EIP-AGRI Focus Group

Protecting agricultural soils from contamination

MINIPAPER 5: Sustainable farm management for the preservation of the soil

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1. Introduction

Intensified agricultural production has caused degradation and contamination of soils and harmful environmental and social impacts (Balmford et al., 2018). For example, the unregulated use of pesticides has not only resulted in decreased biodiversity in soil but also a severe decline in the populations of special farmland birds. Research has continuously shown the challenges of agricultural intensification, particularly in addition to the priorities of biodiversity conservation and the provision of other ecosystem services, such as clean water and pollination (Kleijn and Sutherland, 2003; Kremen and Miles, 2012; Pimentel, 2006; Weinzettel et al., 2013).

Soils provide 95% of our food and can potentially hold three times as much carbon as the atmosphere thus soils are fundamental for biomass and food production, to mitigate climate change, and to offer numerous ecosystem services (FAO 2015, see Fig 1). Despite their importance, 33% of the world's soils are moderately or severely degraded and in urgent need of restoration. Preservation of the soil quality while preventing soil pollution is crucial for sustainable farm management. To address these issues, it is key to identify existing problems and possible solutions for more sustainable agriculture.

Agroecology is a transdisciplinary approach that integrates science, practices and social processes to support more sustainable food production systems that produce more, with more socio-economic benefits and less environmental consequences. Based on context-specific design and organization of crops, livestock, farms, and landscapes, agroecology aims to build synergies in environmental, economic, social and agronomic dimensions.

France is in the frontline of agroecology in Europe. It launched in 2012 its agroecology project in response to the challenges of harmonizing crop production with environmental issues. This is an ambitious, inspirational project that aims to shift agriculture towards the objective of combining economic, environmental and social performance. It has given rise to a wide-ranging action plan, broken down into a variety of projects covering all areas (teaching, support for farmers, reorientation of public support, public and private research, etc.). The aim is for the majority of French farms to be committed to agroecology by 2025 and the project is a joint development between the French Ministry of Agriculture and all key players in the sector (Ministere de l'Agriculture, de l'Agroalimentaire et de la Forêt, 2019).

