SOIL ORGANISMS 93 (1) · April 2021 pp. 1–11

AGENCY REPORT

Biodiversity in agricultural used soils: Threats and options for its conservation in Germany and Europe

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Received 23 February 2021 | **Accepted** 18 March 2021
Published online at www.soil-organisms.de 1 April 2021 | **Printed version** 15 April 2021
DOI 10.25674/so93iss1pp1

Abstract

Agriculture and soil biodiversity are highly interdependent. Agriculture strongly depends on essential ecosystem services of an active and diverse soil life, leading to soil fertility. Fertile soil is the basis for the cultivation of vital, robust and productive crops. However, today's intensive agriculture partly aims at replacing certain natural ecosystem services by intense agricultural practices and the use of agrochemicals. Even more, these intensive practices including intense mechanical soil tillage, pollution from contaminated fertilizers and pesticides pose direct threats to soil biodiversity. Although the biggest share of soil biodiversity has not yet been taxonomically recorded, there is evidence of a decline in soil biodiversity.

There are many opportunities in agriculture to support an active and diverse soil life and profit from its related ecosystem services. Here we present a set of actions to promote soil biodiversity in agricultural used soils including measures from integrated pest and nutrient management, conservation soil cultivation and agricultural diversification. All these actions show synergies for a transition of agricultural productions systems to a more sustainable and climate change smart production. This transition process needs to be understood as a process relevant to society as a whole. Therefore, extra efforts cannot be borne by farmers alone, but adequate subsidies with a clear focus on soil biodiversity need to be implemented in agricultural policies on national and international level. At international level the 15th Conference of the Parties of the Convention on Biodiversity (CBD COP15) can set the frame for the future of soil biodiversity. On European and national level, the Common Agricultural Policy (CAP) and its implementation via the national strategic plans will be key for a transition to a soil biodiversity promoting agricultural production. Investments in research and development help to continuously develop measures and legal frameworks and to invest in effective soil protection in the long term.

Keywords Soil Biodiversity | Agriculture | Threats | Conservation

1. Introduction

Soils, especially in temperate climate zones, are host to a variety of organisms that exceeds the biological diversity above ground (WBB 2002). About 90% of all living organisms are bound to soils in different ways throughout their live-cycles and are part of food webs that closely link above- and belowground biodiversity (Wardle et al. 2004: 1629–1633). Further, soil organisms provide a wide range of ecosystem services that make them ecosystem engineers. These ecosystem services include the processing of detritus by shredding, decomposing and mineralizing, the creation of a resilient soil matrix as well as the natural regulation of pathogens and pests (FAO 2020). With all these activities, soil organisms create the basis for a diverse and vital life

ISSN 1864-6417 (print) · ISSN 2509-9523 (online)

below- and above ground: a fertile soil (Nabel et al. 2021). Fertile soils are distinguished by a well aerated structure, good water infiltration and retention, stable humus aggregation, nutrient retention and availability and a wide range of further parameters. Also, humans strongly depend on fertile soil as valuable and non-regenerative resource as it is the basis of all agricultural activities.

The United Nations' Food and Agricultural Organisation (FAO) directly related the ecosystem services of soil biodiversity to six of the 17 United Nations' (UN) Sustainable Development Goals (SDGs, Fig. 1) (FAO 2020).

Even though life below ground is so far only known and understood to a marginal extent, the loss of soil biodiversity is documented on an international (FAO 2020), European (Orgiazzi et al. 2016), and national level (Nabel et al. 2021) to be as prominent and dramatic as it is documented for above ground biodiversity. Soil biodiversity related ecosystem services are therefore threatened. The consequences for ecosystems and agriculture are severe and will oppose the fulfilment of the SDGs (FAO 2020).

Therefore, the conservation and promotion of soil biodiversity is receiving increasing attention. At an international level the Convention on Biodiversity (CBD) intends to adopt a draft plan of action for soil biodiversity at its next conference of the parties (COP15) (CBD Executive Secretary 2020). At European level soil and soil biodiversity related aspects are included into the Biodiversity Strategy for 2030 (EC 2020a) and the Farm to Fork Strategy (EC 2020b) of the European Union (EU). For Germany with about 50% of the terrestrial area under agricultural use, the Federal Agency for Nature Conservation (BfN) compiled a report on soil biodiversity including actions to conserve and promote soil biodiversity especially in soils under agricultural practice (Nabel et al. 2021).

