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# SoildiverAgro

Soil biodiversity enhancement in European agroecosystems to promote their stability and resilience by external inputs reduction and crop performance increase

## D2.2- E-BOOK ABOUT OUTCOMES FROM SYSTEMATIC REVIEW, DATA MINING AND META-ANALYSIS

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817819

# D2.2. E-BOOK ABOUT OUTCOMES FROM SYSTEMATIC REVIEW, DATA MINING AND META-ANALYSIS


Summary

One of the main objectives of the WP2 is to identify the soil biodiversity problems of the European Farmers and develop strategies to help to solve them. This was made through an exhaustive process of data mining and literature review.

This deliverable presents, in the form of an appendix, an e-book with the results of this the litarature review. The aspects considered in this revision book are:

- The importance of the soil biodiversity in the design of cropping systems.
- Crop rotation and its effect over the edaphic fauna.
- The effect of tillage on the communities that inhabit in the cultivated soils.
- The ability of soil fauna to regulate the proliferation of pathogenic fungi related to certain crop diseases.
- Different types of bacteria that promote plant growth.
- The relationship between soil contamination and biodiversity.
- The effect of organic and synthetic fertilizers on the biodiversity of the edaphic fauna.
- The development of alarm systems that allow the early detection of pathogens.
- The increase in soil quality associated with the use of cover crops.
- The use of trap crops to reduce the use of pesticides while maintaining production and quality.


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| Dissemination Level | PU | Public | X |
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# Table of content

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# 1 Introduction

When analyzing the situation of soil biodiversity in agricultural soils throughout Europe, it is important to carry out a review work to determine which are the main problems and the possible solutions to these problems. This has been done in this work package (WP2), trying to summarize in a single book, "INTERACTIONS BETWEEN AGRICULTURAL MANAGEMENT AND SOIL BIODIVERSITY: AN OVERVIEW OF CURRENT KNOWLEDGE" (included in Annex I), the importance of soil biodiversity and the challenges that European agriculture must face to improve soil quality from a biological point of view.

Thus, this book includes aspects such as the effect of crop rotation and tillage on edaphic fauna, the ability of some microorganisms to regulate the proliferation of fungal diseases, and the ability of certain bacteria to promote plant development, among others.

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# 2 E-book

# INTERACTIONS BETWEEN AGRICULTURAL MANAGEMENT AND SOIL BIODIVERSITY: AN OVERVIEW OF CURRENT KNOWLEDGE

EDITED BY DIEGO SOTO-GÓMEZ,MERRIT SHANSKIY AND DAVID FERNÁNDEZ-CALVIÑO

NOVEMBER 2020

# INTERACTIONS BETWEEN AGRICULTURAL MANAGEMENT AND SOIL BIODIVERSITY: AN OVERVIEW OF CURRENT KNOWLEDGE

EDITED BY DIEGO SOTO-GÓMEZ, MERRIT SHANSKIY AND DAVID FERNÁNDEZ-CALVIÑO

NOVEMBER 2020

This Ebook is a deliverable of WP2: Identification of main challenges in European agricultural cropping systems and data mining of the SoildiverAgro project financed by the European Union´s Horizon2020 research and innovation programme under grant agreement Nº. 817819.

The book was revised by two external reviewers: Avelino Núñez Delgado (Universidade de Santiago de Compostela) and Alessandra Trinchera (Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria-CREA).