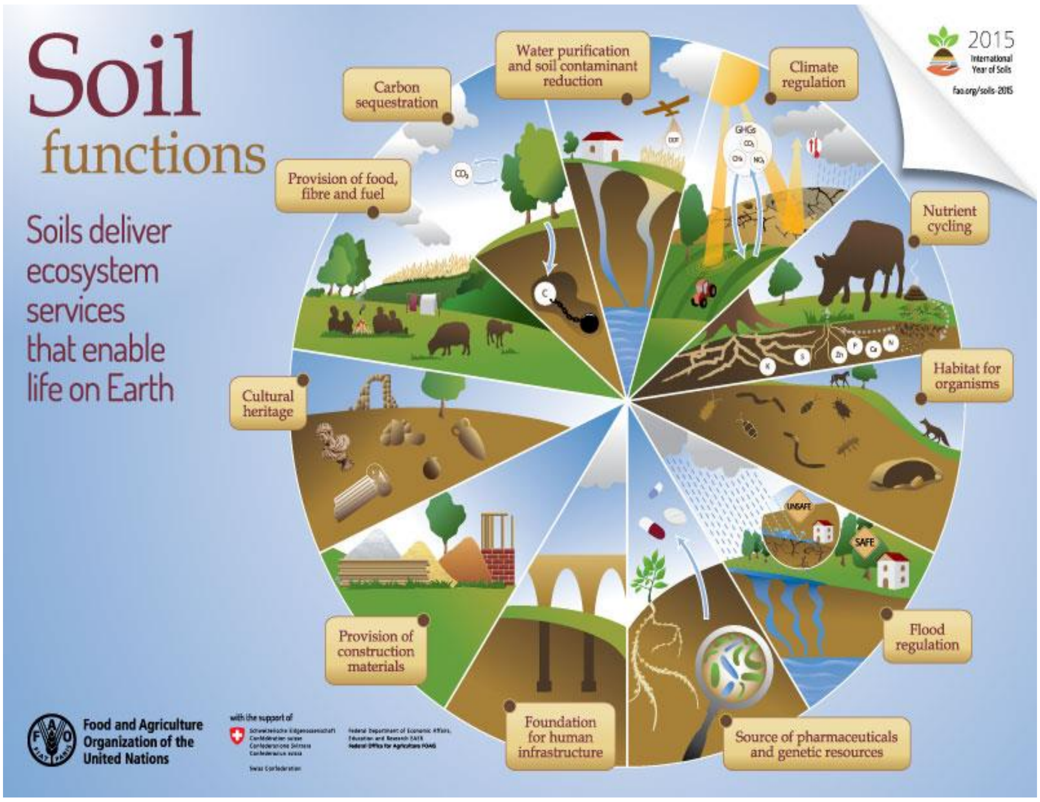

Figure 1 : The myriad of ecosystem functions and services provided by soils (source FAO)

2. Solutions, possibilities, and opportunities

Appropriate on-farm practices can enhance the preservation of agricultural soil, improve soil physical health, and sustain soil fertility such as organic matter and nutrients contents (Zhen et al. 2017). For instance, the agroforestry system or crop rotation can create higher resilience and productivity through enhanced pollination and reduced infection of plants from pests and diseases. Planting legume species or applying legume-cereal rotation can assist nitrogen fixation in soil and consequently maintain and increase soil fertility. This will not only lower the input demand for the synthetic agrochemical fertilisers but also prevent agricultural soil from contamination and reduce N-related greenhouse gases emission (Power 2010). In this paper, we focus on the existing best practices and possible solutions to (i) optimise the use of fertilisers and pesticides while maintaining high yields, (ii) increase the organic matter in agricultural soil, and (iii) increase the biodiversity in agricultural soils.

2.1. Optimizing the use of fertilisers and pesticides while maintaining high yields

Fertilisers represent an important tool for farmers in securing high yields from their crops and economic benefits. Nevertheless, food security and preservation of soil health require their responsible or adequate use. The fertiliser best management practices can be described under the method known as 4 R approach that means, that fertilise application with the Right source (or product) at the Right rate, Right time and Right place (IFA, 2009; Johnston and Bruulsema, 2014) in order to increase the nutrient use efficiency, reduce the application rates and the environmental losses of nutrients as explained below:

- **Right source** means applying fertilisers that match the crop need and soil properties considering balanced fertilisation between nutrients, their form, also in relation to soil properties, like pH.
- **Right rate** means applying fertilisers in quantities that match crop need by soil testing, yield goal analysis, crop removal balance, plant tissue analysis, record keeping, and variable-rate application technology;
- **Right time** means applying fertiliser nutrients in a way available to the crop when they are needed by splitting time of application, using slow and controlled release fertiliser technology, stabilizers and inhibitors, such as organic-based fertilisers. Applying fertilisers once the crop has emerged to reduce leaching, or using fertilisers that are not subjected to losses in pre-sowing; Avoid spraying fertiliser when the weather is very windy or heavy rains are forecasted to avoid dispersal, leakage, and run-off;
- **Right place** means applying nutrients where crops can use them best. Using adequate machinery to increase use efficiency (reduce leaching) of fertilisers and pesticides

One of the typical eco-friendly integrated farming systems is **precision agriculture** that takes into account detailed environmental and plant factors so that the crop can best utilise the agricultural inputs. For example, a key element of precision agriculture is the use of detailed, site-specific data to customize cultivation practices and inputs to specific needs, including variations within fields. This prevents the overuse of inputs where they are unnecessary, thus improving overall resources use efficiency and reducing waste and contamination to a minimum.