Agriculture strongly depends on soil biodiversity related ecosystem services including the maintenance and promotion of soil fertility. On the other hand, intensive agriculture is one of the major threats to soil biodiversity (Tsiafouli et al. 2015: 973–985). Many of the agricultural practices that threaten soil biodiversity mimic the natural ecosystem services provided by soil organisms. Even though many different factors like soil sealing and different sources of soil pollution are responsible for the decline in soil biodiversity (Orgiazzi et al. 2016, Mathews et al. 2020: 95–98), we will focus only on agricultural aspects in this article. We will exhibit how agricultural practices and policies endanger soil biodiversity and which agricultural actions would be suitable to conserve and promote the diversity of organisms in agricultural soils. Here, the proposed actions are beneficial for soil organisms, soil fertility and therefore also for farmers themselves. We want to open a win-win situation and show a common path for nature conservation and agriculture. In line with the SDGs, the presented measures are suitable to adapt agricultural practices to climate change and increase food security as well as ecosystem resilience.

2. Threats to soil biodiversity

Even though soil biodiversity and its ecosystem services receive increasing attention, large parts still remain hidden underground. Estimations assume 75% of earth worm -, 50% of ant – and 50% of all mite species are not yet taxonomically recorded. For soil fungi species (6% are described) and soil microorganisms (1% are discovered) the lack in knowledge is even bigger (Barrios 2007: 269–285, UBA 2015, Orgiazzi et al. 2016, Phillips et al. 2017: 1). However, already today it is obvious that the state of soil biodiversity shows the same negative trend which is

Figure 1. Six of the UN SDGs are directly linked to a diverse and active soil life.

well documented for above ground biodiversity over the past decades (Orgiazzi et al. 2016, Díaz et al. 2019). For Germany, the nationwide red lists document that 37 % of earth worm-, 22 % of isopod-, 24 % of millipede-, 35 % of ground beetle- and 25 % of fungi species are endangered (BfN 2011, BfN 2016a, BfN 2016b). Also, 28 % of vascular plants, whose roots and diaspora represent an important part of soil biodiversity, are endangered (BfN 2018). It should be emphasized that species adapted to agricultural areas are particularly affected (Meyer et al. 2015: 432–442, BfN 2017).

The reasons for this decline are manifold. For the agricultural sector, they can be narrowed down to the ongoing intensification in the past decades. In the process of intensification, many ecosystem services provided by soil biodiversity were replaced by chemical and mechanical treatments of agricultural soils and crops (Nabel et al. 2021). The care and maintenance of an active and diverse soil life and its positive effect on soil fertility faded into the background. The related losses in soil fertility were partly compensated by progress in plant breeding and developments of synthetic fertilizers and pesticides. However, this intensive agriculture, depending on high input of agrochemicals and heavy machinery, comes at high ecological costs (BfN 2017). In the following sections, major aspects of intensive agriculture are analysed on their influence on soil biodiversity.

2.1 Chemical Threats

Agricultural soils and their related soil organisms, especially under intensive agricultural production, are exposed to diffuse substance discharges (Beaumelle et al. 2021). Residues of multiple pesticides and contaminations from fertilizers accumulate in soils over time (Courvoisier 2018). Even though levels of individual substances might not exceed critical levels, their combination can cause cross reactions (Pisa et al. 2017).

Most of the applied pesticides on agricultural soils are not selective to the target organism of the substance but have a broad spectrum, thus affecting many non-target species (FAO & ITPS 2017, Courvoisier 2018). Lethal and sub lethal effects on soil organisms can be the consequence and weaken the populations of soil organisms in the long term. So far, these effects are not taken into consideration within the European procedures for authorising plant protection products (EASAC & Leopoldina April 2015). Soil organisms are responsible for the degradation of pesticide residues and other harmful organic substances. However, metabolites that are intermediate products of this degradation process can still be toxic and pose a risk to soil organisms (Sparling & Fellers 2007: 535–539). Accordingly, herbicides, fungicides and insecticides are related to shifts in distribution or changes in species assemblage of 80 %, 87 % and 95 %, respectively (Puglisi 2012: 62).

