services or best express the concept of soil health. For example, to describe the contribution of soil to water regulation ecosystem service, the integrated parameter describing all the processes within hydrological cycle such as infiltration, soil hydraulic conductivity, field water holding capacity, permanent wilting point, porosity etc. The aim should be to simply rate soils in terms of improving ecosystem service function or increasing soil health.

Development of simple and reliable indicators of soil biodiversity describing the proportion and quantity of microorganisms or soil biota key to soil health

Soil microorganisms contribute to a number of ecosystem functions in the soil, either through nutrient cycling, transformation of organic matter and storage of stable forms of carbon in the soil, or the formation of stable soil aggregates and thus a positive effect on soil physical properties. However, the main challenge is to understand what defines an optimal state in terms of the quantitative and qualitative representation of soil microorganisms and soil biota and which simple but reliable indicators can be used to assess the state of soil biodiversity in terms of optimal impact on soil health and soil ecosystem functions. Perspective indicators could be, for example, the quantification of the ratios of the main functional groups of soil microorganisms through the analysis of phospholipid-derived fatty acids (PLFA) or metabarcoding.

Methods for monitoring large-scale changes in soil health using remote sensing and fixed sampling points

Assessing positive or negative changes in soil health is very difficult at large spatial scales due to the high heterogeneity of soils. However, the ability to monitor changes in soil health over large areas is a potentially important tool for assessing the success of regenerative agriculture practices or, conversely, an early indicator of the need to adapt these practices to specific local conditions. The potential for large-scale monitoring of soil health is provided, for example, by remote sensing methods, but due to the possible influence of several factors and therefore the lower reliability of remote sensing approaches, it is necessary to ensure their calibration, for example by analyses at fixed sampling points.

Underpants before and after burrial in a healthy soil. The cellulolytic activity of the soil microbes has largely decomposed the cotton

Source: https://www.swissinfo.ch/eng/sci-tech/buried-underwear-proves-good-soil-in-private-gardens/47938014

3.2. Synchronisation of existing soil health and regenerative programmes

The Mission Soil under Horizon Europe, marks a significant increase in funding for soil health and regeneration research. This initiative, alongside other projects from other EU programmes (as PRIMA, LIFE or ERC), and national or private funding, underscores the need for complementary efforts to avoid duplication, maximize impact, and accelerate progress towards soil regeneration goals. Effective coordination among projects is imperative to build upon existing knowledge, prevent gaps, and ensure diverse geographical and socio-economic coverage across the EU. Stakeholder involvement is crucial for practical implementation of soil regenerative practices, requiring enhanced coordination efforts within each Member State to prevent stakeholder fatigue and ensure broader engagement. Research needs focusing on co-constructing guidelines with project coordinators and national representatives to enhance synergies and avoid duplications at both project and field implementation levels.

4. Ideas for innovations

4.1. Ideas for innovative projects /solutions

1. **Design a platform to help match clusters of RA practices to outcomes**
   In order to effectively evaluate the outcomes of regenerative agriculture, it is necessary to look for indicators or combinations of indicators that describe key ecosystem services, either individually or in combination, as quantifying ecosystem services can help develop a comprehensive assessment of regenerative management.
   Following the large scale, long-term soil sampling campaign (BENCHMARKS), develop a database and software that can predict, based on the previously mentioned contextual factors, which cluster of RA practices lead to which outcomes.
2. **Result-based models (RBMs), particularly in agri-environmental schemes**
   For the required paradigm shift towards regenerative agriculture, a combination of conventional and result-based payments may be a way forward and is worthwhile experimenting. Result-based models (RBMs), particularly in agri-environmental schemes, offer a participatory and efficient monitoring mechanism. RBMs encourage farmers to engage in designing tools and making management decisions aligned with defined outcomes. While RBMs have been tested in specific contexts, more modalities tailored to EU regions are needed. This approach requires clear environmental objectives, agreed upon by all stakeholders, and easily applicable indicators, developed through a co-construction process. Continued local support mechanisms, such as technical advisory offices and field visits, are essential for successful implementation. Despite significant resource requirements, RBMs facilitate farmer awareness and training, exemplified by pilot projects in Ireland, Spain, and Portugal.

4.2. Potential EIP-AGRI Operational Groups

1. **Soil (biological) quality indicators at farm level to evaluate effects of specific RA practice**. Farmers need to be able to use easy, practical and cheap tools to evaluate the effects of specific RA practices on soil health. Essential is that farmer see the evolution of soil quality as influenced by specific RA practices. From this, also more general beneficial effects of specific RA practices can be derived and extrapolated to other regions. OG can create Inventories of existing easy to use tools and apply them with specific RA practices; monitor the evolution over time. They can also use or develop Apps to assess and interpret the soil quality.
2. **Develop Functional microbiome assessment methods** as a tool to advise farmers how to evaluate and modulate soil microbiota before applying biofertilizers or biostimulants. These measurements can be done for major parameters such as soil heath (biodiversity, functionality), disease incidence (pathogens target for crop species), stress adaptation (biotic and abiotic stress) and nutrition metabolization (macro and micronutrients) (Biome makers ®). By targeting what is missing in soil, farmer can adjust and be more precise on their appliance in field operations.

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Decomposition study using tea bags https://www.fibl.org/fileadmin/documents/shop/1098-teabag.pdf

FAO-SOIL COMPACTION AND AERATION: MOTTLES https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/New_format_EN/P05-Mottles-EN.pdf

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FAO-Soil water content: gravimetric method https://www.fao.org/fileadmin/user_upload/GSP/GSDP/Field_exercises/NEW_Field_exercises/P06b-gravimetric-soil-water-EN-1-2.pdf

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Mini Paper 4: Value creation through regenerative agriculture

Félix Noblia (Coord.), Thomas Weber, Knud Bay-Smidt, Teresa Pinto-Correia

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Disclaimer

This Mini Paper has been developed within the frame of the EU CAP Network Focus Group 'Regenerative agriculture for soil health' with the purpose of providing input to the Focus Group discussions and final report.

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1. Introduction and motivation

The advantages of regenerative agriculture are described in literature and recognised as having a significant and positive environmental impact, especially on the increase and conservation of soil organic carbon and on the subsequent physical, chemical and biological properties of soil (e.g. soil fertility, water storage capacity, resilience to climate change, biodiversity protection, carbon sequestration and water retention). So far, despite its advantages, regenerative agriculture is not widely adopted. For instance, agricultural practices focusing on soil conservation are practiced solemnly on around 10% of arable areas, but it is growing. In past years, multiple examples throughout the world have shown that regenerative agriculture moved from an elusive concept to being a proven solution, and a solid answer to the future of farming.

Many farmers take the decision to change their management most often based on the expected monetary cost-benefit balance. But so far there exists still a lack of systematic evidence on such cost-benefit balances for regenerative agriculture, covering different types of farms and bio-physical as well as socio-economic contexts.

The challenge for our future is to provide economic benefits for the application of regenerative agriculture to make it more competitive or profitable compared to conventional agriculture. This paper gives an overview on the costs avoided by farmers farming in a regenerative way, the new potential markets opened by environmental benefits as well as ideas for further research and innovative projects / actions..

2. Overview on key issues

While ecological benefits are well documented, the value created, cost reduction and new benefits for the farmer are little known and measured. This slows down the attractiveness for and diffusion among the rest of the farmers. There may also be risks and losses for the farmer in the first period after that change of their production system. These can be related with reduction of productivity or the difficulty of mastering new techniques as well as additional workload linked to training and new purchases (new materials, new seeds, etc.). The environmental and economic cost-benefit analysis should be done all the way through from the start of the transition to the phase where there is a new relative stable state in the farm, although the improvement is a process which will continue even after achieving this first relative stable state.. In practice, we need to analyse the first 10 years of the transition. In that way, we will be able to identify the financial support farmers need to engage in a safe transition.

The value generated by regenerative agriculture must be weighted against the risk of the transition for the farmer. The value generated must also increase in profitability of regenerative agriculture – and the interest raised among the farming community and the actors that interact with this community.

Furthermore, regenerative agriculture should be supported by society as it provides common goods (e.g. clean water, store carbon, cool the climate).

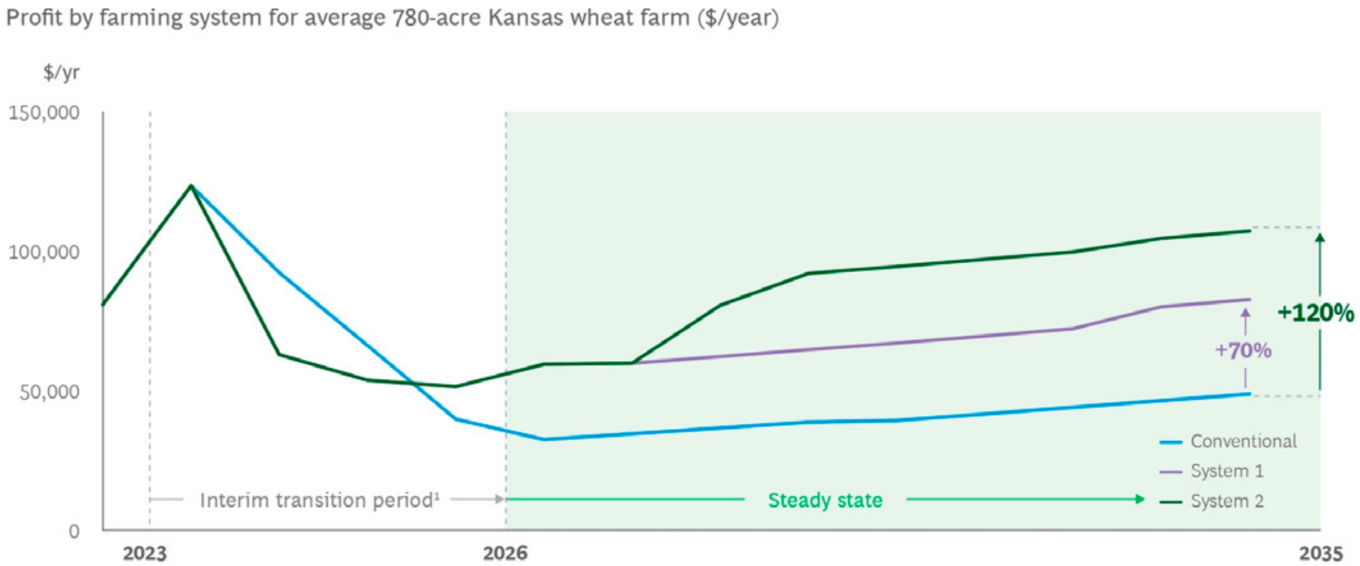
3. Potential drop in profitability in the first years after implementation

When a farmer adopts a regenerative farming approach, he relies more on the bio-services provided by nature as he starts working with natural processes instead of regulating them by using external inputs (e.g. pesticides, mineral fertilisers and deep ploughing). Therefore the transition may cause a temporary drop in profitability.

This drop could be traced to:

1. The learning curve: farmers need to learn how to manage their farm differently. It means that they are experimenting, failing, learning, and improving. The failures that are inherent in the learning process cause yield and profit losses.
2. The duration of the soil fertility regeneration process: soil which has for a long time been mechanically loosen, chemically fertilised and treated with pesticides need time for (a) create a stable structure favourable to root growth, (b) accumulate organic matter which will retain and provide water and nutrients as well as help improving soil structure, (c) regenerate biological communities which can support crops in accessing nutrients as well as resisting to pest and diseases.
3. The investments needed: regenerative farming often requires new types of machinery (e.g. direct seeding machine). Investing in this costly equipment without completely mastering the new production system and lower yields in first years after the transition generate profit losses which may be difficult to handle.