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Image by Loren Gu. https://stocksnap.io/photo/green-grass-F7QL500KX9

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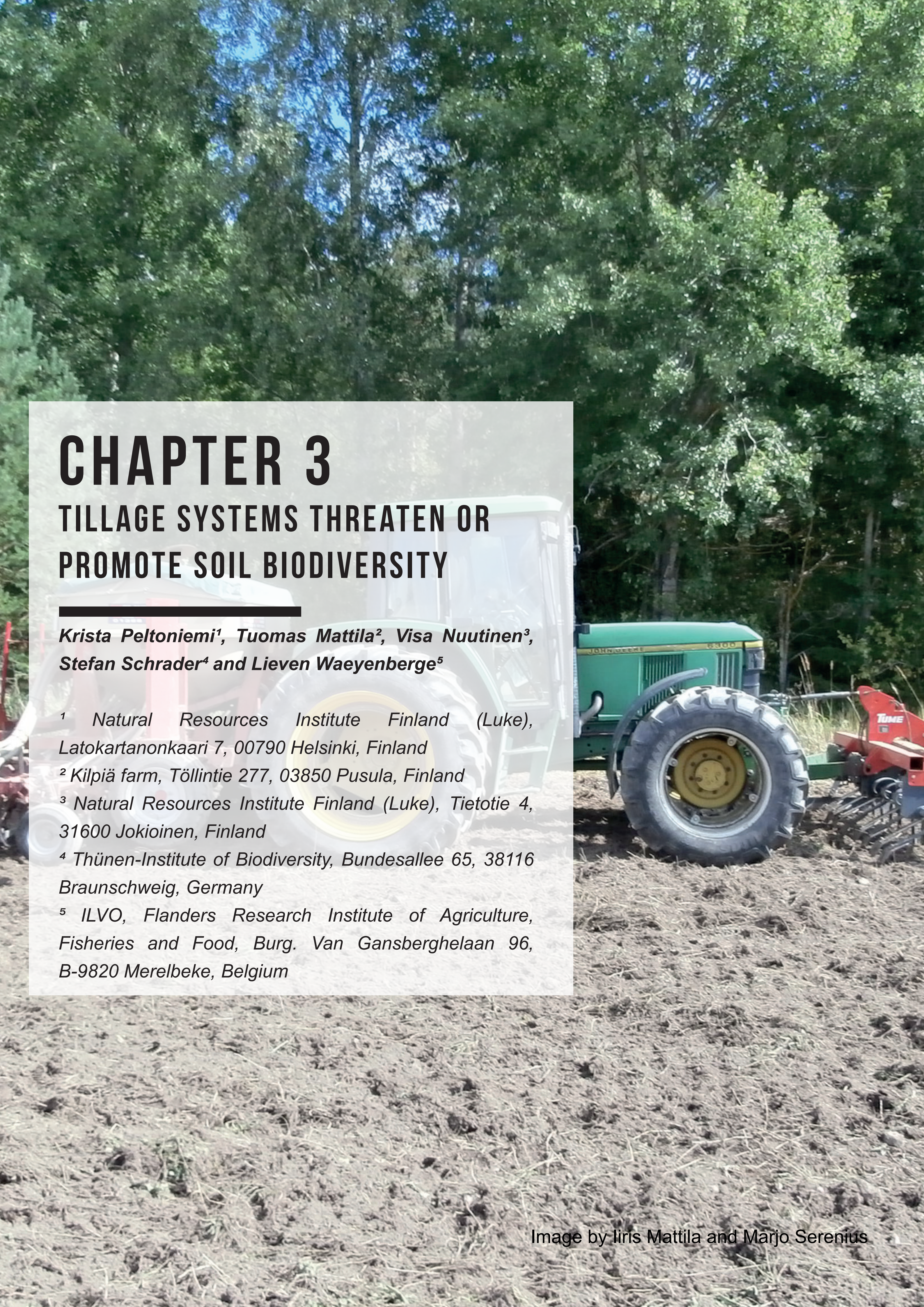

# CHAPTER 3

## TILLAGE SYSTEMS THREATEN OR PROMOTE SOIL BIODIVERSITY

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Image by Iiris Mattila and Marjo Serenius