Today, 74 % of the global nitrogen fertilization is derived synthetically thus enriching the global nitrogen cycles causing eutrophication of ecosystems including soils. Plant biomass from ecosystems affected by eutrophication has a closer ratio between Carbon and Nitrogen and thus a lower content of stable Carbon structures like hemicelluloses or lignin. A decline in abundance and diversity of organisms, specialised to the degradation of such substances is a consequence (Orgiazzi et al. 2016).

On the other side, the abundance of organisms specialised on the degradation of easily degradable plant materials is increased. In the long term the humus- and carbon content of soils decreases, affecting the basis of all soil organisms (IASS et al. 2015). Further, plants in ecosystems affected by eutrophication do not depend on symbioses with mycorrhiza or rhizobia anymore. Therefore the release of exudates from roots is minimised or even stopped with far reaching consequences for all organisms in the rhizosphere (Gryndler et al. 2006: 159–166, Bonilla & Bolaños 2009: 253–274).

Sulphur emissions were a major source for acidification of soils in the past. Today, mainly Nitrogen emissions are responsible for soil acidification. Acidification of soils has direct influence on the ratio of fungi and bacteria und thus can influence nutrient availability for plants, directly and indirectly (Orgiazzi et al. 2016).

Mineral and organic fertilizers can be contaminated with heavy metals or organic pollutants harmful to soil organisms. Mineral fertilizers like potassium or sulphur, depending on their origin, can be a source of heavy metals that accumulate in agricultural used soils over long periods (Tsiafouli et al. 2015: 973–985). Organic fertilizers like sludge or manures can contain residues and metabolites of veterinary drugs and antibiotics that are commonly used in intense livestock production systems (WBB 2002, Tsiafouli et al. 2015: 973–985). Already in the short run antibiotics can create a selective advantage for resistant organisms (Gullberg et al. 2011: e1002158). In the long term, these resistant organisms can cause health issues also for humans (WBB 2002). Antiparasitic agents often are used as preemptive measures to avoid infection of grazers. These agents pass the gastrointestinal tract of animals and remain in the dung on pastures. Usually, dung represents a valuable food source and habitat for soil organisms. However, the antiparasitic agents make contaminated dung unavailable for soil organisms or harms them directly (Schoof et al. 2019).

New emerging pollutants of soils are micro- and nano plastic particles. Even though their impact on physical and chemical traits in soils has already been proven (Souza Machado et al. 2018: 1405–1416), the extend of the direct impact on soil organisms is still being investigated (Rillig et al. 2018: 17–24).

2.2. Physical Threats

Of all mechanical forms of tillage, plowing has the most serious influence on soil biodiversity since the topmost soil layer that is enriched with living and organic material, is shifted to a depth where many organisms can no longer work effectively. In addition, passages and pores are destroyed (Courvoisier 2018). Earthworms in particular are often directly affected (Orgiazzi et al. 2016) when they are injured by the plow and moved to the soil surface, where they are easy prey for birds and other predators (Giller et al. 1997: 3–16). In general, the macro and mesofauna are particularly affected by mechanical interventions in the soil structure, leading to the fact that the soil life on arable soils is less diverse and mainly consists of microorganisms (Tsiafouli et al. 2015: 973–985). However, fungi, which can form widely branched networks of fungal hyphae in the soil, are also affected by the mechanical interference. Consequently, in arable soils the symbiosis of cultivated plants with mycorrhizal fungi is also permanently disturbed (Briones & Schmidt 2017: 4396–4419).

Intensive tillage also destroys the natural soil structure and increases the vulnerability to soil compaction. In the EU, 35 % of agricultural soils show significant compaction damage (IASS et al. 2015). Compacted soils offer larger soil organisms such as arthropods or worms only a limited habitat, since the energy expenditure for locomotion in compacted soil becomes too great. Another consequence is an increased vulnerability to erosion and waterlogging, which disrupts an adequate oxygen supply for soil life. Since the topsoil is particularly rich in organic material and thus essential for soil life, it holds the highest species density (Orgiazzi et al. 2016). A disturbed soil structure in combination with increased surface runoff cause an erosion of this biodiversity-rich topsoil by wind and rain. In Europe, 45 % of the soils have already lost a significant amount of organic matter in the topsoil (IASS et al. 2015).