Other good farming systems include **sowing in the period** when the crop will be affected less by weeds and diseases. Furthermore, using **plant biostimulants** to facilitate nutrient assimilation, translocation, and use, helps protect nutrients from leaching or running while using organic-based fertilisers, which enhance fertiliser use efficiency through a natural, slow-release of nutrients like nitrogen and phosphorus in organic form are very useful. The benefits are also visible when they are used in combination with mineral fertilisers (the so-called organo-mineral fertilisers), because the nutrient use efficiency is higher than the use of mineral fertiliser/organic fertiliser alone.

Organic fertilisers include unprocessed, on-farm sources like manures and **"green manures"** that allow for efficient recycling of local sources of nutrients. Contrary to common thinking, organic fertilisers also include refined industrial products, which convert various by-products from the production of several value chains into high-quality products with consistent compositions that can be safely and economically transported over longer distances than unrefined organic fertilizers. (ECOFI, 2019). When on-farm sources of nutrients are insufficient, refined organic-based fertilisers deriving from industrial manufacturing processes help to fill nutrient gaps;

Another important farming practice with great impacts on soil fertility and health is **crop diversification** known as the **use of a variety of plants in the same piece of land** to combine the ecological services of the different species for low-input management practices. Crop diversification helps to recover soil nutrients and avoid specific pathogens. Crop diversification can have various forms in implementation, such as crop rotation, multiple cropping and intercropping.

Crop rotation is the yearly succession of different crops on the same land parcel while **multiple cropping** is the growing of different crops in a seasonal succession, within the same year, on the same land. Sanchez-Navarro el al (2019a,b) studied multiple cropping with cowpea and broccoli crops while reducing fertilization by 20% compared to broccoli monoculture in a 3-year field experiment. They found that the combination of broccoli/cowpea multiple cropping maintained high soil nutrient content and high broccoli yield despite reduced external inputs. **Intercropping** consist of growing two or more crops at the same time in the same space in a beneficial manner. Intercropping management can cultivate plants in strips, rows or all plants can be mixed together.

Based on the outcomes of the Annex III of the Directive 2009/128/EC the following ideas and principles are suggested for the sustainable crop production and farm management:

1. The prevention and/or suppression of harmful organisms should be achieved or supported especially by:
   - crop rotation,
   - use of adequate cultivation techniques (e.g. stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning and direct sowing),
   - use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material,
   - use of balanced fertilisation, liming and irrigation/drainage practices,
   - preventing the spreading of harmful organisms by hygiene measures (e.g. by regular cleansing of machinery and equipment),
   - protection and enhancement of important beneficial organisms, e.g. by adequate plant protection measures or the utilisation of ecological infrastructures inside and outside production sites.

2. Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.

3. Based on the results of the monitoring the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organisms threshold levels defined for the region, specific areas, crops and particular climatic conditions must be taken into account before treatments, where feasible.

4. Sustainable biological, physical and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.

5. The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms and the environment.

6. The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g. by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.

7. Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-

resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.

8. Based on the records on the use of pesticides and on the monitoring of harmful organisms the professional user should check the success of the applied plant protection measures.

2.2. Increasing the organic matter in the soil

Preserving and enhancing soil organic matter (SOM) content is vital for agricultural soil. The increase of SOM helps enhance the aggregation of soil particles, thus improve aggregate stability and soil structure (Apostolakis et al. 2017). Stable soil aggregates reduce surface seal formation, promote water infiltration, and enhances water retention capacity, thus reducing drought stress, surface runoff generation and associated soil erosion (Martínez-Blanco et al. 2013). Other proved benefits are improved microbiome diversity and activity, better nutrient supply for plant development, suppressed soilborne diseases, higher crop yield and better nutritional quality of products (Cesarano et al. 2017, Martínez-Blanco et al. 2013).

