EU CAP Network Focus Group

'Regenerative agriculture for soil health'

Mini Paper 5

Systemic integration of regenerative practices

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Content

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.**

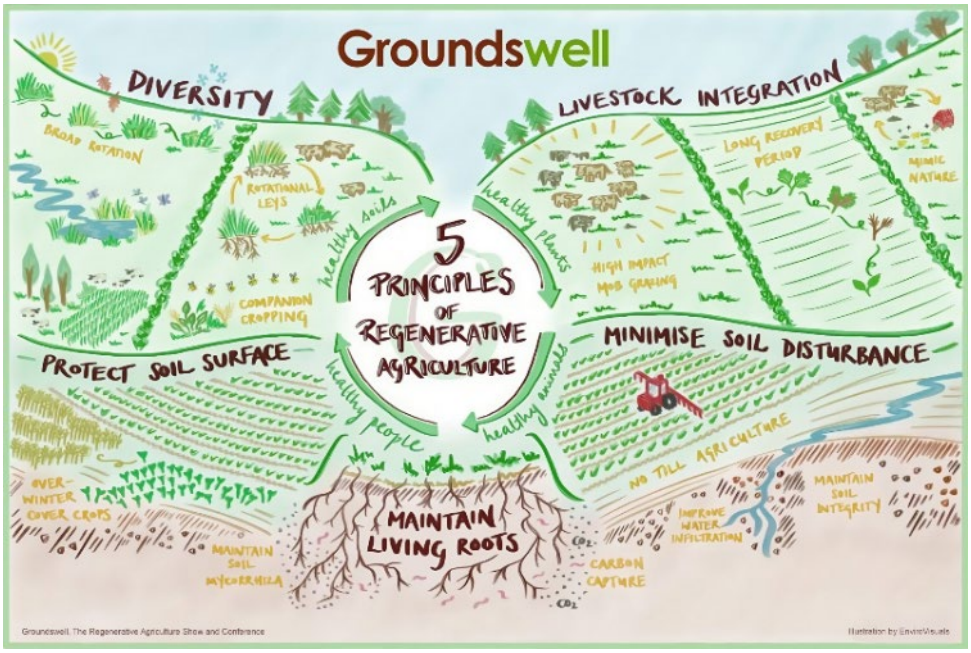

Figure. Principles of Regenerative Agriculture. Source: https://groundswellag.com/wp-content/uploads/2021/02/Groundswell-5-Principles-e1614009904156.jpg

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).

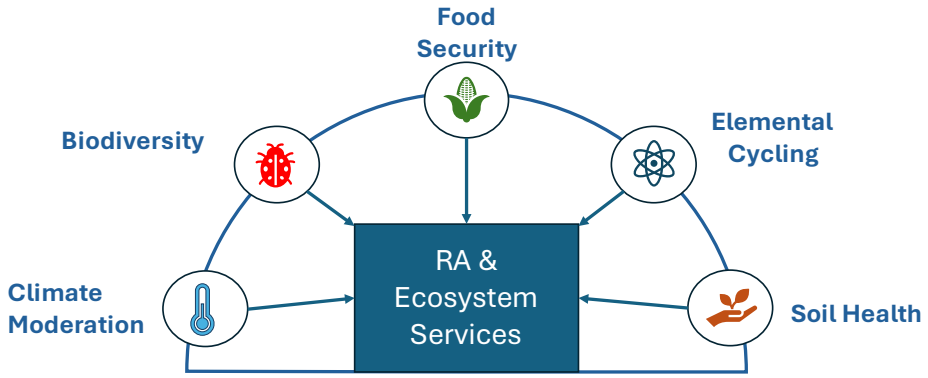

Figure. Regenerative Agriculture and Ecosystem Services. Source: Adapted from Jayaraman et al. (2021)

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.

Regenerative agriculture practices

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.