# ABSTRACT

Tillage is one of the most common soil management practices in agroecosystems worldwide. Conventional mouldboard ploughing is motivated by the efficient incorporation of crop residues, seed bed preparation and weed management. Ploughing induces many physical, chemical and biological changes in soil, with some well known negative effects. Reduced soil quality due to the loss of carbon and other nutrients, together with negative effects on soil structure, challenges the use of intensive and frequent ploughing as the ideal tillage regime. Ploughing also changes the composition of soil communities, and can lower both abundances and diversity of beneficial soil organisms. These include microbes and soil animals as: (i) chemical engineers in decomposing soil organic matter and recycling of carbon and other nutrients; (ii) biological regulators in controlling other soil organisms; and (iii) ecosystem engineers in forming and maintaining favourable soil structure. Their important contribution to ecosystem service provision in agricultural soils demands our understanding of the impacts of tillage on soil biodiversity. Reduced- and no-tillage systems, in conjunction with the retainment of crop residues as well as the application of diversified crop rotations, are known to promote soil biodiversity. There is a need to implement and further develop alternatives to conventional ploughing, as well as employ and preserve soil biodiversity, in order to improve the sustainability of agriculture. This chapter discusses major effects of soil tillage on soil organisms within a functional framework, in order to provide perspectives for their maintanance and enhancement in field management.

**Keywords**: tillage; soil biodiversity; soil quality

# 1. TYPES AND IMPACT OF SOIL TILLAGE

Soil tillage systems can be assigned to conventional-, reduced- or no-tillage systems (Table 3.1). Conventional tillage refers to mouldboard ploughing, which turns soil at up to depths of 15–35 cm (“inversion tillage”). Reduced tillage refers to treating only shallower soil, without turning; and no-tillage refers to direct seeding.

Tilling arable fields aims at incorporating crop residues, manure and other organic fertilisers, speeding up decomposition and nutrient cycling while controlling weeds and plant pathogens, as well as loosening, levelling and aerating the soil for seedbed preparation (Whalen and Sampedro 2010). Tillage thoroughly modifies the physical, chemical and biological properties of soil. Type and magnitude of the effects vary depending on soil properties, climate conditions and the tillage equipment used. For example, when soil is mouldboard ploughed seasonally, the topsoil organic matter content may decline, and the soil surface which is left bare by tillage becomes vulnerable to erosion and nutrient leaching (Palm et al. 2014). In soils prone to compaction, seasonal ploughing induces the development of a plough pan, separating top- and subsoil, as a barrier for root gowth and water infiltration. Furthermore, tillage can alter the inhabitable pore spaces for soil organisms, radically affecting their mobility.

Table 3.1. Tillage systems, according to mechanical impact on soil.

| Tillage system | Impact on soil | Shallow (<8 cm) | Deep (~15-35 cm) |
|---|---|---|---|
| Conventional tillage | Inversion | Disc harrow, shallow plough | Plough |
| Reduced tillage | Mixing–no-inversion | Cultivator with sweeps, harrows (tine-, rotary-, straw-, power-) | Cultivator, spader, rotavator |
| No-tillage | No mixing–no inversion | No till | Subsoiler |

# 2. STRUCTURE AND FUNCTION OF SOIL BIODIVERSITY

Soil biota can be variously grouped according to size or ecological role. Here we will use Turbé et al. (2010) classification which recognises three different guilds according to their functional role: (i) chemical engineers include decomposers such as bacteria and fungi, some protists, some nematodes, springtails, many mites, potworms and earthworms. They are responsible for decaying plant residues and controlling nutrient cycles; (ii) biological regulators are grazers on soil microorganisms, or predators of soil fauna, and thus shape soil communities in space and time. This guild includes many protists and nematodes, springtails, some mites, potworms and earthworms; (iii) ecosystem engineers modify soil structure by producing soil aggregates and pore networks, which provide habitat for smaller organisms, and control the soil water balance and soil aeration. Potworms and earthworms belong to this guild. This classification reflects the multifunctionality of soil organisms, and therefore certain soil biota may be assigned to more than one guild.