There is a set of practices that could help to maintain and enrich soil organic matter. They include **No-till cultivation**, use of **organic-based fertilisers**, either alone or as a complement to mineral fertilisers. No-tillage and organic-based fertilisers help improve soil health by maintaining or increasing soil organic matter content over the long term and create better resistance to erosion and leaching.

Other sources are the **composts** that contain organic materials and multiple nutrients (e.g., N, P, and K), microbiomes, and water that are vital for agricultural production. This makes compost an interesting option for the purposes of preserving agricultural soils. Nevertheless, application of composts may also have safety problems and result in environmental and agronomic drawbacks, such as increased inorganic/organic salts and heavy metal pollutants, gaseous and leachate emissions depending on the compost substrates (Hargreaves et al., 2008). On-farm composting is considered as the most sustainable option for environmental benefits and economic viability.

Research in different contexts demonstrates that it is possible to produce composts of good quality on the farm by simple and cost-effective techniques (Pergola et al. 2018). This allows farmers to recycle agricultural biomasses, such as manure and crop residues, for recovering soil carbon and nutrients without soil contamination and market involvement. This represents an important contribution and valuable opportunity to improve the circularity of agricultural production at the local scale.

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Figure 2. Green beans inside the currants is a practice in bidynamical production to increase soil fertility (Home farm Vukelić, Croatia)

2.3. Increasing the biodiversity in the soil

Practices that help to maintain and increase biodiversity in the soil include organic mulching with crop residues or composts, crop rotation and management of field margins and boundaries such as Hedgerows and grassy strips, and use of organic-based fertilising products

Organic mulching with crop residues or compost helps retain heat, preserve moisture and prevent erosion. Organic mulches can be broken down by soil organisms and help to structure the pores and architecture of soils, as well as sustain microorganisms. Applying well-rotted organic residues (manure or compost) to the soil provides food for soil organisms and a good structure for ecosystem engineers like earthworms.

Crop choice is also significant. **Rotating the type of crops** planted can help prevent the build-up of pathogens and pests and preserve nutrients in the soil. Meanwhile, **field margins and boundaries** can be managed to encourage biodiversity and bring it closer to crops. **Hedgerows and grassy strips** around fields provide stable habitats and food sources for organisms whose work in structuring the soil can help it combat pest outbreaks.

By providing "food" for microorganisms, **organic fertilisers** help beneficial soil microorganisms. This important microbiota can also be enriched or remediated through the use of **microbial biostimulants** that provide microorganisms with various functions such as fixing nitrogen, solubilizing phosphorus and other mineral elements in the soil, and stimulating root growth (EBIC 2019). Using plant biostimulants to facilitate nutrient assimilation, translocation and use help to preventing nutrients from leaching and reducing eutrophication of water bodies.

No-till cultivation is often associated with higher soil biodiersity than conventional tillage (Adl, Coleman et al. 2006). No-till benefits especially to mycorrhizal fungi and earthworms (Roger-Estrade, Anger et al. 2010). Indeed tillage is a major stress factor by fragmenting the fungal hyphae network and by destroying the earthworms burrows.

The European regulation on fertilising products

The market of fertilisers is partially harmonised through Regulation (EC) N. 2003/2003. In general terms, the existing Fertilisers Regulation covers conventional and inorganic fertilisers. Around 50% of the fertilisers on the market are left out of the scope of the Regulation (in particular all fertilisers produced from organic materials, such as animal or agricultural by-products and recycled bio-waste from the food chain). Furthermore, the existing Fertilisers Regulation doesn't address environmental aspects relating to contamination of soils, waters, and foods by fertilisers (European Parliament, 2016).

These issues lead to the revision of Regulation (EC) N. 2003/2003 and publication of new Regulation (EU) 2019/1009 in June 2019. In Regulation (EU) 2019/1009, 'fertilising product' means a substance, mixture, microorganism or any other material, applied or intended to be applied on plants or their rhizosphere or on mushrooms or their mycosphere, or intended to constitute the rhizosphere or mycosphere, either on its own or mixed with another material, for the purpose of providing the plants or mushrooms with nutrient or improving their nutrition efficiency.