2.3. Other Threats

Today, agricultural land is used for various reasons, which leads to a further intensification of land management. In Germany, for example, 56 hectares are sealed daily for transport and settlement areas, although the demand for agricultural products is constantly increasing (KBU 2013). The pressure on agricultural land is particularly high in regions where animal husbandry and biogas use meet. In the EU, 60 % of the grain harvest ends up in a trough instead of directly on the plate (IASS et al. 2015). The growing bioeconomy leads to an increasing use of agricultural land for the production of industrial raw materials or bioenergy fuels. The growing pressure on land results in massive changes in both land use and environment and nature. For example, 83 % of extensive grassland habitats in Germany are severely endangered (Finck et al. 2017). This not only has fatal effects on biodiversity aboveground: 47 % of individuals in the soil are lost when extensive grassland is converted to arable land and the biomass of soil life drops by 37 % (Yin et al. 2020).

The EU's Common Agricultural Policy (CAP) has a major impact on the way land is managed. Currently, EU agricultural subsidies are paid per hectare of land. Yield-oriented and often non-agricultural investors benefit particularly from this. This means that a large part of the money is passed on indirectly to landowners. Structural weakness and social instability in agricultural companies often lead to land and companies sales in the course of generation change and end in high concentrations of ownership of land by locally and supra-regionally organized holding structures (Laschewski & Tietz 2020). In the period from 2009 to 2019, the prices for arable land and grassland increased by a factor of 2.3 (Destatis 2019). Such misguided developments currently make it difficult for farmers to invest in long-term farm planning that is oriented toward soil life and soil fertility.

3. Actions to conserve and promote soil biodiversity

In the political discussion about the transition to a more sustainable agricultural practice, promoting biodiversity in agricultural areas is an increasing issue (BMU 2019, EC 2020a, EC 2020b). Despite the fact that many measures for above ground biodiversity have beneficial synergetic effects for soil ecology, targeted measures for soil conservation and fertility remain to be implemented. The FAO proposals for a conservation agriculture, which includes integrated crop management (ICM) and integrated pest management (IPM), can be considered as overarching guidelines for transition pathways to agricultural systems that serve both food production and (soil) biodiversity (GFG 2016, FAO 2017, Gabor et al. 2017, Corsi 2019). As the FAOs main concern is food security, for the sole purpose of nature conservation more strict soil protection measures are conceivable. In the case of agricultural production systems, the transition to sustainability, where biodiversity is a production goal that serves profitability, has to be accompanied by targeted financial support for farmers (Schweppe-Kraft et al. 2019). To be sustainable, financial support has to be measurable and it must support the protection or deliverance of public goods (Pe'er et al. 2019: 449–451). The increase in soil organic matter, for example, is measurable, and the protection of fertile soils is a public good. Nevertheless do farmers need to be actively involved in the process of transition as they are the main stakeholders (Nabel et al. 2018). The core elements of conservation agriculture, with a focus on soil biodiversity, are outlined in the following sections.

3.1 Conservation Agriculture

Soil, along with its diversity of living organisms, needs to be understood as the essential basis of all sustainable land cultivation activities. The FAO sets soil fertility as the central element of its concept of conservation agriculture (Corsi 2019). The concept builds on the three main key elements conservation soil cultivation, permanent ground cover and agricultural diversification, but also expands to integrated pest management (IPM) and integrated nutrient management (INM) (Kassam et al. 2009: 292–320).

3.1.1 Conservation soil cultivation

In order to disturb the soil habitat as little as possible, conservation soil cultivation aims at preserving the natural soil horizons and especially conserving the topsoil, rich in organic matter (Orgiazzi et al. 2016, FAO 2017). At the same time, soil organisms experience only little mechanical disturbance and are not translocated to deeper soil layers. The soil matrix with pores and subterranean tunnels remains in good condition, including a wide range of microhabitats for soil organisms (Kladivko 2001: 61–76, Sengupta & Dick 2015: 853–859).

An already well established method is direct seeding. However, in most cases it solely depends on broad-spectrum herbicides for weed control with far reaching negative effects on the biodiversity of agricultural ecosystems (Chauhan et al. 2006: 1557–1570, Boutin et al. 2012: 79–92). Negative effects of herbicides, especially of glyphosates, on belowground biodiversity have been shown in the past (Zaller et al. 2014: 1–8). Here, mulch drilling systems might offer an alternative, reducing the dependency on broad herbicides. The mulch covers the soil surface and thus suppresses weed germination, provides cover and a nutritional basis for a wide range of soil organisms (Dybzinski et al. 2008: 85–93).