# 3. TILLAGE CHANGES SOIL BIODIVERSITY

Burial of surface residues during ploughing removes the living habitat of species associated with the litter layer. Natural galleries and pore spaces in the soil are disrupted, and soil temperature- and moisture regimes change. Frequent tillage may result in long term decline of soil organic matter, the resource base of decomposers; and this can reduce the soil's ability to sustain populations. It is therfore not surprising that soil biodiversity benefits from low tillage frequency and intensity (Tsiafouli et al. 2015). In general, large bodied soil invertebrates, which are most vulnerable to physical damage caused by tillage, benefit the most from low physical disturbance (Kladivko 2001). However, not all soil organisms respond in the same way, as was shown in a literature review of 150 sources (van Capelle, Schrader, and Brunotte 2012). For instance, abundance and species diversity of springtails and mites decrease when tillage intensity is reduced; and potworms benefit from reduced tillage, though their abundance declines under no-tillage regimes (van Capelle, Schrader, and Brunotte 2012). In the following sections, we will describe tillage-induced changes in soil communities, using typical representatives of chemical engineers (bacteria and fungi), biological regulators (nematodes) and ecosystem engineers (earthworms) as examples.

# 3.1. CHEMICAL ENGINEERS: BACTERIA AND FUNGI

Generally, there is less microbial biomass in conventional tillage systems than in no-tillage systems (Whalen and Sampedro 2010). Based on results from more than 60 European multiyear field experiments, reduced tillage is often accompanied by a higher microbial carbon content, compared to ploughing (D'Hose et al. 2018). Bacterial potential to produce polysaccharides that promote soil aggregation, was not reduced after tillage (Cania et al. 2019); and another study reported that relative abundances of dominant bacterial phyla were similar between reduced tillage and no-tillage plots (Tyler 2019). These results suggest that bacterial communities are not strongly affected by tillage. Tillage has, however, been reported to alter the vertical distribution of soil bacterial- more than that of fungal communities (Sun et al. 2018). It is generally assumed that fungi are affected by tillage more than bacteria, since their large hyphal networks are disrupted by tillage. Fungi seem indeed to dominate over bacteria in no-tillage systems (Hendrix et al. 1986), and their hyphal length is shortened under tillage regimes (Oehl et al. 2004). In many studies, tillage has also been shown to be a major stress factor leading to a decrease in fungal inoculum potential (e.g. Jasper, Abbott, and Robson 1991; Usuki, Yamamoto, and Tazawa 2007; Al-Karaki 2013). Säle et al. (2015) found a high diversity of arbuscular mycorrhizal fungi under reduced tillage. Thus, no-tillage systems appear to be favourable habitats for both plant root-colonising mycorrhizal fungi and saprotrophs that grow on plant residues.

Often the impacts of tillage cannot be separated from the influences of other factors, such as conventional versus organic management, or the physical environment in which organisms live (bulk soil or rhizosphere). For example, Hartman et al. (2018) found that in conventional and organic management systems with different tillage intensities, soil bacterial communities were primarily structured by tillage; whereas soil fungal communities responded mainly to management type, with additional effects resulting from tillage.

Reduced tillage does not necessarily lead to a more diverse microbial community. Essel et al. (2019) suggest that changes in community composition can be explained by taxon loss, rather than taxon replacement. Therefore, microbial indicator taxa that respond to tillage methods could in some cases be more effective in detecting the direction of change than measures of overall diversity.

# 3.2. BIOLOGICAL REGULATORS: NEMATODES

Treonis et al. (2010) have reported increased number of decomposer microfauna after the addition of organic amendments and tillage at 0–5 cm depth, with a decline in the abundance of plant-parasitic nematodes. They observed that tillage alone reduced the relative abundance of fungus-feeding nematodes and increased the density of bacteria-feeding nematodes. Another experiment reported that tillage in general had little effect on densities of most nematode species examined, and crop rotation appeared to be more important than tillage for managing plant-parasitic nematodes (McSorley and Gallaher 1993). A study by Ito et al. (2015) reported that tillage inversion exerted stronger effects on the nematode community, compared to cover crop treatment and manure application. Organic farming is considered beneficial for soil biodiversity; however, frequent tillage operations, which are required for incorporating organic amendments or to control weeds, decreased nematode community diversity to the level observed in a conventional system (Berkelmans et al. 2003). It can be concluded that results on tillage impacts on nematodes remain inconclusive, and even contradictory. An approach that considers variation within and between different systems, soil type and climate is needed in order to reach more reliable and general conclusions. Molecular profiling of nematode communities can support these efforts (Bongiorno et al. 2019).