A EC fertilising product belongs to one Product Function Category (PFC). For each PFC (see Fig 3), specific requirements for quality (contents of nutrients), safety (contaminants, pathogens) and labelling are defined. A PFC fertilising product is composed of CMCs (Component Material Categories). Products must ALSO comply to CMC relevant requirements.

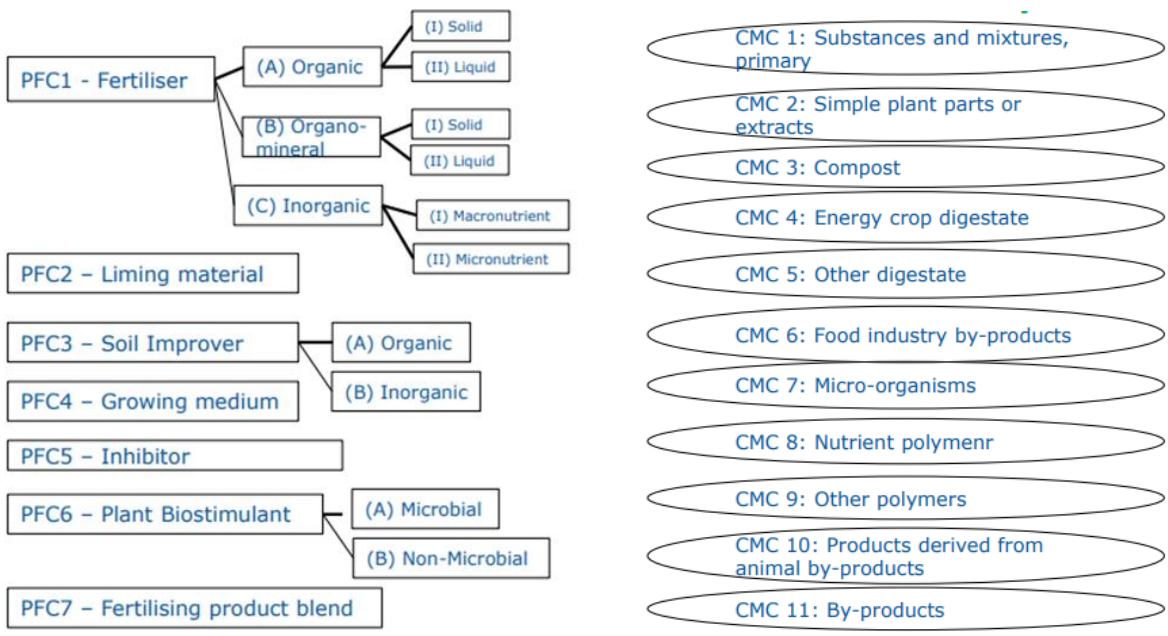

Figure 3. Categories of fertilising products (Source: Johanna Bernsel European Commission DG GROW, Fertilising Product Regulation Implementation, 1st Summit of the Organic and Organomineral Fertiliser Industry in Brussels, 6 June 2019)

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3. Research needs

Sustainable farm management is a systematic control of risks and improvement of resource use efficiencies in the production of plants to provide goods and non-commercial services, based on know-how about different types, scales, and complexities of farms. Part of the research needs to develop the **farm-centered approach**. At present farm management or development is often at a conceptual level and extends to some related models, but they are not effectively translated into quantifiable and practical practices. One important area for research in sustainable farm management is how to **incorporate wider biophysical and business components** within the farm-centered approach.