Figure 1. Farmers embracing regenerative agriculture can expect significant financial gains



Sources: OP2B and BCG analysis.

Note: System 1 is the basic/intermediate phase that includes cover crops, less-frequent tilling, intercropping, mulching, and the reduced use of crop protection chemicals, among other practices. System 2, which includes more diversified crop rotation, formal livestock integration practices, and other landscape changes, carries the transition through to completion.

The Boston Consulting Group (BCG) describes the profitability gap and return on investment well in its report on 'Cultivating Farmer Prosperity: Investing in Regenerative Agriculture' (for details have a look at the full report). One of the main messages is that within the first years of implementing regenerative agricultural practices farmers are likely to see a decline in profits of up to 60% or more, due to lower crop yields and the added cost of seeds and new machinery.

Over time, however, and once farmers reach a relatively steady state of regenerative practices and increased soil fertility, existing data indicates a positive long-term business case for farmers, resulting in between 70% and 120% higher profitability and a return on investment of 15% to 25% over 10 years compared to conventional farming.

1 Declines in profit due in part to wheat prices returning to long-term average.

3.1. Added value of soil conservation

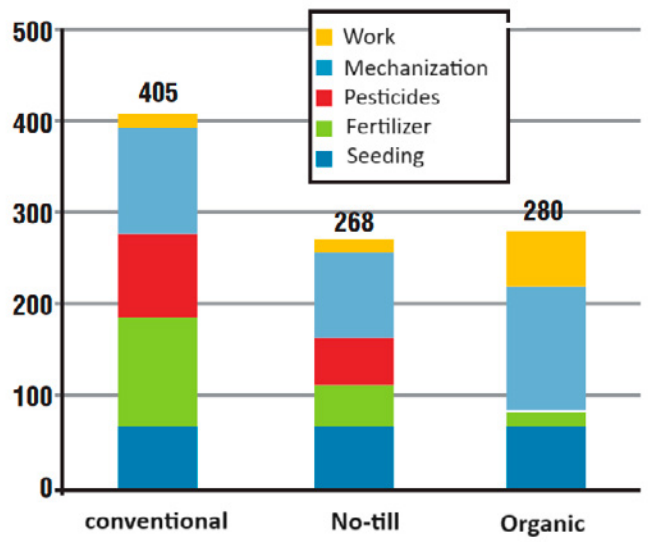
Machine and fuel

The farmer will need to have access to a new type of seeder, by renting or purchasing it. These seeders allow the seed to be placed in the soil without tillage, being the tillage replaced by the work of (cover crop) roots. The use of this type of seeders makes it possible to reduce the overall mechanisation load.

When a farmer switches to a soil conservation system, his soil structure will be improved by (cover) crop's roots. He will sow a diversified cover crop (e.g. phacelia, fava beans, peas, radish, rye, etc.) whose roots will structure and crack the soil. When this cover is terminated, the roots of the plant cover will die, creating preferential paths for the roots of the following crop and for biology.

As the figures in TCS magazine explain, a farmer who switches from ploughing to direct seeding has to part with some of his equipment. He needs less powerful tractors and reduces his use of tillage equipment. The average number of tractors per farm is reduced by a third.

Figure 2. Comparison of production costs of three farming approaches in a cruising situation



Source: Cedar Meadow Farm, PA (USA)

Diesel consumption per hectare is also greatly reduced. It's halved. The farmer goes from an average of 52 l/Ha to 26 l/ha.

A French farmer, Julien Senez, estimated that after 10 years, he reduced the costs on his farm by 110€/ha, mainly through fuel and machine cost reduction, which is consistent with the estimations from Toque et al. (2010) in Labreuche et al. (2010). In parallel, he increased yield and added carbon credit benefits (42 euros), leading to a 270€ net margin increase due to less costs.

Nutrients and fertiliser saved

Soil conservation also prevents nutrient loss through erosion. The main elements leached are N, Ca, P, K and Mg. In a tropical environment the savings can go up to 567 EUR. according to the CIRAD (165 kg N per ha = 129€, 453 kgK per ha = 181€, 514 Ca+Mg kg per ha = 257€. Total 567€). In temperate area, cover crops can typically store 80 kgN, 25 kgP and 185 kgK.

By preventing part of nutrient loss from leaching, thanks to the plant cover which recycles the elements, the farmer will reduce the amount of fertilizer needed. This represents up to 225 €.

3.2. Added value of regenerative grazing

A farmer who includes in his farm ruminant rotational grazing reduces the production costs, as this technique improves grass growth and meadow productivity. It also makes livestock farming compatible and complementary with intercropping soil cover practices. Moreover, during the pasture period the animals collect their feed without mechanisation. Grazing even reduces the need for additional fertilisers, as animals fertilise the ground with manure. In the end, carrying out rotating pasture management on the farm reduces the total mechanisation needs over the year. Moreover, grazing increases carbon sequestration in the soil.

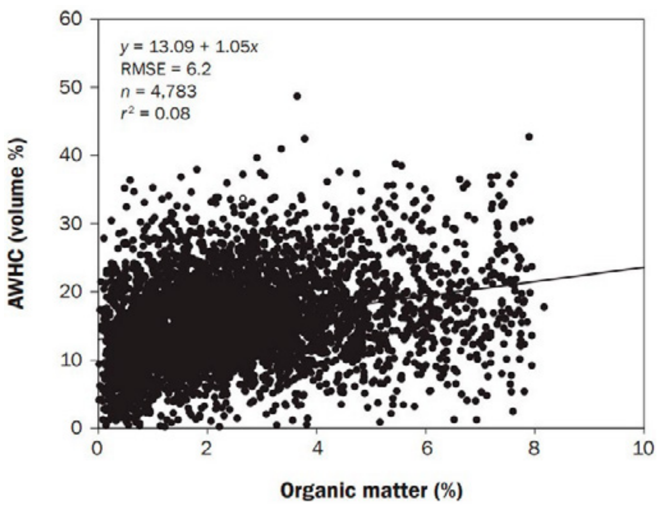
4. Provision of public goods through regenerative agriculture

4.1. Water quality and sequestration in soil

Many elements contribute to infiltrability like vegetation by its diversity, its regularity over the year and its quantity, direct seeding and residue retention on soil surface. The plant cover breaks the kinetic energy of the droplets which do not create a crust on the surface and infiltrate better into the soil. It also helps reduce water loss from the soil through evaporation. The higher the percentage of organic matter, the more capable the soil is of infiltrating rainwater and storing water for crops. Soil conservation practices enable farmers to save water. These elements show how the regenerative agriculture approach can reduce the risk of erosion and flooding through better infiltrability.

Regenerative agriculture and vegetation cover play a major role in protecting soils against heat and drought and therefore the crops as well. First of all, regenerative practices – especially by improving the level of organic matter – allow soils to retain more water and keep plants in a state of non-hydric stress for longer.

Figure 3. Soil available water-holding capacity (AWHC) versus soil organic matter (SOM) for (a) 0% to 8% range and (b) 0% to 100% range of SOM



Relation entre teneur en O des sols et réserve facilement utilisable (Libohova et al., 2018)

Measuring the results of these practices with an adapted risk assessment approach could help reduce insurance costs for farmers who engage in good practices and present fewer risks of crop dryness. For example, insurance could be 30% cheaper.

Insurance against climate risks linked to floods paying for flood damage.

This involves developing value transfer mechanisms for farmers to reduce the risk incurred with the transition. The more agriculture damages the rate of soil infiltration, the greater the risk of flooding. We can therefore suggest that the opposite is also true. The more the soil can infiltrate water, the less likely flooding will occur and cause damage. Payment thresholds could be imagined by insurance to protect watersheds from flooding by improving practices for better water infiltrability.

Avoid pollutants in water

These value transfers already exist in catchment areas. Farmers are paid in protection zones (La protection des captages d'eau potable Contre les pesticides Publié par FNE Languedoc-Roussillon Novembre 2018) and supported to work organically and avoid the use of pesticides on the main infiltration points.

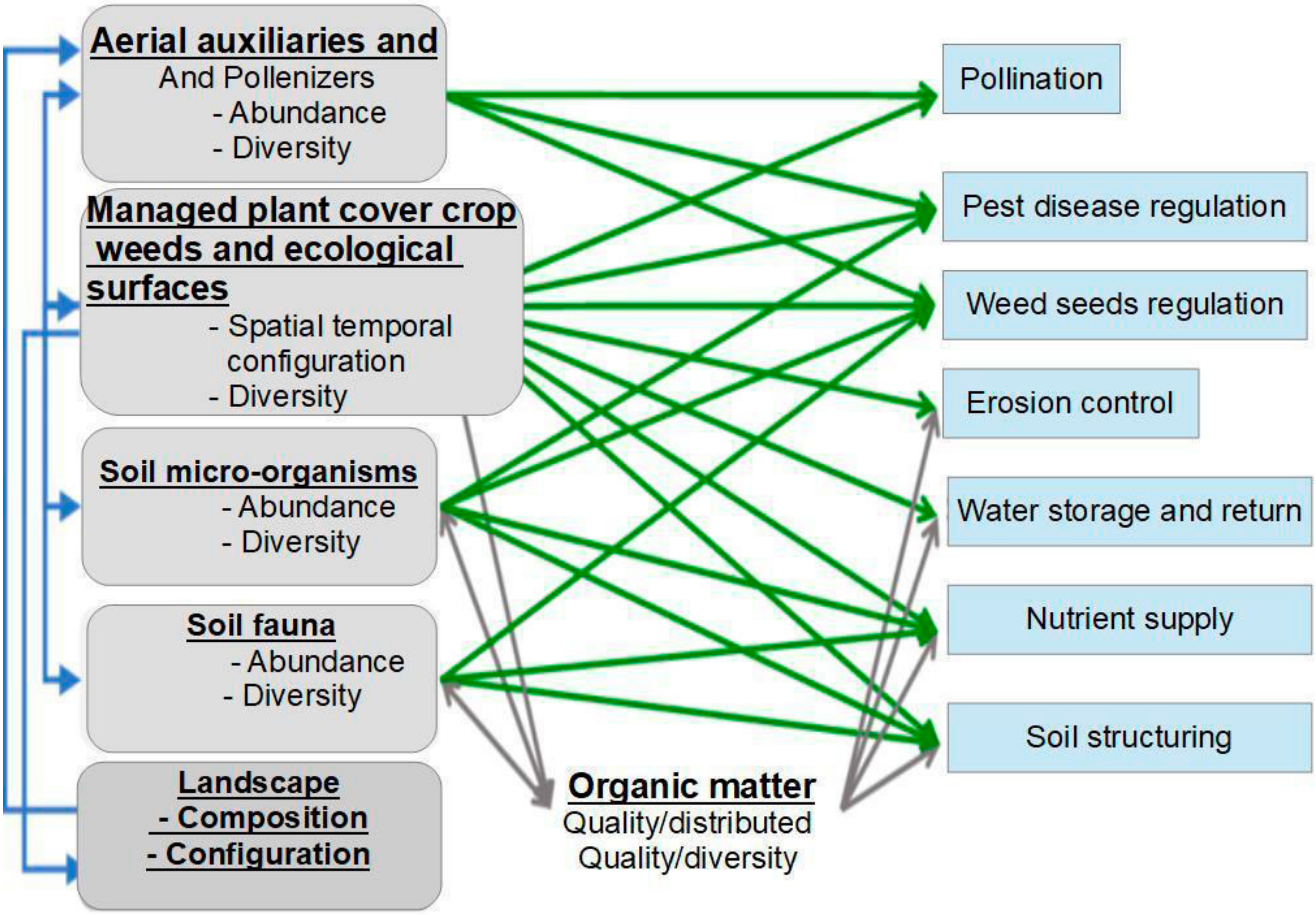
4.2. Improvement of biodiversity better yield and avoid cost

Ecosystem service for better yields

Regenerative agriculture provides food and shelter for a large part of the trophic chain. This type of agriculture, which favors cultivated biodiversity and preserves habitats, helps to develop biodiversity. Agro-ecological infrastructures (hedges, trees, wetlands, etc.) are encouraged, developed and maintained in this form of agriculture.