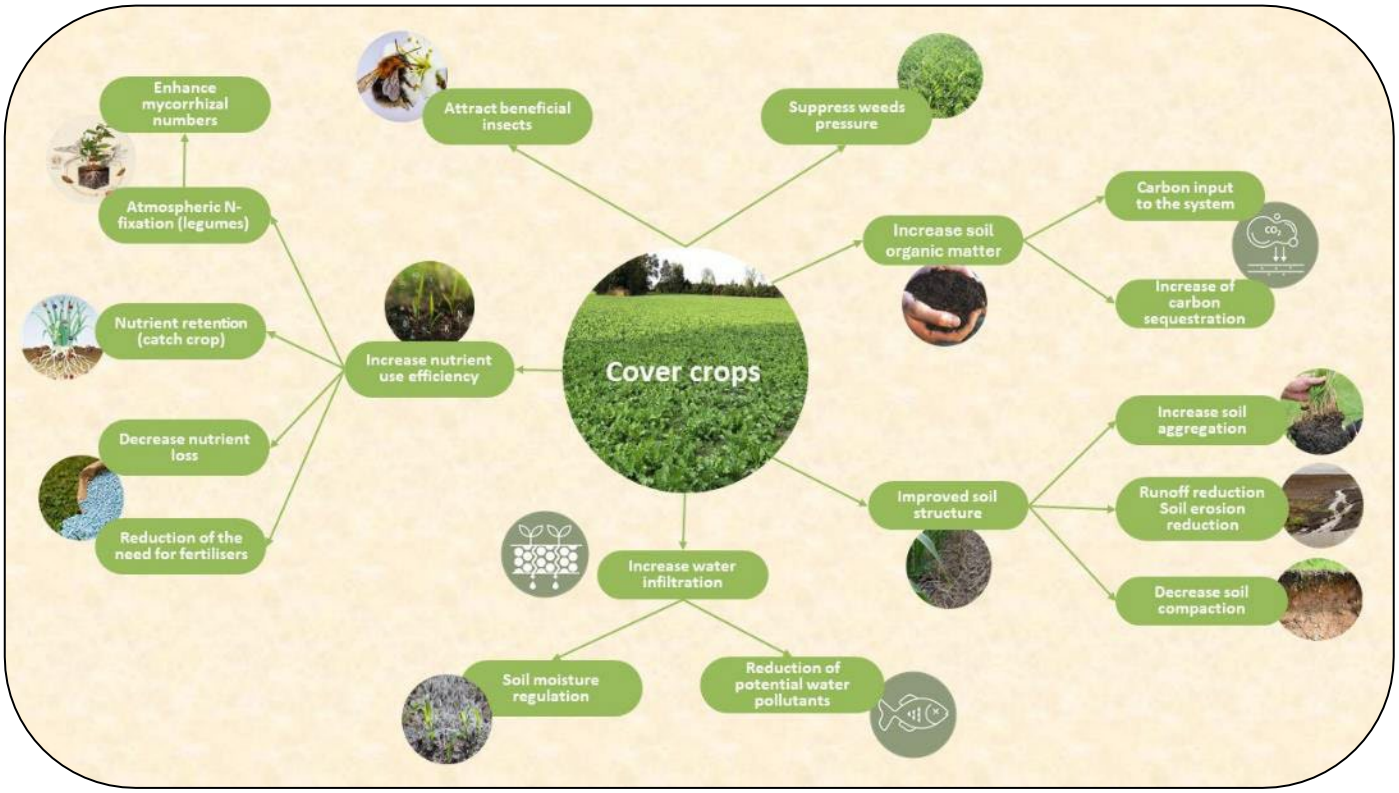

Figure. Benefits of introducing cover crops. Source: Adapted from Magdoff and VanEs, 2021

a. 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.

Figure. 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. Minimise soil disturbance

a. 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.

Figure: No-till in sunflowers. Source: ECAF

b. 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.

Figure: Strip-till. Source: Julio Román, ECAF

c. 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.

Figure: Minimum tillage. Source: Julio Roman, ECAF

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.

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.

Figure: Groundcover in olive grove. Source: Julio Román, ECAF

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.

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

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.

Figure: semi-permanent cover of white clover under winter wheat sown with the preceding winter oil rapeseed. Source**:** Gabriele Fortino

Table: Recap for combination of living mulch, no-till crops and crop rotation. Source: European Commission

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.

b. 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.

Figure: No-till maize following temporary grassland, Source**:** Gabriele Fortino

Table: Recap for combination of temporary grasslands, crop association and no-till/reduced tillage. Source: European Commission

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.

c. 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.

Figure: Mechanical termination of a triticale cover crop with a roller-crimper, Source: C. Vasilikiotis-Perrotis College, 2023

Table: 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

d. 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.

Figure: Cover crop management by chisel ploughing in a rainfed almond orchard in mid-spring. Source**:** María Almagro

Table: Recap for combination of reduced tillage, green manure in organic orchards Source: European Commission

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

e. 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.

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.

Figure: Crop rotation (peas after wheat) under no-till. Source: Julio Roman. ECAF

Table: Recap for combination of no-tillage, permanent soil cover, crop rotation and cover crops (European Commission)

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

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

a. Vincent Picot Farm

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.

France. Source:European Commission

Figure: 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.

Figure: Vincent Picot. Source: Gabriele Fortino

Figure: 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.

Figure: 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

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.

Spain. Source : European Commission

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.

Figure: Diversification of species by crop rotation. Source: ECAF

Figure: 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.

Figure: 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.

Figure: 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.

Figure: 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)

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.

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.

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.

References

Blanco-Canqui, H., Ruis, S. J., Holman, J. D., Creech, C. F., & Obour, A. K. (2022). Can cover crops improve soil ecosystem services in water-limited environments? A review. *Soil Science Society of America Journal*, *86*(1), 1-18.

Jayaraman, S., Dang, Y.P., Naorem, A., Page, K.L., & Dalal, R.C. (2021). Conservation Agriculture as a System to Enhance Ecosystem Services. Agriculture 11, 718.

Kassam, A.H., Friedrich, T., Shaxson, F., & Pretty, J.N. (2009). The spread of Conservation Agriculture: justification, sustainability and uptake. *International Journal of Agricultural Sustainability 7(*4), 292–320.

Lal, R. (2013). Enhancing ecosystem services with no-till. *Renewable agriculture and food systems 28*(2), 102-114.

Magdoff, F. and Van Es, H. (2021). Building soils for better crops. Ecological management for healthy soils. Edited by Sustainable Agriculture Research and Education (SARE), USDA.

Morugán-Coronado, A., Linares, C., Gómez-López, M.D., Faz, Á., & Zornoza, R. (2020). The impact of intercropping, tillage and fertilizer type on soil and crop yield in fruit orchards under Mediterranean conditions: A meta-analysis of field studies. *Agricultural Systems*, *178*, 102736.

Salako, F. K., & Tian, G. (2003). Soil water depletion under various leguminous cover crops in the derived savanna of West Africa. Agriculture, Ecosystems & Environment, 100(2-3), 173-180.