In case high weed -, pest - or disease pressure demand for tillage, this practice should be accompanied by immediate organic fertilization to enrich the topsoil with organic matter and allow for a fast and successful repopulation with an active and diverse soil life (Hansen & Engelstad 1999: 237–250).

3.1.2 Permanent ground cover

Catch crops are widely implemented in today's agriculture to protect soils from erosion and nutrient leaching outside the vegetation period. They provide shelter and food for a variety of organisms in periods between harvest and seeding of new crops and enrich the topsoil with organic matter (Pimentel & Kounang 1998: 416–426, Bender et al. 2016: 440–452). As a method of IPM, catch crops also supress the emergence of unwanted weeds (Ringselle et al. 2015: 309–319). The long term effects of catch crops on soil conservation also increases the income potential of the fields as soil fertility and crop yield are positively affected (Gabriel et al. 2013: 23–32). To achieve the greatest positive effect, catch crop mixtures have to be composed of diverse and regional species as these support the greatest variety of species below and above ground (Dybzinski et al. 2008: 85–93). Nurse crops, which are sown together with the main crop but are not harvested, suppress unwanted weeds during the vegetation period. They remain on the field after the main crop is harvested and later serve the same purpose as catch crops.

3.1.3 Agricultural diversification

Crop rotation is the succession of different crops in consecutive years. Planting the same crop every year on the same field promotes the spread of adapted weeds, pathogens and other pests. The application of a crop rotation is therefore a method of IPM. A diverse (many different crops) and wide (long period until the crop sequence repeats) crop rotation is beneficial to soil biodiversity (Tiemann et al. 2015: 761–771). Multicropping combines two or more different crops on the same area at the same time and provides a higher resource use efficiency (Amossé et al. 2013: 158–167). It enhances the diversity of crops and soil biodiversity as each crop offers a microhabitat for a specialized community of soil organisms in its rhizosphere (Orgiazzi et al. 2016). In agroforestry, annual crops are planted between perennial plants, such as trees or shrubs, which can be used for energy production. In terms of soil conservation, these systems provide disturbed and undisturbed soils on a small scale combined with a relatively diverse plant community

(Rigueiro-Rodríguez et al. 2009: 43–65). In other multi cropping systems, perennial wild flowers are used for biogas production or a mixture of grass and clover is used for cattle fodder (van Eekeren et al. 2009: 254–263, Nabel et al. 2017: 207–213).

Beside measures to increase soil cover and diversification directly on the cultivated area, the context of the agricultural landscape should also be taken into account (Nabel et al. 2021). Trees, shrubs and hedges as well as waysides strips offer habitats that remain undisturbed over long periods and thus can serve as refuge. Further, the deep reaching root systems of the perennial vegetation reaches deeper water reservoirs. Via hydraulic lift, part of this humidity can be accessible to soil organisms helping them to survive longer drought periods (Horton & Hart 1998: 232–235). As soil organisms for the most part are not very mobile, landscape elements need to be well connected and the shape and size of arable fields should be capped. Only in this way, a successful repopulation of agricultural area from perennial landscape elements can be achieved.

3.1.4 Integrated Nutrient Management (INM)

Fertilization should aim to increase soil fertility and thus allow for the cultivation of vital and robust crops (Collette 2011). Accordingly, fertilizer formulations should apply individual nutrients in well balanced ratios and should not contain any contaminations. A sufficient supply with organic matter via organic fertilizers is essential to sustain an active and divers soil life and can increase soil fertility in the long term. Consequently, organic fertilizers should be the basis of all fertilization planning. In Germany, organic fertilizers are not homogenously distributed as livestock production is concentrated in regional hotspots. A link between area and livestock production could dissolve these hotspots and support an even distribution of organic fertilizers, promoting circular economy and closed nutrient loops (Osterburg 1996: 1–28). Where organic fertilization via sludge or manure may not be an option, phosphor mobilizing and nitrogen fixing crops should be integral component of fertilization and crop rotation (Wezel et al. 2014: 1–20). Mineral fertilizers should only be used to close gaps in demand of fertilizers and secure a balanced nutrient ratio. Nutrient surpluses need to be excluded at any time to avoid eutrophication and ground- and freshwater contamination. To compensate for possible acidifying effects of nitrogen fertilizers, moderate liming can be an option to sustain the pH level of agricultural used soils.