With the diversity in singular elements, e.g. the components of the agro-ecological infrastructures (hedges, trees, wetlands, etc), also the landscape benefits (HDLF), as the landscape level mosaic becomes more heterogeneous. The preservation of linear elements as riparian corridors and hedgerows in cultivated fields, and in general the heterogeneity in the landscape results in a reduction in erosion risks (deriving from wind as well as water). It also means higher resilience of crops in relation to pest and diseases, due to the biotope effect of the singular elements, which also act as shelter for wild animals.

Figure 4. Main relationships between the components of biodiversity and soil organic matter and ecosystem services (ES) provided to the farmer i.e. underlying agricultural production (adapted from Therond et al., 2017c*)



Main relationships between the components of biodiversity and soil organic matter and ecosystem services (ES) provided to the farmer i.e. underlying agricultural production (adapted from Therond et al., 2017c*). For reasons of readability, the feedback loops between ES and biodiversity and ES and organic matter is not represented. Only the ES analyzed in this study are represented here.

The cost of the loss of pollinating insects in France is estimated by the WWF at 15 billion euros over the next 25 years. This cost is linked to the failure of entomophilous plants to pollinate. We could imagine investing 600 million euros a year to provide more ecological niches and food for pollinating insects.

4.3. Better nutritional value of final product for consumer

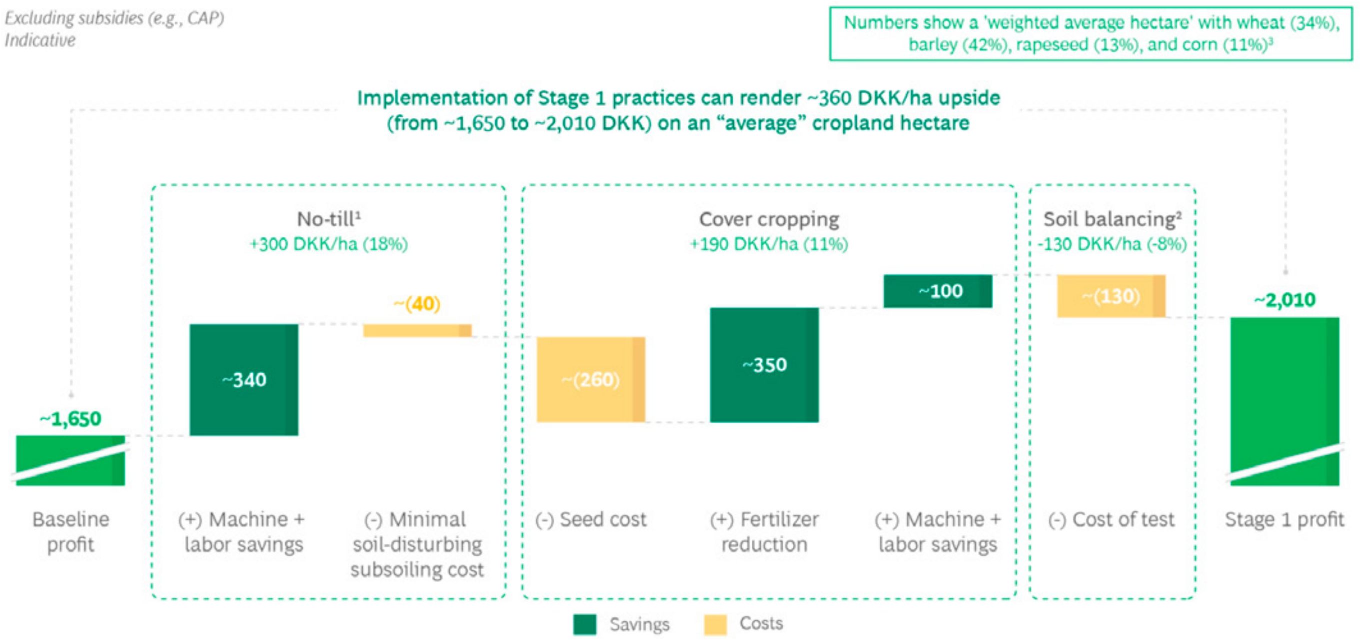
Regenerative agriculture provides better soil, increasing better plant nutrition and greater plant nutrient richness. Mongomery's study explains the links between regenerative agriculture and plant nutrition. Healthier soils from regenerative agriculture contain more trace elements. The plants growing on it are more balanced and healthier. It also produces more vitamins and antioxidants. Soil health for plant health for human health (it also works for animal health).

Animal nutrition also plays a role in health. For instance, in France, there is the blue white heart (bleu blanc coeur) association, which guarantees a better presence of antioxidants in milk and meat.

5. Remunerating farmers for common goods

As described above, the main values added by regenerative agriculture for society that go beyond the provision of high quality food are the sequestration of carbon, the increase of soil fertility, the increase of water storage and retention capacity, the reduction of soil erosion potential and the support of (soil) biodiversity. The pending question is how to make a business case for farmers out of these additional services in order to accelerate the transition towards regenerative agriculture. Companies and private initiatives have the potential to play a key role in value creation either through providing private payments for public goods (5.1) or through providing a price premium at farm gate for regenerative products (5.2). Public payments are also playing a role, either through action-based payments or result based payments (5.3)

Figure 5. Stage one regenerative practices could increase farmers' direct profits by up to 20%



Sources: SEGES; Statistics Denmark; expert interviews; BCG analysis.

Note: Excluding subsidiaries & only considering yield revenue + direct costs (for example, seeds, labor, machine, etc.)

5.1. Value creation for regenerative agriculture via private payments of public goods – the example of the carbon market

Markets for the products/services connected with regenerative agricultural practices as well as improvement of soil health and productivity in agricultural soils need to be developed in order to push the transition. Markets for carbon credits are being developed as illustrated by subsequent examples.

2 Including minimally disruptive subsoiling
3 Test for mapping microorganisms
4 Based on Danish cropland distribution between the crops

5.2. Value creation by decreasing greenhouse gas emissions (GHG)

Regenerative farming models use less synthetic fertilisers which have a high greenhouse gas impact. This form of agriculture is also more fuel-efficient (see previous section). These emission reductions are accounted for in the GHG emissions of farms that commit to such transition schemes. The calculation of GHG emissions is important for the agri-food industry. These sectors need to reduce their carbon footprint as well as the carbon footprint of their value chain due to legal requirements on GHG reporting (Scope 3 in GHG protocol emissions from suppliers of suppliers). Agri-food chains are sometimes willing to pay for emissions measurement, as well as setting up chain premiums on low-emission products. The goal for all companies is to achieve carbon neutrality.

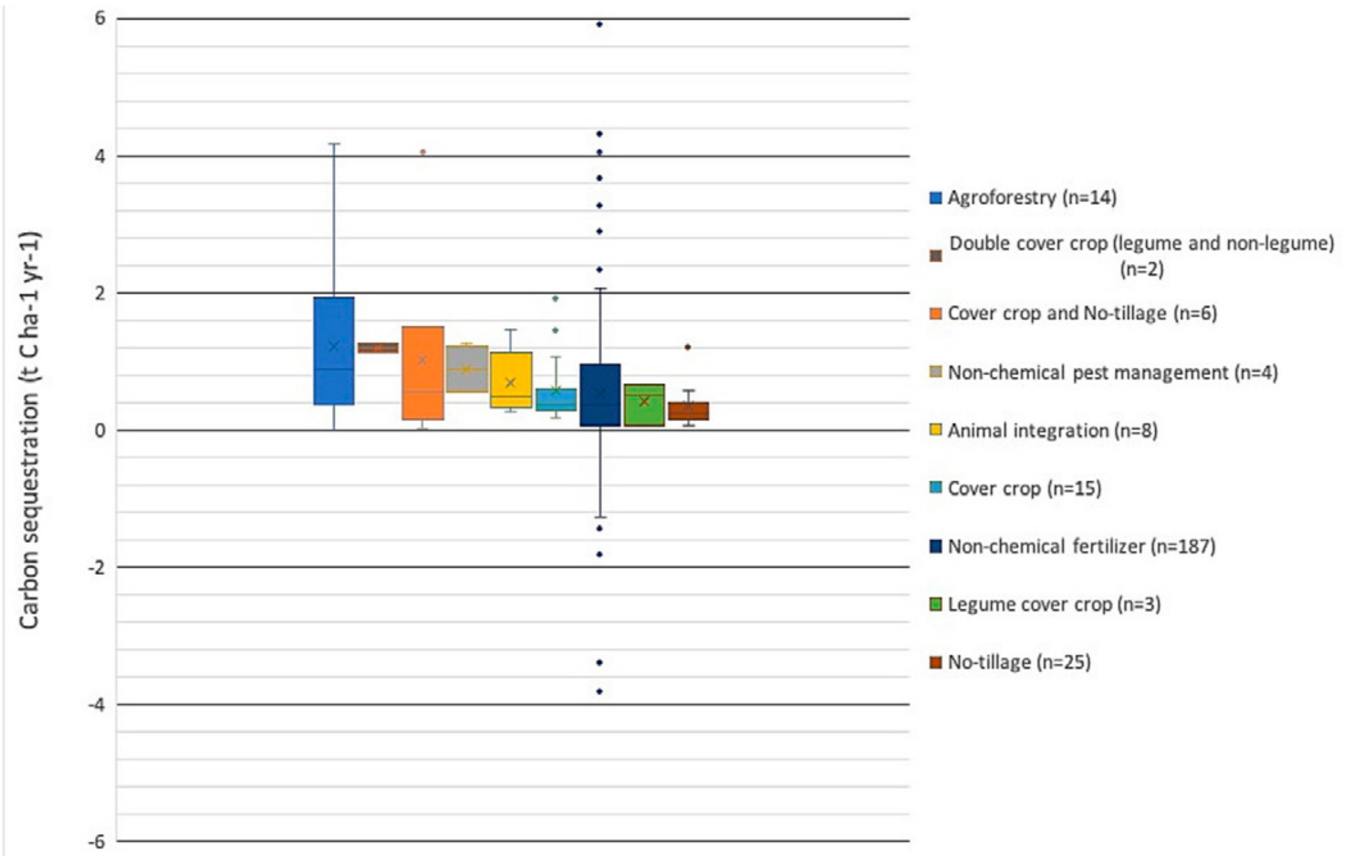
In Austria for example the dairy company 'Berglandmilch' recently launched a programme where it helps its farmers who sell their milk to Berglandmilch in generating additional income via selling of certificates (based on Verified Carbon Standard (VCS)) which they can generate when the demonstrably reduce the GHG emission of their farm (e.g. methane reduction due to specific feed additives). Similar programmes or projects could be taken into consideration, developed and implemented for regenerative agricultural practices.