# 3.3 ECOSYSTEM ENGINEERS: EARTHWORMS

According to a recent meta-analysis, the density of earthworms was, on average, 137% higher in no-tillage soils, and 127% higher under reduced tillage, compared to ploughed soil (Briones and Schmidt 2017). Corresponding percentages for biomass in no-tillage- and reduced tillage soils were 196% and 101%, respectively. Positive effects built up over time, as effects were more pronounced in soils that had been under reduced tillage for more than ten years. Furthermore, these positive effects were relatively strong in warm temperate climates, and in fine-textured and clayey soils.

Earthworm species can be divided into three ecological groups: litter dwellers, shallow burrowers and deep burrowers. Litter dwellers and deep burrowers have been shown to benefit the most when soil is not ploughed (Briones and Schmidt 2017). This is understandable as inversion tillage turns their food source, crop residues, below the soil surface. The mentioned meta-analysis further showed that retaining crop residues on the soil surface generally amplifies the positive effects of reduced tillage. All earthworms are exposed to mechanical injuries caused by tillage implements. Ploughing can also bury them in unsuitable soil layers, an effect which may be particularly harmful for earthworm juveniles and egg capsules.

In arable soils, the impacts of earthworms are not necessarily beneficial in all instances and respects. Earthworm foraging can have detrimental structural effects in the topsoil (Shuster, Subler, and McCoy 2000); water and nutrient flow along earthworm burrows may be excessive (Shipitalo and Gibbs 2000), and earthworm activity increases gaseous emissions from soil, which may not be fully compensated by their simultaneous stabilisation of soil carbon (Lubbers, Pulleman, and Van Groenigen 2017). However, the increased abundance of earthworms under reduced tillage and no-tillage can be regarded as predominantly a beneficial change, thanks to their contribution to soil ecosystem services, such as increasing crop yield, as well as enhancing nitrogen availability (van Groenigen et al. 2015), water regulation (Andriuzzi et al. 2015), soil formation (Shipitalo and Le Bayon 2004) and biological control (Wolfarth et al. 2011).

# 4. A FARMER'S STORY

As a child in the 1980s, our farm landscape in Southern Finland was always black from October to April. The crop rotation consisting of spring cereals and mouldboard ploughing was the norm. In the 1990s, ploughing was gradually replaced with reduced tillage, using a tined cultivator on some of the area. When I started farming in the 2000s, I applied the knowledge learned during my years in university and had a good look at our farm's soils. Earthworms were few, soil aggregation was poor, roots were few and the soil was badly compacted. I had to do something.

My first step was to introduce grasses and legumes into the rotation, as I thought that stronger roots could improve the soil structure. I was partially right, but the soil was already compacted, and worsened with ploughing (then regarded as necessary); and terminating the grass ley made problems worse. I also had winter sown cereals, which seemed to work better than the spring sown variants. Even after ploughing down a good grass crop in autumn, our soils were hard in the spring, and required power harrowing to create a seedbed. Then, one year, I was surprised with the weather, which resulted in a big change in our tillage system.