Farm management presents a multi- and interdisciplinary field of academic and practitioner practice rather than a single discipline. Technical feasibility and economic viability are prerequisites of agricultural production. Decision supporting tool for farmers and advisors that could link crop health and protection, soil management, pollution prevention, and organization and planning is essential for adaptation of adequate measures and practices to sustainably manage the farm. This includes recycling nutrients and energy on the farm, rather than using external inputs; integrating crop and livestock farming; diversifying species (and therefore genetic resources); and focusing on the ways, in which crops and livestock can mutually benefit each other, rather than on individual species. By using organic matter and improving the soil, farmers can promote better plant growth. This is an agroecology knowledge-intensive system, but the knowledge is developed by the farmer through understanding local conditions and experimenting.

4. Ideas for innovations

More sustainable agriculture may be secured by **holistic integrated farm management approaches**. Modern tools and technologies should co-exist with traditional practices in respect of the specific sites and field/crop conditions. Farming systems should not only address the final yield. They should also take into account other no-direct effects on agroecosystems by **balanced nutrient cycles** adapted to crop demand, preservation, and enrichment of **soil fertility**, maintenance, and improvement of **diverse environments**. **Crop protection** should combine biological, technical and chemical methods in an appropriate way with the goal to protect environment while maintaining farmers' profitability.

Soil microorganisms can help the plant growth by reducing the pressure of pathogens, improving nutrient acquisition or alleviating chemical stresses. These beneficial interactions can be enhanced in agriculture through inoculation of soil microbiome (Barea 2015). Other technics to improve the soil microbiome plant interactions may rely on the eco-evolutionary feedbacks. Indeed a soil microbiome and plants that evolve in the same environment can select for the soil microbiome that is the best to alleviate the stress for plants that are the best suited to make interactions with the microbiome. In order to take advantage of this potential for eco-evolutionary feedbacks between plants and soil microbes, plants breeding could be directly performed in the fields in an intercropping like design: rows of plants for harvest mixed with rows for seeds production. This technique is based on the hypothesis that production of seeds from the fields would allow a selection of plants that benefit more of the stress reduction from the soil microbial community. In a similar way, perennial plants may be chosen over annual plants to improve the interactions with the soil microbiome. Indeed, perennials have a better developed root system and a longer residence time that increase their potential for interactions with the soil microbiome (Glover, Reganold et al. 2012).

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Further research needs coming from practice, ideas for EIP AGRI operational groups and other proposals for innovation can be found at the final report of the focus group, available at the FG **webpage**.

5. Conclusions/ key messages

5.1. Existing practices

To preserve environment and mitigate the effects of climate change, the EU program of rural development proposed a set of good practices to encourage adaptation by farmers. The good practices are:

- Soil treatment and sowing on a sloping terrain for annual one-year crops
- Maintainance of permanent crops and cover crops
- Preservation of lawns for great natural values
- Establishing pole strips
- Extensive orchards and tree cover
- Preservation of endangered and protected domestic animal breeds
- Drywall maintenance
- Hedge maintenance
- Use of pheromones, visuals and feeding traps as pest confusion method in orchards and perennial fields
- Enhanced intermediate space maintenance in orchards and perennial fields
- Application of ecological fertilizers in orchards and perennial fields
- Mechanical destruction of weeds in rows of orchards and perennial fields

The voice of farmers – an example from an organic farm in Ireland

The IOA (Irish Organic Association) has developed a draft of eco-scheme that follows the principles of agroecology and organic farming. Data from the Farm of Mr. Fergal Byrne show that for a period of only five years of conversion from conventional to organic farming the yields are even higher. In fact, much of the yield increase is a result of better soil health and fertility. Mr. Byrne uses organic compost to fertilise his soils and grows red and white clover to feed lambs, cattle, and sheep (see Fig.3). Red clover is especially high in protein and very nutritious for the animals.

Soil quality is increasing at an unprecedented rate. A test made in late summer on site cultivated with red clover showed an amazing number of earthworms and beetles that are typical indicators of soil fertility and biodiversity. Furthermore a large number of nitrogen-fixing nodules and mycorrhizal fungi were vigorously thriving on red clover roots fixing nitrogen from the atmosphere into the soil.