The counting of carbon stored through measurement must be separated from the evaluation of GHG emissions. Separating the reduction in emissions and sequestration in a carbon credit makes it possible to enter into the notion of credits of different values. The food sector can encourage the reduction of emissions through sector premiums and the farmer can sell the sequestration carbon credit in addition. This also makes it possible to segment the source of value for the farmer. No private or public actor can provide the level of value necessary to finance the transition alone.

5.3. Value creation via Carbon Sequestration in soil

Figure 6. Below-ground C sequestration rates for regenerative practices on arable land

Boxplots represent the 25th–75th percentile of data, the 'x' represents the mean, and horizontal lines represent the median. Each dot represents averages calculated in one independent study, with the total number of studies for each practice shown in the legend. Positive values represent a below-ground carbon sink, while negative values represent C emissions.



Source: Villat J. and Nicholas K.A. (2024) Quantifying soil carbon sequestration from regenerative agricultural practices in crops and vineyards. *Front. Sustain. Food Syst.* 7:1234108. doi: 10.3389/fsufs.2023.1234108

The carbon sequestered in the ground belongs to the farmer, who can choose his/her customer (price market)

Regenerative agriculture produces more humification than mineralization. Therefore the amount of organic carbon in the soil increases overtime. Carbon stored in soils could be bought by companies to compensate for scope 3 reporting requirements or sold as an environmental contribution for corporate offsetting. For example, Microsoft buys 'soils based' projects with proven methodologies.

In mechanisms for transferring value or creating new sources of value, measurement is a key element. The market needs proof. The more vague the evidence, the greater the risk of greenwashing. The more verifiable and transparent the proof of environmental benefit, the more legitimate the justification for value transfer and remuneration.

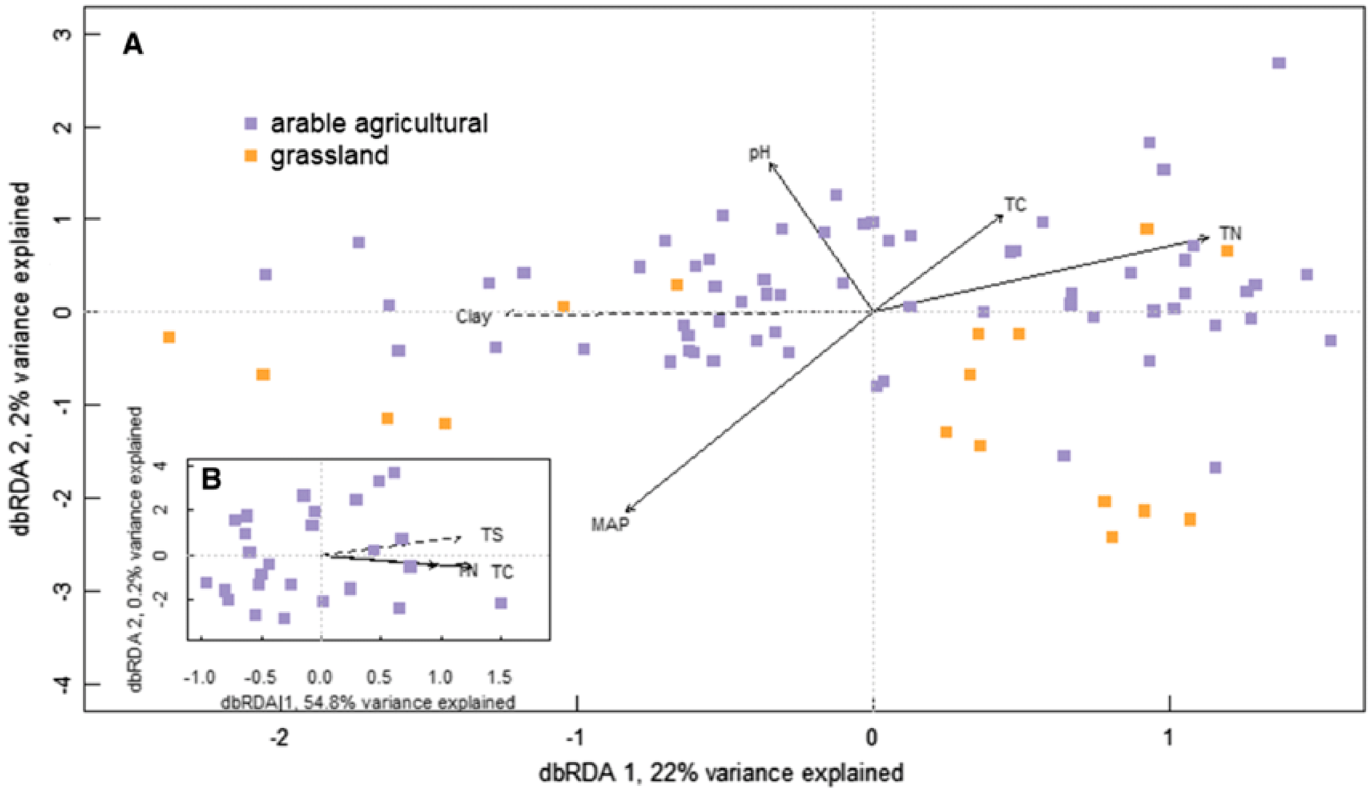
5.3.1. Importance of measuring and not modelling for proof of impact

For a carbon credit buyer, several elements are important. The robustness of the MRV (measurement, reporting, verification) is important but also for the overall credibility of agricultural carbon credits. This market must progress if we want it to become a tool for financing the transition. Proof of the reality of the existence of this credit, the robustness of acquisition of this evidence as well as the verification of this evidence are crucial for the transparency and credibility of this market.

Therefore the proof of the result must be based on measurement. Modelling on most aspects, such as soil organic carbon, presents high risks of approximation and error. Humification and mineralization mechanisms depend on biological parameters and physico-chemical balances that are impossible to control in detail and therefore must be considered and measured with in-situ sampling.

Figure 7. Dissimilarity ordination of microbial detritus contribution to soil Carbon in arable agricultural and grassland soils

MAP=mean annual precipitation, TN=total soil nitrogen, TC=total soil carbon, TS=total soil sulphur.



Source: Coonan, E., Kirkby, C., Kirkegaard, J., Amidy, M., Strong, C., & Richardson, A. (2020). Microorganisms and nutrient stoichiometry as mediators of soil organic matter dynamics. Nutrient Cycling in Agroecosystems, 117, Article 10076.

Therefore the carbon stored in soils must be measured, not modelled. For example, in the following study we can see variations of more than 50% on non-modeled elements. In agricultural systems, stoichiometrically balanced nutrient addition to Fresh Organic Matter can increase C transfer to Soil Organic Matter by 6 to 52% and importantly reduce the mineralization of pre-existing Soil Organic Matter by 24 to 50%."

This is only part of the margin of error found on the models on some elements. The risk of a greenwashing scandal for models with unproven carbon compensation can weaken the entire private agricultural environmental contribution mechanism.

On the other hand, it is also important to take into account the possibilities of the market and the transfer of value to define sampling grids compatible with the financing restitution capacities for the farmer. The entire value does not have to be spent on performing the measurement. A major part of value must go back to the farmer.

The best existing tools/systems to provide new value based on regenerative agriculture is measurement of benefits over time.

A measurement (sampling and laboratory analysis by loss on ignition, and soil density measure) on a specific GPS point gives a comparable value of this point in time.

For example, to measure organic carbon stock in soils, the FAO and the Verra Standard recommend using the ESM Method (in detail): crossing density and concentration at several depths).

Furthermore, the models do not allow for the inclusion of innovative practices and link real results to them (use of biostimulants, use of microorganisms, permaculture, relay cropping, associated crops, rotational grazing, use of humic acids or compost extracts).

5.3.2. Overview of private value creation initiatives

- Zukunft Erde: This project of the company Raiffeisen Ware Austria rewards cereal farms if they increase the soil humus content. Therefore soil samples are taken and targeted fertilisation and cultivation recommendations are derived. If the soil humus content has increased in the control periode the farmer earns money from the sale of CO2 certificates to companies that want to declare themselves to be climate neutral. By 2023 around 100 farmers took part in the programme.
- Genesis; measure biodiversity, carbon, fertility, water but does not generate carbon credits and value for farmers
- Indigo; model and measure a few samples to learn the model (but no in europe)
- Humus + Modell Ökoregion Kaindorf: Humus formation programme started in 2007 in which almost 400 farmers throughout Austria are currently taking part. Its main aim is the incorporation of CO2 into the soil. Participating farmers have to take soil samples and build up humus within a period of five to seven years and can obtain carbon certificates for trading
- ReGeneration measures the impact of agricultural practices on soil carbon, biodiversity and water resources. Generates a carbon certificate including these three parameters (Triple C) with international standards VM0042 (for carbon). They also support farmers with an individual agronomist.
- Agreena; Models the carbon, using the cool farmtool and satellite.
- Climate farmers; Models the carbon, at the same time, they have an associative network for sharing knowledge
- Klim is certifying and selling carbon credits from removals and emission reductions in the agricultural sector by modelling. They are mainly performing it within a given supply chain, hence seeking to reduce Scope 3 emissions from food companies, such as Nestlé or Lorens (in-setting). Yet (1) the positive effect on climate change of emission reduction certificates sold to compensate other emission is highly questionable, (2) the way the emission reductions as well as the carbon storage is calculated is still far from the field reality
- SoilCapital, models the carbon footprint of farms using the cool farmtool and DNDC models. They thus sell the reduction in the footprint of products for the agri-food sectors

5.3.3. Other groups in area of regenerative agriculture

- ReGeNL; a 240 million EU societal programme to be launched in 2024 in NLD to set in the agricultural transition towards regenerative practices. Government, value chain actors, universities and farmer organisations are participating.
- European Alliance for Regenerative Agriculture (EARA) is a recently founded group of European farmers intent on claiming regenerative practices and adding value to the definition and practice.
- CREA Road4Schemes A combined database for more than 160 schemes in the EU, with a business model for carbon storage within forestry and agriculture.
- SAI A platform for over 170 major companies and organisations within agriculture and food.
- OBC is an organisation which attempts to build a biodiversity certificate and biodiversity credits for ecosystems including agriculture

5.3.4. Value creation via supply-chain integrated approaches

Another promising approach for value creation would be the development of premium price concepts as regenerative agriculture has a great story to tell – products based on these practices help to fight climate change, make the agricultural system more resilient, improve soil fertility and biodiversity and contain more trace elements, vitamins and antioxidants (see previous sections). Companies like Nestle, Bel, Mars, Mac Donald or Rabobank and FrieslandCampina for example are committed to supporting the transformation of their supply chain.

An inspiring best practice example on how to achieve value creation for an agricultural practice different to conventional farming is the hay milk production in the alpine region, mainly in Austria. Farmers renounce to produce and feed silage to their cows and therefore receive a higher price for their milk. The association ARGE Heumilch started to collaborate with retailers very early and the retailers on the other hand used the environmentally friendly and romantic way of hay production (cows on pastures, flowers in the hay, herbaceous smell of hay instead of sour smell of silage, etc.) as marketing asset. Therefore, while less than 3% of the milk produced in the EU fulfils the criteria of hay milk, hay milk accounts for more than 15% of milk delivery in Austria. A similar approach could also be implemented for regenerative agriculture in order to accelerate the uptake of regenerative agricultural practices due to a price premium provided by the market as regenerative agriculture also comes along with topics ideal for marketing (soil fertility, flouring cover crops, earthworms, etc.).