2012 was a very wet year, and the growing season was cold. Consequently, our harvest of field beans was due to end in September, and many of the fields were already waterlogged. I had to leave the beans unharvested on one of my fields, and the undersown crop of annual ryegrass was left to grow until spring. When I started to till the soil in spring, I could not believe my eyes – the soil that was usually cloddy and hard looked like it came from a flower bed. The soil was crumbly, and easy to till and dig with bare hands. What had happened? I learned that our soils are silts, which have poor aggregate stability if the aggregates are not maintained and built over winter by living roots and soil organisms. This started our transition to using living roots as our main tillage implement (Figure 3.1a). Currently, we aim to be without plants growing in the soil for less than three weeks out of the year. We plant cover crops among each of our crops and allow the cover crops to overwinter (Figure 3.1b). The overwintered cover crops are gently mulched to the top of the soil with (low disturbance) cultivator sweeps, and the next crop is sown under the mulch layer.

Did the cover crops and continuous plant cover solve everything? Certainly not; however, our focus is now on improving soil structure and deepening the layer of active roots. We focus on good drainage and reducing compaction, through a combination of subsoiling and root activity. The combination of good soil structure, mulching and root activity has provided a beneficial environment for earthworms, which are a welcome addition to our arsenal of tillage providers. Nowadays, I'm surprised when there are less than four worms in a spadeful of soil.

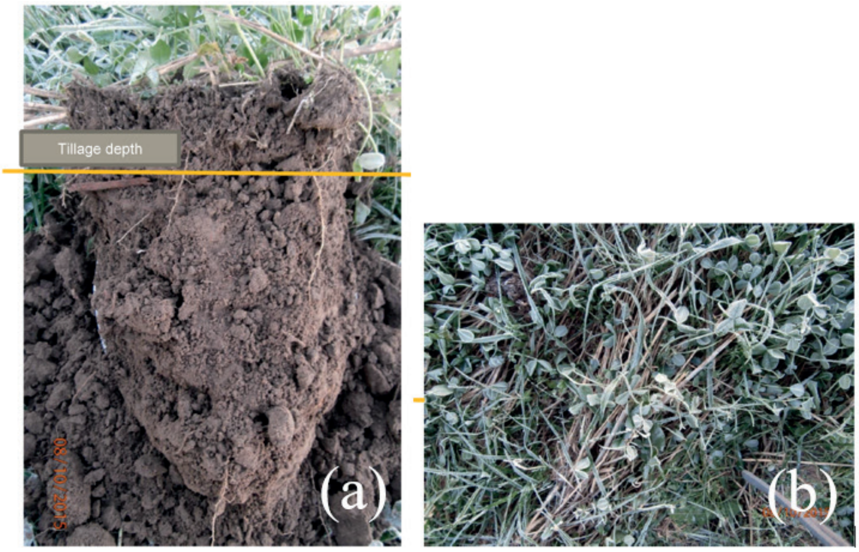


Figure 3.1. a) Soil tillage target for autumn, for silty and sandy soils: mulch cover, living roots and no compaction. b) Soil preparation in spring involves terminating the white clover cover crop with a pass of a cultivator and sweeps.

# 5. FUTURE PROSPECTS FOR SOIL BIODIVERSITY MANAGEMENT

Due to increasing awareness of the problems that intensive ploughing can cause, other systems such as reduced tillage and no-tillage regimes have been introduced. Conservation agriculture constitutes a set of practices where reduction in tillage is accompanied by retention of adequate levels of crop residues on the soil surface, as well as through the use of crop rotation. These practices are effective for erosion control, as well as for increasing soil organic matter content in the uppermost soil layer. The effectiveness of these practices in soil biodiversity conservation has been less consistent and needs to be more fully explored (Kleijn et al. 2019).

A diverse soil community is a key factor in preventing erosion as well as the loss of water, carbon and other nutrients; and there is a need for better understanding of how arable soil biodiversity is affected by management practices. Highly sophisticated methods for soil biodiversity studies are available, and they are continuously adjusted in order to provide the best available tools for identification- and quantification of soil life. We recommend strong collaborative research actions, in partnership with farmers from Europe in order to cope with future challenges in agriculture, which climate change will accentuate. This is necessary in order to preserve and develop a sustainable food production system for future generations.

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