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Figure 3. The Red and white clover growing in the farm of Mr. Byrne

Mr. Byrne also grows cereal crops, such as organic oats which are used to make organic porridge for human consumption. He grows oats in a mixture with barley and peas (see Fig.4) that also fixes nitrogen from the air. This crop is harvested and then rolled to feed cattle, sheep, and turkeys. The mixture of the two grains has potential to provide 18 - 20% of protein to animals. When the two plants grow together, they complement each other in terms of weed and disease control and soil fertility improvement.

Mr. Byrne uses cover crops to protect soil. The soils are always covered with vegetation, even before sowing the next crop. By doing so, the lands benefit from reduced soil erosion and increased soil fertility. Rape crop is grazed by lambs in January/February; composts or farmyard manure (FYM) is then applied and plowed, after which seeds are sown four to five days later. Later on when the crop is up, he applied compost of tea extract and plant extract. Following such an approach, no chemical fertilizers or chemical pesticides, herbicides or fungicides are needed on farm. The organic oat yield in 2019 was 6.5 tons per hectare.

Figure 4. Combi-crop from a mixture of barley and pea (left) and organic oats (right)

5.2. Key messages

Optimizing the use of fertilisers while maintaining high yields	Optimizing the use of pesticides while maintaining high yields	Increasing the organic matter in the soil	Increasing the biodiversity in the soil
Apply fertilisers from the right source, at the right rate, time and place Use of sustainable fertilising products (organic-based fertilisers, plant biostimulants) Precision agriculture Sowing in the right period Crop diversification	Precision agriculture Sowing in the right period Crop diversification and rotation Careful selection of cultivars and planting material Balanced fertilisation Cleaning of machinery and equipment Protection and enhancement of beneficial organisms Monitoring harmful organisms to decide whether and when to apply plant protection measures Sustainable biological, physical and other non-chemical methods when possible Specific pesticides Right doses to level that is necessary Anti-resistance strategies Check the success of the application	No-till cultivation Use of organic-based fertilisers Use of composts	Organic mulching Crop rotation Management of field margins and boundaries Provide food for microorganisms by organic fertilisers Stimulation of microbiota by plant biostimulants

5.3 Conclusions

Sustainable farm management for preserving soils should focus on (i) optimising the use of fertilisers and pesticides while maintaining high yields, (ii) enhancing soil organic carbon, and (iii) increasing soil biodiversity. Improved soil structure and health can upgrade the ability of soils to retain nutrients, deliver crop and water benefits, and reduce pollution pressures resulted from the irrational use of fertilisers and pesticides on soil and freshwater.

In agricultural landscapes, more efforts should be put to mitigate soil erosion, nutrient loss and maintain soil health (e.g. planted buffers, grassed stripes or shelterbelts) can simultaneously support biodiversity by increasing landscape heterogeneity. Field margins and buffers also provide habitat for pollinators and pest predators that benefit agricultural production. Soil biodiversity can directly

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benefit agriculture. Healthier, more biodiverse soils support mycorrhizal networks crucial to plant health and host beneficial organisms that can suppress soil-borne diseases and pests. This can reduce yield losses while enabling reduced use of pesticides.

To support soil and environmental quality since 2015 onwards, the Common Agriculture Policy (CAP) for the period 2013-2020 introduced a new policy instrument in Pillar 1, otherwise known as the Green Direct Payment. This accounts for 30 per cent of the national direct payment envelope and will reward farmers for respecting three obligatory agricultural practices, such as ***the maintenance of permanent grassland, creation of ecological focus areas and diversification of crops***. As the green direct payment is compulsory, it has the advantage of introducing practices that are beneficial for the environment and climate change mitigation on most of the utilised agricultural area and to improve biodiversity also in other forms of land use including ecological focus areas and permanent grasslands. (EC, DG Agriculture and Rural Development, 2014).

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