The agri-food group will be able to sell a more virtuous product (for which proof of virtue is the measure of results) at a higher price. The cost will be borne by the consumer. We must be vigilant to ensure that the farmers sell their product more expensively (industry premium). Regenerative agriculture must not become a market standard without providing value to the farmer.

5.4. Value creation via public payments

5.4.1. Action based payments

All EU Member States incentivize regenerative agricultural practices (like erosion protection, cover crops, minimum tillage, and grassland ploughing prohibition) via action-based payments under the CAP. For the 2023-2027 period, the main interventions are eco-schemes (Article 31 of Regulation (EU) 2021/2115) and agri-environmental and climate commitments (Article 70 of the same regulation).

5.4.2. Results based payments

This CAP support approach pays farmers for achieving specific results rather than following prescribed practices. This method allows farmers to use their expertise to meet agreed targets. The website of the EU CAP Network provides some good examples, though it does not cover all CAP 2023-2027 measures. Most current results-based payments in the EU focus on biodiversity. However, due to legal requirements (Article 70(4) of Regulation (EU) 2021/2115), these payments are still based on compensating additional costs and income foregone, most likely associated to the achievement of the results not the value of the service provided to other sectors or society.

6. Conclusions

The existing data and evidence shows largely the advantages of regenerative agriculture for the environment as well as for society and farmers themselves but in some cases they could arise only after a transition period with increased investments and management costs as well as decreased yields, especially within the first years.

The agronomic and economic benefits that could prompt farmers to make the transition are tangible. But the pending question is how to generate a visible income flow and agronomic support to farmers that implement regenerative agricultural practices. On the other hand, many farmers do not want to change their practices as regenerative agriculture comes along with additional dependencies on natural processes. Risk aversion is increasingly important for European farmers. Overall indebtedness and costs are on the rise, as is climate risk.

Therefore agronomic support and economic incentives will be key to successfully transforming farms from a conventional system to regenerative agriculture. This agronomic support responds to two obstacles. The first is that farmers are not alone in the face of local societal pressure. They share these doubts and obstacles. The second is that they acquire agronomic knowledge. They are making progress on technical itineraries adapted to these new schemes.

On the economic side, regenerative agriculture needs to prove its virtue. Socially, it must become a response to the challenges of the future. Measuring the benefits of regenerative agriculture is the basis for the possibility of comparison of regenerative agriculture with other farming practices as well as remuneration of its implementation. Farmers in these new schemes can therefore boast of the environmental benefits achieved thanks to measurement. The implementation of value transfers linked to the environmental benefits detailed above would To make this new form of agriculture more competitive, the value resulting of the environmental benefits (described in previous sections) should be transferred across the food chain towards the farmers level

Measurements are more credible and robust than modelling for environmental results. The combination of the measurements and modelling could reduce costs of acquisition of data on regenerative agriculture. The goal is to finance farmer transition and not just the measurements and certification. The credibility of programs depends on the real environmental value created by and the level of financial support associated with the implementation of regenerative agricultural practices. All this with the aim of avoiding greenwashing scandals which penalise the whole situation like what has already happened in the renaturation of tropical ecosystems.

7. Research needs

7.1. General issues

Impact of regenerative agriculture an all three pillars of sustainability

So far the research on regenerative agricultural practices is mainly focused on the ecological dimension of sustainability. More research is needed on how the transition to regenerative agriculture affects the social and economical dimension of sustainability as well as on the advantages/disadvantages/trade-offs of all three dimensions of sustainability in different types of farms (arboriculture, market gardening, field crops, livestock) at the different stages of transition within different socio-economic and biophysical contexts.

Applicable to all types of farms that apply or want to apply regenerative agricultural practices. Relevant mainly for farmers and farm advisors.

Impact of climate change on regenerative agricultural practices

The accelerating climate change will have an impact on regenerative agricultural practices. Promising approaches that have been implemented within the last years may not be fit for the near future shaped by higher temperature and weather uncertainty due to climate change (e.g. due to mild winters, longer vegetation periods, etc.). Data is needed to understand the impact of climate change on regenerative agricultural practices.

Applicable to all types of farms that apply or want to apply regenerative agricultural practices. Relevant farmers as well as farm advisors but it varies due to the variety of impacts of climate change on agricultural production.

7.2. Technical issues

Investments in regenerative agriculture – initial hurdle or overrated?

The implementation of regenerative agricultural practices comes along with a need of new machineries, tools and methods. Purchasing for example a new seeder or min-tillage machinery is a huge initial hurdle for many farmers. Research is needed on low input investments to make implementation of regenerative agriculture less cost intensive.

Applicable to all types of farms that apply or want to apply regenerative agricultural practices but e.g. dry regions will face other investment needs compared to humid regions. Relevant farmers as well as farm advisors and agricultural machinery manufacturers.

Make organic no-till systems the number one choice

Organic direct seeding comes along without the use of pesticides and synthetic fertilizers which allows the accumulation of a broad variety of environmental benefits. But so far more understanding is needed on understanding of interactions between regenerative practices and organic production systems. The aim is to combine benefits of organic farming and regenerative agriculture based on better understanding of interactions between these two agricultural practices.

Applicable to all types of farms that apply or want to apply regenerative agricultural practices in combination with organic practices. Relevant mainly for farmers and farm advisors.

Long term comparability of soil samples

Across the EU and even within Member States different methods are used for soil sampling. In order to increase the knowledge on the soil quality and soil dynamics the quality and comparability (between regions but also between years) need to be increased, especially if long term comparisons are pursued.

Applicable to all of the EU agricultural area and very high relevance to RA but also to other agricultural systems or compensation programs that make use of soil sampling.

7.2.1. Ecological performance

Impact of regenerative agriculture on the environment

There is a significant need for better and consolidated access public data on the environmental benefits of regenerative agricultural practices (humus, water, air and biodiversity) based on measurement in different agricultural regions and farm types. This information is highly necessary for communicating the value added towards consumers/society, demanding higher product prices from downstream supply chain partners and monetizing the environmental services provided by implementing regenerative agricultural practices.

Impact of regenerative agriculture on the water cycle

There is still research needed in order to identify the impact of and interactions between regenerative agricultural practices and the water cycle. More knowledge is needed on the infiltrability of water in soils, link between vegetation and groundwater, the levels of evapotranspiration of different crops as well as the impact of regenerative agricultural practices on infiltration, retention and water availability.

Applicable to all types of farms that apply or want to apply regenerative agricultural practices. Relevant especially for arable farmers in dry regions with reduced (ground) water availability as well as farm advisors.

Safeguard soil fertility in times of accelerating climate change

The climate has a crucial influence on soil fertility. As human-induced climate change is accelerating knowledge is necessary on how it affects soil fertility of agricultural land (e.g. due to heavy rainfalls, drought, etc.). It is not enough to increase soil fertility in the short term but to keep it high in the long term although external factors like climate are changing. Knowledge is needed on how to achieve this state.

Applicable to all of the EU agricultural area and very high relevance to RA but also to other agricultural systems that rely on soil fertility.

Maintenance of already high humus content in soils

In several agricultural areas of the EU (especially in areas with a long tradition of organic farming or reduced tillage and catch crops) a high/optimal humus content has already been reached. What needs to be considered in the management of those agricultural areas in order to maintain the high humus content, which management practices fit the most? How can maintenance of high humus content be incentivized?

Applicable in regions with high humus content, e.g. regions with long tradition of organic farming. Relevant mainly for arable farmers.

7.2.2. Economic performance

Data on farm performance as leverage for success

In order to accelerate the implementation of regenerative agriculture technical and economic data of farms and its in-depth analysis are needed (risk aversion, debt dependence, willingness to invest in regenerative agriculture, etc.). Such data will also make it possible to precise potential gains and losses linked to the transition as well as reductions and increases in costs, productivity and investments.

Applicable to all types of farms that apply or want to apply regenerative agricultural practices. Relevant farmers as well as farm advisors.

Generate value added for regenerative agricultural practices from supply chain

Regenerative agriculture has a great marketing potential for downstream supply chain partners which so far is widely unused. In order to accelerate the uptake and implementation of regenerative agriculture in the EU concepts are necessary on how to increase revenue for farmers applying regenerative agricultural practices and communicate the benefits of those practices towards consumers.

Applicable to all of the EU agricultural area where RA practices are implemented. Relevant for farmers as well as downstream supply chain businesses like mills, bakeries, retailer, etc..

Regenerative practices impact on productivity

There is still not enough information available if and how and under which conditions regenerative agricultural practices reduce or increase productivity as well as yield per hectare compared to conventional farming practices. How could lower yield/productivity be reduced and how could higher yield/productivity be increased.

Applicable to all of the EU agricultural area and relevant for all approaches of RA in the different regions of the EU.

Cost and time efficient practices for mechanical removal of catch crops

By now the most ‘efficient' practice for the removal of catch crops and its residues is the use of chemical herbicides (e.g. glyphosate) which come along with a lot of disadvantages for the environment like harm to non target species. In order to make regenerative agriculture more sustainable alternative practices for removal of catch crops need to be developed that aren't harmful for environment but also economically attractive.

Applicable to all of the EU agricultural area and very high relevance to RA but also to other agricultural systems that contain catch crops as well as companies that produce organic plant protection products or machineries for mechanical removal.

8. Ideas for further actions / innovative projects

- New technical itineraries
  - Climate change necessitates adapting farming techniques and increasing risk management.
  - Farmers learn new methods: few tillage/no-tillage, plant cover, biostimulants, biomass production, agroforestry.
  - Knowledge sharing between farmers and training of farmers through agronomic support and territorial groups are crucial for transitioning.
- Public data on environmental performance evolution
  - Private companies' measurements form the basis for value transfers, potentially centralized by the European Commission.
  - The Agri-food data portal of EC could offer anonymized data access, especially on agro-ecological practices and precise environmental analyses of CAP implementation.
  - Mapping European soils with this data helps link practices to environmental outcomes, enhancing local societal pressure for sustainable practices.
- Soil Organic Content (SOC) measurement
  - SOC measurement helps characterize European soils, tracking carbon content and its evolution.
  - Data on water infiltrability, consumption, and biodiversity performance aids in comparing trends over time.
  - Reliable measurements inform strategic agricultural policy, potentially funded by the European Commission.
- Satellite data integration
  - Plot-level data (water, carbon, biodiversity, cover crops) combined with satellite images (albedo, NDVI) reveal agrosystems' radiative effects.
  - This comprehensive data could refine indicators for measuring agriculture's climatic impact, beyond CO_2, CH_4, and N_2O.
  - Different agrosystems' seasonal impacts on radiative effects of water vapor can be considered.
- Marketing strategies for regenerative agriculture
  - Regenerative agriculture offers marketing potential with increased soil biodiversity and sustainable practices.
  - Collaboration among farmers, processing companies, and retailers can create premium markets for regenerative products.
  - Projects need to highlight visible regenerative agriculture's benefits like increased earthworms, flowering cover crops, and rich humus soil.
- Potential EIP-AGRI Operational Groups
  - Pilot projects with 3-5 transformed farms measure social, environmental, and economic impacts in a territory.
  - Combining agronomic approaches, environmental/energy externalities, and innovative legal structures to test the feasibility of regenerative models.
  - Funding pilots should involve various stakeholders for environmental benefits, such as biodiversity, water resources, and carbon sequestration.
- Comparison of environmental results from different models
  - Comparing regenerative, organic, and conventional agriculture in similar contexts can reveal the real value of each model.
  - Measuring environmental, social, and economic results in territories helps approximate the effectiveness of different agricultural systems.
  - Insights from these comparisons can guide better agricultural practices and policy decisions.