3.1.5 Integrated Pest Management (IPM)

In the toolbox of crop protection methods, chemical products can have non-target effects and pose a threat to biodiversity and functionality of agricultural soils (Kremer 2018: 247–263). Since 2009, the principles of IPM are implemented in European law. IPM includes all methods that are suited to control for unwanted weeds, pathogens and animals. The fundamentals of IPM consider chemical crop protection as the last option, after all other techniques, such as soil cultivation, crop rotation and biological pest control had been implemented (FAO 2014). Also, IPM requires the use of damage thresholds for each application. Using these thresholds properly requires the inclusion of external costs, for example for the contamination of water and the loss of ecosystem services through non-target species. If species get affected by an unavoidable pest control method, the restoration of their population has to be ensured. This can be acquired by the provisioning of areas of refuge which are ecologically valuable and from which treated areas can be repopulated (BMU 2019). Despite its significance to protect biodiversity, to this day there is no consistent application of IPM in day to day practice (ECA 2020).

3.2 Research and development

Soil organisms are one of the least considered organism groups in research, resulting in knowledge gaps about the mode of life and population development for a large number of species (BfN 2011, BfN 2016a, BfN 2016b, BfN 2018). Thus, there is a risk that species will decline sharply or even become extinct before they and their significance for the respective ecosystem have been adequately explored. The consequences for ecosystems are unpredictable. To close the gaps in knowledge and expand research and development in the field of soil biodiversity is therefore pressing (Gardi et al. 2009: 807–819, KBU 2020). In addition to the further development of methodological standards for recording biodiversity and the associated ecosystem services, new methodological approaches such as metabarcoding and eDNA should be used increasingly in order to be able to characterize the undiscovered mass of soil life more comprehensively and to develop suitable types of indicators (Orgiazzi et al. 2016, Guerra et al. 2020: 3870). An expansion of applied research is equally important in order to put promising approaches for the protection of soil biodiversity into practice. 'Living labs' could initiate collaboration between civil society, land users and science. This can promote long-term cooperation and model regions with innovative approaches, for example arable farming systems that promote soil life and agricultural technology. However, an important requirement for many research approaches is the training of a sufficient number of professionals to become species experts. An example of this is the EU call for tenders concluded in February 2021 for raising the taxonomic capacity in EU Member States with regard to pollinating insects as part of the preparatory implementation of the EU Pollinator Monitoring Scheme (EU-PoMS) (Potts et al. 2021). Similar initiatives for the generation of knowledge are also desirable for the protection of soil life.

Furthermore, in agricultural training, vocational and technical schools as well as universities and technical colleges, an emphasis should be put on soil life and its great importance for soil fertility. Just as important is that farm advisory services focus more on the aspect of soil biodiversity and soil fertility. This requires targeted training and further education of appropriate advisors. So far, the general public hardly knows about life in the soil. Citizen science projects and innovative educational formats can involve the public, raise awareness and at the same time help to increase knowledge about the species in the soil (Pettibone et al. 2018: 222–225, Xylander & Zumkowski-Xylander 2018: 79–94, Xylander 2020: 203–212).

The importance of soil must be placed much more strongly than before in the centre of social and technical discussions in order to be acknowledged by politicians and to generate appropriate research funding.

3.3 Agricultural policies: subsidies, marked regulations

The EU's biodiversity strategy for 2030 intends to ensure that soil protection is also implemented within the framework of the EU's Common Agricultural Policy (CAP) (EC 2020a). The CAP is currently the most harmonized legal framework for soil protection at EU level (Schneider & Köder 2019). It also is the most influential and currently the financially best equipped funding instrument to protect agricultural soils. Furthermore, it is the most important funding instrument for biodiversity in the agricultural landscape. However, with regard to financial resources, measures and regulations for the protection and promotion of soil biodiversity, the contribution of the CAP has so far been marginal at best (Schneider & Köder 2019, Schweppe-Kraft et al. 2019). There is an urgent need for a paradigm shift in the CAP, which has to consistently recognize and promote environmental and nature conservation as public services. CAP instruments and measures must go beyond the merely protection of soils against material inputs and erosion. They must explicitly acknowledge the soil as a medium itself and focus on its protection accordingly (Pe'er et al. 2020: 305–316). Consequentially, the protection and promotion of soil biodiversity in agricultural soils must become a priority under the CAP in order to preserve many ecosystem services that are also important for production. This applies equally to the first and second pillar of the current policy model of the CAP.