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Mini Paper 5: Systemic integration of regenerative practices

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Disclaimer

This Mini Paper has been developed within the frame of the EU CAP Network Focus Group 'Regenerative agriculture for soil health' with the purpose of providing input to the Focus Group discussions and final report.

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1. Introduction

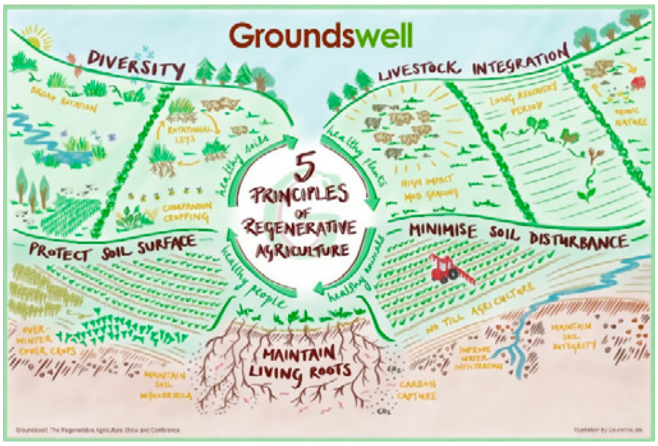
Regenerative Agriculture (RA) is an agricultural system that is postulated as a sustainable solution to the current problems and challenges in agricultural production. A variety of definitions are used to define regenerative agriculture, leading to confusion among farmers, policymakers, agribusinesses, consumers, and society. To avoid this confusion, this paper adopts the following definition: Regenerative Agriculture is an outcomes- and principles-based approach to agriculture that focuses on restoring and enhancing soil health. It promotes the implementation of a system of practices adapted to the local context. By restoring soil health, regenerative agriculture also aims to:

1. reverse biodiversity losses.
2. restore well-functioning water cycles.
3. adapt to and mitigate climate change.
4. increase economic profitability.

Five principles are considered as fundamental to regenerative farming practices:

- Minimize soil disturbance.
- Maintain soil covered with living plants.
- Maintaining living roots.
- Foster plant diversity.
- Integrate livestock.

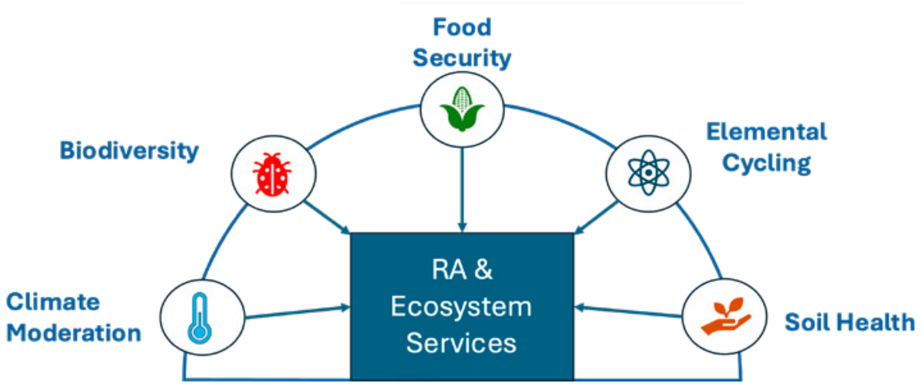
Figure 1. Principles of Regenerative Agriculture



Source: https://groundswellag.com/wp-content/uploads/2021/02/Groundswell-5-Principles-e1614009904156.jpg

Thus, the adoption of regenerative agriculture principles promotes sustainable production systems and the conservation and enhancement of soil biodiversity and its ecosystem services (Lal, 2013; Jayaraman et al., 2021).

Figure 2. Regenerative Agriculture and Ecosystem Services.



Source: Adapted from Jayaraman et al. (2021)

The adoption of = regenerative agriculture principles must be accompanied by a series of practices that optimize of production inputs. Sustainable production systems are dynamic systems that offer different combinations or practices that need to be prioritised according to specific conditions and possible local production constraints (Kassam et al., 2009).

Regenerative agriculture can play an enormous role, not only in regenerating soil, but also in regenerating biodiversity, landscape functions, water bodies, air, economy and society. At the same time, different methods will influence each other, and it does need a systemic approach from farmers, advisors and scientists to fully realise the potential of regenerative farming in practice. It is then necessary to provide tools capable of supporting the implementation of this agroecosystem approach.

This mini paper illustrates how the combination of different sustainable practices can be integrated in the European agriculture to provide the outcomes targeted by regenerative agriculture. It also aims to provide tools demonstrating how combining different agricultural practices based on the aforementioned principles is necessary to achieve the full potential of a regenerative farming system.

2. Regenerative agriculture practices

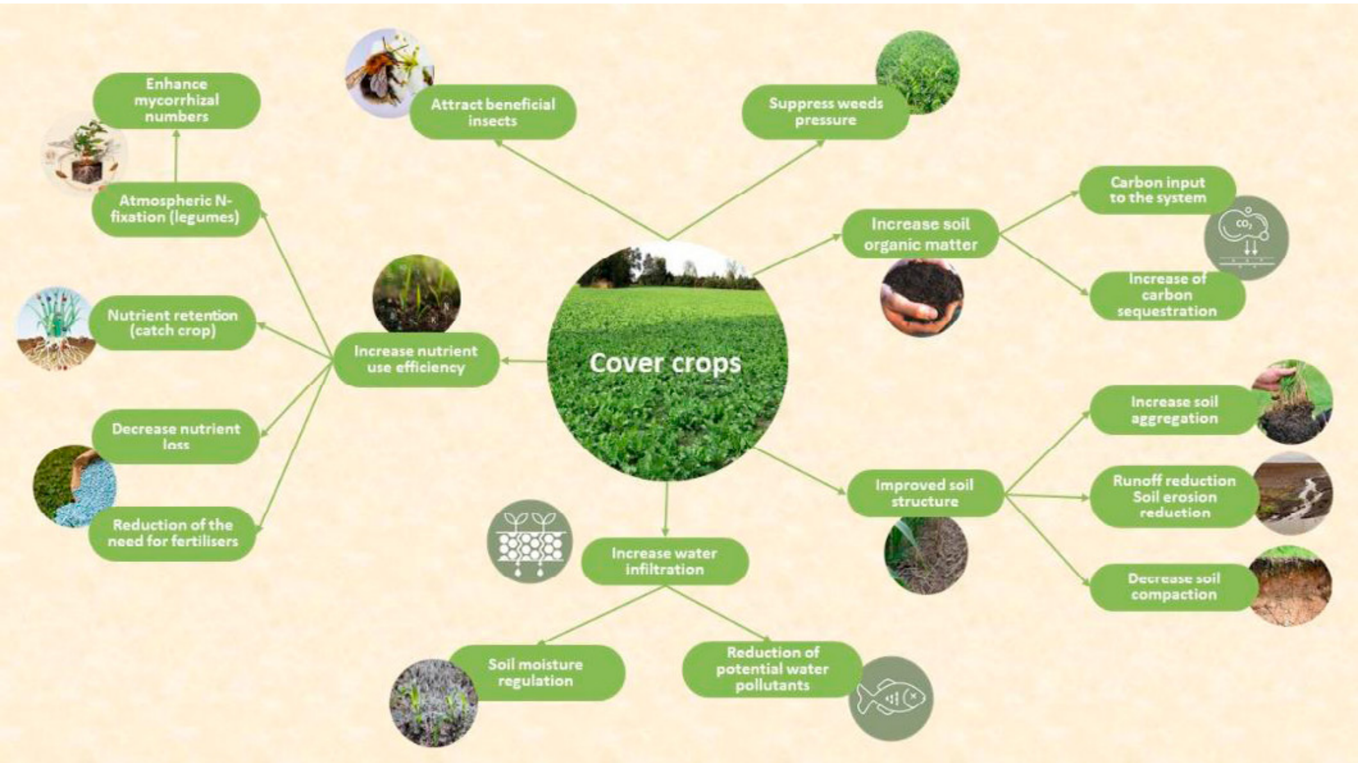
2.1. Cover crops

Cover crops play a fundamental role in the integration of regenerative agriculture, as they can be introduced in almost any combination of practices to achieve the integration of regenerative agriculture principles. This document gives particular attention to cover crops, highlighting their high potential for adoption and integration in transforming conventional farms into regenerative ones.

Cover crops are service crops grown temporarily between main crop cycles as an alternative to fallow. They are mainly introduced in farms to provide soil protection and soil improvement between periods of normal crop production and can also serve as animal feed. Depending on the main objective, cover crops are also called 'catch crops' when they are used to retain nutrients, or 'green manures' when they include legumes and act as a source of nutrients. The introduction of cover crops is recommended when there is a sufficiently long period between main crops, and this period can vary depending on climatic conditions and cover crop species used.

The implementation of cover crops is a perfect example of highlighting the variety of effects a single practice can have. When cover crops are implemented as a mixture of different species, the soil can benefit at varying depths from their root effects. Some species can introduce new nutrients into the soil system (e.g. legumes fixing nitrogen), others help retain nutrients which would otherwise leach into groundwater (e.g. nitrates) or mobilize nutrients, which otherwise be less available to plants (e.g. phosphorus). These beneficial effects reduce the need for applying mineral fertilizers. Cover crop roots release root exudates and therefore not only feed soil microbes, but also capture carbon at different depths along the soil profile and enhance soil structure and aggregate stability. This can have a positive effect on soil water infiltration and therefore is an optimal management strategy to increase agricultural soil resilience to climate change. The implementation of cover crops also serves to protect soil from wind and water erosion, thus preventing environmental pollution from soil contamination that could lead to dead zones in rivers and oceans. Another benefit is the support of beneficial insects, pollinators and wildlife in general. Cover crops with a high ground cover's rate will also contribute to weed suppression, reducing the need for herbicide applications.

Figure 3. Benefits of introducing cover crops



Source: Adapted from Magdoff and VanEs, 2021

2.1.1. Systemic integration of cover crops

Cover crops, as seen in point 2.1, play an essential role and contribute to soil health, and therefore certain aspects need to be considered when implementing this practice alone or in combination with other regenerative agricultural practices.

a) Cover crops establishment

The establishment of cover crops can be achieved at different times during the year; at the same time as the main crop, during the main crop's growing season, after harvest or as a permanent cover. The most common practice is to seed just after harvest. This can be done with a Direct Drill or by broadcasting the seed on the surface and mixing it within the soil using a cultivator. The challenge with these practices is timing, since harvest can be late, and the cover crops must be established in time to perform properly.

b) Cover crops termination

The main challenge is terminating them at the right time to ensure that nutrients are available at the time when the following main crop can utilize them. If termination is too early, there is a risk that some nutrients (nitrogen and potassium) will leach out, while if termination is too late, a cover crop with a high C/N ratio can capture the applied nitrogen, leading the main crop to suffer from nutrient deficiency.

There are three main methods of killing cover crops: natural (winter kill species), chemical and mechanical. Cover crops can also be grazed or harvested as silage. Therefore, the decision on the method of termination of cover crops should be part of the farm's management strategy.

Direct seeding of soy in cover crop

Source: Johanes Zauner

c) Climate adaptations

In northern region of the Europe, climate significantly influences the selection of suitable cover crops. On many occasions, the use of cover crops is mandatory, primarily to retain nutrients and prevent contamination of water bodies. In this sense, the choice of species can be dictated by the country's authorities, and usually, Brassicas are chosen due to their ability to retain nitrogen. The decomposition of cover crops can release significant amounts of nitrous gases under certain conditions. Therefore, the timing and methods of cover crop termination are often complex to manage due to the many factors that need to be considered.

One of the challenges in arid and semi-arid areas is the correct selection and management of cover crops. Questions such as which species or varieties are best for cover crops, whether they can withstand high temperatures, or whether they will reduce the amount of available water for the main crop emerge. Unfortunately, not all the solutions proposed for mesic regions are suitable for dry and warm regions. Rainfall patterns and variations in those patterns can determine whether or not a cover crop will succeed. In some cases, predicted rainfall may not occur in time after planting, resulting in uneven germination of the cover crop.

One way to address this is by using mixtures of cover crops with varying moisture requirements. By mixing seeds, you can ensure that while some cover crops require more moisture for germination and early growth stages, others can thrive with less, creating a balanced and resilient cover crop system. Later in their growth stage, cover crops can conserve soil moisture by shading, acting as a living mulch (Salako and Tian, 2003).

2.2. Minimise soil disturbance

2.2.1. No-till

No-till refers to sowing crops directly into a field that has not been tilled since the previous crop. The term no-till is used interchangeably with the terms zero-till and direct seeding. Soil-disturbing activities are limited only to those necessary to plant seeds, place nutrients and condition previous crop residues.

No-till in sunflowers.

Source: ECAF

2.2.2. Strip-till

Strip-till is a practice that minimizes tillage. Strip-till consists of tilling the soil at a 15-20cm depth in strips covering less than 30% of the field surface. This practice describes a system of establishing a crop that minimises the amount of soil disturbance and maximises efforts to retain the integrity of crop residues on the soil surface.

Strip-till.

Source: Julio Román, ECAF

2.2.3. Minimum tillage

Minimum tillage is a practice that promotes a minimum soil disturbance for a successful crop production. It includes a variety of practices without plowing (Labreuche et al., 2014). Shallow tillage consists of tilling to a maximum depth of 10 cm, while ultra-shallow tillage concentrates on the first 2-3cm.

Minimum tillage

Source: Julio Roman, ECAF

2.3. Groundcover in perennial crops

Introducing groundcovers in perennial crops is a prime example of regenerative agriculture for tree crops. This practice consists of maintaining a living or residue cover in the area between the crop lines, and it could be considered a type of 'intercropping' (Morugan-Coronado et al., 2020). This promotes the principle of permanent soil cover and crop diversification. The living vegetation cover can be sown or consist of native vegetation. Similarly, inert material such as shredded pruning residues or mulched tree leaves can be used.

The key management issue of using covers is avoiding competition for water or nutrients with the main crop. This control must be carried out at the appropriate time, taking into account the most sensitive stages and periods of the main crop, such as flowering, since a reduction in available water and nutrients generally leads to a reduction in production.

Different types of control are possible for cover crops:

- Mechanical control: using brush cutters, which can have a horizontal axis (hammers) or a vertical axis (chains).
- Chemical control: use of herbicides as part of integrated management.
- Grazing.

Groundcover in olive grove

Source: Julio Román, ECAF

Control by ploughing is not allowed in Regenerative Agriculture, as it would violate the principle of minimum soil disturbance and the principle of permanent cover by not keeping the soil covered throughout the year.

2.4. Combination of Practices

A major challenge in integrating a regenerative agriculture system on the farm is combining various practices. Developing strategies to combine these practices is therefore key to the successful integration of regenerative agriculture in Europe.

2.4.1. Combination of living mulch, no-till crops and crop rotation

Semi-permanent cover of white clover under winter wheat sown with the preceding winter oil rapeseed

Source: Gabriele Fortino

Living mulch is essentially a semi-permanent companion crop. It can be sown before, during or after a main crop and generally lasts from 18 to 36 months. During this period several crops are sown with no-till techniques. This combination of practices mimics a grassland, because after the main crop harvest the living mulch restarts and covers the soil, even during dry periods.

Living mulch species are often perennial legumes that add nitrogen to the system, improve soil structure, produce protein fodder, compete with weeds and ensure a rapid start at the beginning of the intercropping period. Main selection criteria are the ability of living mulch species] to reduce competition for nutrients and water with the main crop and even tolerate certain herbicides. They must also be able to grow strongly during intercropping periods. The main species used are white clover, red clover, alfalfa and birdsfoot trefoil.

Mastery of the living mulch is crucial, because, if not controlled it can penalize the main crop by competing with it for water, light and fertilising elements in the soil.

Table 2. Recap for combination of living mulch, no-till crops and crop rotation

Practices combined	Applicable to	Adaptations	Benefits
› **No-Till** › **Living Mulch** › **Crop Rotation**	This combination is more adapted to winter crops, due to the competition between the living mulch and the main crop.	Living mulch species should be chosen according to the soil type (pH, texture.)	› Improve soil structure. › Reduce run-off and erosion. › Control weeds and pests. › Increase soil biodiversity. › Increase soil organic carbon content.

Source: European Commission

2.4.2. Crop rotation with temporary grasslands, crop association and no-till/reduced tillage

Temporary grasslands integrated into a succession of annual crops is of major interest for soil quality, since 3-to-5-year period, the soil is permanently covered by vegetation that stimulates soil biological activity, transforms CO_2 into soil organic matter, stores nutrients, prevents erosion, and it is not exposed to pesticide use or tillage. To make these benefits long-lasting, it is important that no-till or reduced tillage practices are implemented at the crop rotation scale. Grasses can be **associated** to annual species (oat, faba bean) in order to ensure a good soil colonization. During grassland cultivation, **soil compaction prevention** (while harvesting or applying slurry) is also important for being able to sow the following crop without any tillage. For this, a chemical or mechanical mulch should be done well before the sowing, to avoid the grass regrowing within the main crop. Adapted cultivars and sowing date, localized fertilization and pest monitoring are also crucial.

No-till maize following temporary grassland

Source: Gabriele Fortino

Table 3. Recap for combination of temporary grasslands, crop association and no-till/reduced tillage

Practices combined	Applicable to	Adaptations	Benefits
› **Crop rotation with temporary grassland.** › **Crop association.** › **No/ Reduced Tillage.**	Ruminant livestock cropping systems or arable cropping systems that can interact with ruminants. EU scale.	Possible in organic farming with mechanical mulching of the grassland during dry periods.	› Improve soil structure. › Reduce run-off and erosion. › Control weeds and pests. › Increase soil biodiversity. › Increase soil organic carbon content.

Source: European Commission

2.4.3. Organic no-till field crop production

Organic no-till field crop production integrates several regenerative agriculture practices to enhance soil health and agricultural productivity. This approach involves the use of cover crops during the off-season, followed by mechanical cover crop termination and direct no-till sowing of the main crop. In organic crop production, the additional practice of crop rotation is also implemented.

This combination of practices utilizes four of the five regenerative agriculture principles: minimum soil disturbance, continuous soil coverage with living plants and maintenance of living roots and increased plant diversity. By adopting the combination of these practices, farmers can enhance soil ecosystems, improve water infiltration, promote nutrient cycling and biodiversity, resulting in more resilient and sustainable agricultural systems.

Mechanical termination of a triticale cover crop with a roller-crimper

Source: C. Vasilikiotis-Perrotis College, 2023

Table 4. Recap for combination of organic farming, no-till, field crop production (European Commission)

Practices combined	Applicable to	Adaptations	Benefits
› **Cover Crops** › **Mechanical cover crop termination** › **No till**	Field crops such as corn, soybean, cotton in Mediterranean farming systems	In the Mediterranean climatic zones, the cover crops need to be seeded early to take advantage of fall rains. For no-till seeding, crops will need to be irrigated with drip lines or with overhead micro-sprinklers.	› Improve soil structure. › Reduce run-off and erosion. › Control weeds and pests. › Increase soil biodiversity. › Increase soil organic carbon content. › Avoid the use of chemical pesticides and fertilisers

2.4.4. Reduced tillage frequency plus green manure in rainfed organic almond fields under semiarid conditions

This combination of agricultural practice consists of green manure combined with tillage frequency reduction (twice per year; 0-20 cm depth) compared to conventional tillage (four-five times per year; 0-20 cm depth) in organic rainfed almond (*Prunus dulcis* Mill.) orchards under stony calcareous semiarid soils (SE Spain). The aim is to protect soil against erosion and increase its organic matter and nitrogen content in the 7-10-meter-wide strips between the almond trees by seeding different varieties of legumes (*Vicia sativa* L. or *Vicia ervillia* W.) and cereals (*Avena sativa* L. or *Hordeum vulgare*) in early fall to provide a cover crop during winter (i.e., green manure). Given the water scarcity of this region (300 mm/year), early termination of green manure is desirable to avoid competition for water with the main crop. However, since winter-early spring temperatures are also low in this region, where mean altitude ranges from 1000 to 1400 m above sea level, green manure is normally terminated in early May to ensure a certain development of these cover crops in terms of biomass (although management can be adapted to each year weather conditions), after which plant residues incorporated into the soil by chisel ploughing to 15-20 cm depth.

This practice has been proven to enhance soil organic matter content, its structure (aggregate stability) and water infiltration capacity, while reducing soil erosion. Although main crop yields penalties will probably be expected in the short-term, main crop yields can be recovered and even enhanced after a few years. Trade-offs between environmental and economic benefits must be considered both from the farmer and the policy-maker perspective. Even though lower crop yields can be expected, soils more resilient to extreme rainfall events and droughts will be build, which will result into more stable crop yields in the long-term.

Cover crop management by chisel ploughing in a rainfed almond orchard in mid-spring

Source: María Almagro

Table 5. Recap for combination of reduced tillage, green manure in organic orchards

Practices combined	Applicable to	Adaptations	Benefits
› **Groundcover** › **Reduced tillage**	Olive and almond groves, vineyards, and any woody crop under rainfed or irrigated conditions	Groundcovers must be carefully managed (i.e., appropriate termination date) to avoid competence for water and/or nutrients between the main crop and the cover crop. In case a brush-cutter is used an appropriate one must be chosen in stony soils	› Improve soil structure. › Reduce run-off and erosion. › Avoid the use of chemical pesticides and fertilisers

Source: European Commission

2.4.5. Combination of no-tillage, permanent soil cover, crop rotation and cover crops

To minimise soil disturbance from no-till and ensure crop production, it is necessary to introduce practices associated with the principle of species diversification, such as crop rotation and cover crops.

Once the rotation has been planned, it is important to create a mulch to keep the soil covered, which will take place at harvest. To ensure an even distribution of the crop residues, the harvester must be equipped with the necessary accessories for chopping and spreading the crop residues.