The CAP regulations coming into effect in 2023 do not yet provide for any special protection for soil biodiversity. However, the development of the national CAP strategic plan provides leeway in the selection of more detailed options. This opportunity must be used to achieve the environmental goals set by the new CAP regulation itself and by the European Green Deal and its strategies (EC 2020a, EC 2020b). Thus, regarding the conditionality of the first pillar, standards for 'Good Agricultural and Ecological Condition' (GAEC) with special consideration of soil life must be a prerequisite for all farms that receive direct payments. The maintenance of permanent grassland at a high level should be ensured by GAEC standards, also outside of Natura 2000 areas and the plowing of grassland for purely administrative reasons has to be prevented. Furthermore, the restoration and new establishment of melioration measures on organic soils must be prohibited. To maintain the soil structure, further standards need to aim at an effective erosion protection. To benefit soil organisms even more, a year-round surface cover, e.g. via cover crops, as well as effective crop rotations have to be ensured. Crop rotations should include at least five different types of crops. Finally, it is necessary to establish non-productive areas on at least 10 % of all agricultural land as habitats for organisms above and below ground.

Concerning the new eco-schemes of the first pillar of the CAP, farmers must be offered ecologically effective and financially attractive measures. They have to be beneficial for the biological diversity in soils on arable land and grasslands. To achieve this, measures can promote an expansion of the proportion of non-productive areas beyond the GAEC requirements, including hedges and field trees, or the creation of preferably perennial areas or strip elements (e.g. flower strips and fallows) on arable land and grassland, with reduced or no use of fertilizer and no chemical pesticides. Perennial elements are likely to have a particularly high ecological value due to the pause of tillage and thus should be preferred (Ganser et al. 2019: 123–131, Albrecht et al. 2020: 1488–1498). Moreover, Eco-Schemes should be used to promote organic agriculture.

Agri-environmental and climate measures (AECM) of the second pillar which specifically aim at promoting soil life must be developed and integrated into the funding programs. If possible, they should be co-financed through national funding guidelines in order to enable nationwide implementation. Appropriate measures can also create synergies for climate protection by increasing the soil's binding capacity of the climate gas carbon dioxide.

In line with the cross-sectional goal of the new CAP to 'promote knowledge, innovation and digitization in agriculture', the second pillar of the CAP should provide funding for farm advisory services that consider the protection of soil as a habitat for a large number of organisms. Also, investment programs for an enhanced knowledge and acquisition of conservational tillage technology on farms should be implemented.

In addition to immediate support for farmers, applied research in soil biodiversity must be expanded and appropriately financed (Mathews et al. 2020: 95–98). The existing knowledge gaps on species living in the soil and their functions in the ecosystem have to be closed (KBU 2020), for example by using the 'living labs' approach as a cooperation between science and civil society.

4. Conclusion and Outlook

Agriculture and soil biodiversity are highly interdependent. Soil organisms provide essential ecosystem services, including increased soil fertility. Appropriate agricultural management is well suited to promote an active and diverse soil life and the related ecosystem services. The conservation and the sustainable use of soil biodiversity have to be a prerequisite for a transformation to sustainable and climate resilient farming systems of the future. Accordingly, the promotion of an active and diverse soil life should be understood as a common goal, both for agriculture and nature conservation. This is a mission for all of society and cannot be borne by farmers alone. They depend on subsidies for farming practices which clearly promote soil biodiversity. Also, consumers should support the transition to a more sustainable agriculture by favouring appropriate agricultural products. On an international level, CBD COP15 has the chance to adopt an action plan for the conservation and the sustainable use of soil biodiversity and encourage national governments to increase their soil life related legislations. On European level, an ambitious implementation of the EU's Farm to Fork - and Biodiversity Strategy supported by the CAP regulations inter alia can serve the same purpose. On the German national level, the national implementation within the strategic plan of the CAP offers the opportunity to support farmers in their efforts for a more sustainable and soil life promoting cultivation.

5. Acknowledgements

We thank Ursula Nigmann, Sandra Balzer, Detlev Metzing, Daniel Wolf and Oliver Hendrischke as well as the anonymous reviewer for providing their valuable comments and expertise improving the quality of this manuscript.

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