Crop rotation (peas after wheat) under no-till

Source: Julio Roman. ECAF

Proper seeding management is essential to start the no-till rotation. A specific seed drill must be used to introduce direct drilling to the field: Direct seeder or direct drill. The aim is to place the seed in suitable soil conditions that facilitate germination and crop establishment, and the maintain presence of straw on the soil surface. If the interval between main crops is long (more than 60 days), it is advisable to introduce a cover crop into the rotation to extend the period until the next crop is grown, to keep the roots alive in the soil and to improve soil cover. The main limiting factor for the use of cover crops is the amount of rainfall in the area where they are to be established. In areas or periods of low rainfall it may not be feasible to develop this technique. However, it has been scientifically proven that in areas with limited rainfall (<500 mm yr-1) it does not necessarily reduce the yield of the subsequent main crop. It is therefore necessary to define a strategy adapted to the conditions of each region, both in terms of the duration of the covered crops and the species to be planted to achieve the desired objectives. Moreover, among the benefits already demonstrated, in areas with low rainfall it could overcome yield reduction by improving soil quality (Blanco-Canqui et al., 2022).

The choice of when and how to kill the cover crop is probably the most critical decision when it comes to avoiding potential competition with the next main crop: if killed too early, the cover crop will quickly stop doing its job, but if killed too close to planting the main crop, water and nutrient consumption may create some unwanted competition. In the case of a summer crop (such as maize), three to four weeks before planting may be an appropriate time to kill the cover crop, but this will depend on the likely weather and the type and management of the main crop. Another issue is how to kill the cover crop – this can be done mechanically by mowing with a brush cutter or roller crimper, or chemically by mowing with pesticides. Combining no-till, permanent soil coverage, crop rotation and cover crops creates a synergistic effect that promotes soil health, reduces environmental impact, and improves overall farm sustainability.

Table 6. Recap for combination of no-tillage, permanent soil cover, crop rotation and cover crops

Practices combined	Applicable to	Adaptations	Benefits
› **No-Till** › **Permanent soil cover** › **Crop rotation/ diversification** › **Cover crops**	This combination is applicable to annual crops and in any soil and climate.	Crop rotation should be adapted to the characteristics of the region in which the crop is grown, using well-adapted and economically viable species. A good choice of direct seeding equipment, discs or coulters, is important as the success of the crop may depend on it. Cover crops should be introduced according to climatic characteristics and the viability of their development depending on water availability.	› Improve soil structure. › Reduce run-off and erosion. › Control weeds and pests. › Increase soil biodiversity. › Increase soil organic carbon content. › Reduce the use of fertilisers in the mid-term. › Reduce GHG emissions

Source: European Commission

2.5. Successful cases of Systemic Integration of regenerative practices in Europe

a) Vincent Picot Farm

France.

Source: European Commission

Vincent Picot Farm is a dairy farm with energy production (biogas and photovoltaic), with 100 ha of permanent and temporary grassland, maize; rainy oceanic climate and clay soils that dry slowly. Beginning with reduced ploughing in 2010, soil regeneration farming has been seen by Vincent as a way towards self-sufficiency and environmentally friendly farming.

Vincent Picot

Source: Gabriele Fortino

The self-sufficiency of the farm is sought through production of protein feed, so leguminous grasslands are key to the farming system. To maintain the soil benefits of the grassland, reduced tillage is practised throughout the crop rotation. The grasses are sown together with spring oats, which helps to control weeds in the early stages. After 4-5 years, the productivity of the grassland declines and maize is sown using a strip-tillage system, which allows localised application of mineral fertiliser. Maize varieties are selected for their vigour, but also for their short cycle so that an efficient cover crop can be sown after harvest. Home-grown biostimulants are being tested to boost cover crops.

Strip-tiller equipped with frontal fertilizer tank and combined to maize seeder.

Source: Gabriele Fortino

Thanks to this combination of practices, soil organic carbon has increased, and soil erosion has been prevented in an area characterised by a very long rainy season and high rainfall during summer thunderstorms, when the maize canopy is not sufficient to protect the soil. Furthermore, biogas production can be considered as 'carbon extraction', in which case the grassland and cover crops compensate.

Effect of water action on ploughed soil (on the left) and no tilled soil (on the right).

Source: Gabriele Fortino

The main difficulty is the possibility of no-tillage in the wet conditions characteristic of the area. Biogas production has implied a better fertilisation strategy but also required adjustments in terms of cover crop requirements.

'I'm trying to implement practices on my farm that will enable me to produce as much or more while using fewer inputs: manpower, chemicals, equipment or fuel.'

b) Cortijo Maestre Farm

Spain.

Source: European Commission

This farm is located in the south of Spain has a total area of 785 ha of almost entirely rainfed extensive arable crops. The typical rotation of the farm is cereal-leguminous- oleaginous.

Figure. Winter wheat in Cortijo Maestre Farm.

Source: ECAF

This farm, has been applying three principles of regenerative agriculture in the last 20 years, such as crop rotation, keeping the soil covered and not mechanically soil disturbance by tilling when the extensive dryland arable crops are planted.

Diversification of species by crop rotation.

Source: ECAF

Direct drilling in Cortijo Maestre Fard

Source: ECAF

The farm is fully monitored, and operations are carried out using GPS guidance systems, about Precision Farming. This farm employs precision farming techniques, utilizing GPS guidance systems to monitor conditions and carry out operations, reducing inputs. Adopting no-tillage in cereal crops improves the farm's sustainability and profitability. The farm also uses biostimulants to promote microbiological activity in the soil and reduce the need for fertiliser, with very satisfactory results in terms of productivity. In addition, vegetative field margins have been introduced to improve the soil to combat the severe erosion the area suffered and add value to the farm by increasing biodiversity, particularly in the quantity and variety of pollinating insects. The farm is actively involved in research projects and training activities, which means it constantly improves productivity and care for the soil and the environment.

Vegetative Field Margins.

Source: ASAJA Sevilla

Thanks to this combination of practices and techniques, soil health has improved (an increase of about 2 tonnes of SOC per year per hectare, improved soil structure, increased soil biodiversity, better use of water) and soil erosion has been virtually eliminated in an area where soil erosion by water is the major environmental problem.

c) Grand Farm

Austria.

Source: European Commission

Grand Farm is a 90-hectare organic, regenerative arable farm (ROC certified) with a market garden for vegetable production, some agroforestry and some grassland. It is located in Lower Austria, close to Vienna. As well as being a fully productive farm, GRAND FARM is also dedicated to research and demonstration.

Established 25 years ago with a focus on composting and soil health, it went organic in 2006 and adopted minimum tillage, =

Crop rotation includes alfalfa, wheat, maize, hemp, soya, rye and oats, with cover crops and organic direct seeding. In 2016, 5,000 trees and shrubs were planted for agroforestry to increase biodiversity and provide habitat for livestock and bees. The farm also has flower strips to regenerate soil and biodiversity.

Market gardening.

Source: Grand farm

GRAND GARTEN, a nursery focused on vegetable production, also uses a range of practices to restore soil health. Reduced tillage (maximum depth is 8 cm with a power harrow) without a tractor, followed by compost and vermicompost application and mulching with alfalfa produced on the farm. Cover crops are used, and Grand Garden does not use mineral fertilisers or pesticides, only crop rotation, cover crops, beneficial insects, pest collection and insect nets.

Vegetable field.

Source: Grand Garten

This combination of practices creates a healthy ecosystem, allowing 12 of the 17 Sustainable Development Goals (SDGs) (www. sdgs. un.org/goals) to be addressed. The farm has achieved silver-level Regenerative Organic Certification (ROC) (www. regenorganic.org)

3. Conclusions

Regenerating an agricultural ecosystem through suitable and locally adapted agricultural practices is a complex and evolving process that requires the application of the necessary knowledge and tools.

For a system to be considered regenerative, it must adhere to its core principles, recognizing that no single practice can address the system's full complexity. Therefore, it is essential to combine various practices.

Due to the diverse soil and climatic conditions across European regions, there is significant variability in the combinations of practices that can effectively meet farmers' objectives. This document highlights how combinations of practices such as reducing or eliminating tillage, implementing efficient crop rotations, and using cover crops to maintain a protective soil mulch, are effective in regenerating and improving soil health. However, several aspects require special attention to achieve a real integration of the system on European farms. The combination of practices needs to be adapted locally, taking into account not only the climatic and landscape characteristics but also the socio-economic factors that may influence them.

This adaptation of combinations of practices requires knowledge. Having access to successful cases of implementation of the practices adapted to the needs of each farm is useful to homogenise decision-making rules so that local adaptations do not lose sight of the system's objectives and that the adoption of the principles of regenerative agriculture remains a priority.

4. Research needs from practice

1. **Finding solutions for regenerative agriculture mechanization**

One of the main reasons why the transition to regenerative agriculture has been slow is the availability of machinery adapted to the system. There are direct seeding machines that do not disturb the soil surface, but they are not always well adapted to the crops and practices of regenerative agriculture. The high cost of purchase or low availability of machinery from service providers can also be a barrier to adoption of regenerative agriculture. Innovation in the development of more versatile and economical machinery, as well as encouraging farmer associations to share machinery, may be a solution that should be explored.

2. **Assessing the economic and social benefits of adopting regenerative agriculture practices**

One of the reasons for rural depopulation is the loss of economic capacity of farmers. Assessing the socio-economic impact of introducing large-scale and small-scale regenerative agriculture can encourage farmers to switch to this system and thus maintain rural activity.

3. **Assessing the impact of the adoption of regenerative agriculture on ecosystem services**

The impact of different combinations of regenerative farming practices on ecosystem services other than soil health needs to be addressed. Establish indicators adapted to the climatic characteristics of the area, which will facilitate farmers' decision-making and add value to the products obtained from a regenerative agricultural system.

4. **Identification and development of cover crop mixtures for arid and semiarid regions**

Introducing cover crops in areas with low water availability and the impossibility of frost termination is challenging for southern European areas. Therefore, it is necessary to develop cover crop mixtures for herbaceous crops that can be mechanically terminated and adapted to local pedoclimatic conditions (selection of species and cultivars, sowing date, and flowering stage to achieve optimal termination time). There is also a need to develop mixtures of species for use as groundcover for perennial crops well adapted to local conditions.

5. **Weed management strategies in no-till reducing or eliminating herbicide use**

Usually, no-till has used herbicides to control weeds so as not to alter the soil surface. One of the EU's objectives is to improve soil health and reduce the use of pesticides. It is therefore necessary to investigate different strategies for combining practices to reduce or eliminate the use of herbicides and the impact of different dose reductions on soil biodiversity and ecosystems, without losing sight of farm productivity and profitability.

6. **Design crop rotations for regenerative agriculture**

The effects of climate change on temperature and rainfall patterns could make traditional crop rotations difficult. Designing crop rotations that integrate cover crops with annual crops is essential for the successful introduction of regenerative agriculture. The development of crop rotation strategies adapted to the soil and climate conditions of the different European regions would facilitate the integration of regenerative agriculture in Europe.

5. Ideas for innovations

Innovations should be directed towards:

a) **Developing a decision support tool** to assess the impact on soil and other ecosystem services of adopting a single measure and the effect of combining it with other practices.

b) **Creating a cover crop database for Europe** that makes it easier for farmers to choose between the different varieties used in areas with similar soil and climate characteristics.

c) **Creation of a research and demonstrations farm network in Europe**, which allow the introduction of different combinations of regenerative agricultural practices adapted to local conditions. Likewise, these farm networks would serve to train farmers and as experimentation areas for the different EIP operational group projects.

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