Scientific Papers. Series A. Agronomy, Vol. LXV, No. 2, 2022
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

EVOLUTION OF SOIL ECOSYSTEM SERVICES UNDER DIFFERENT CROPPING SYSTEMS: A REVIEW

Elena Mirela DUȘA, Vasilica STAN, Ana Maria STANCIU

University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd,
District 1, Bucharest, Romania

Corresponding author email: mirela.dusa@agro-bucuresti.ro

Abstract

Soil can provide essential ecosystem services that include the supply of food, feed, raw materials and biofuels. It also has an important regulatory role (carbon sequestration, water purification, reduction of contaminants, pest control, climate, nutrient cycle and biological habitat regulation etc.). The simultaneous provision of these multiple services is the result of complex interactions between different aboveground and belowground communities across ecosystems. When a system is not well managed, persistent losses in the ecosystem services can occur. E.g. land use changes affect the structure, function and efficiency of ecosystems, thereby impacting the value of the ecosystem services. Also, various agricultural management practices lead to increased food production, but at the same time affect the ecosystem functions. In this context, the main objectives of this study are to evaluate the evolution of the soil ecosystem services under different cropping systems such as certain crop species, monoculture or various types of crop rotation, organic, mineral or integrated fertilization, soil tillage etc., and to understand the interrelation between soil and ecosystem services.

Key words*: soil, ecosystem services, cropping systems, sustainability.*

INTRODUCTION

Soil represent a key component of the ecosystem due to their slow forming and recovery rate (Pulleman et al., 2012; Jónsson et al., 2016) and the foundation of most essential ecosystem services (Breure et al., 2012; Ferrarini et al., 2018). It sustains human life through the provision of food, feed, raw materials, etc., represents a reservoir of biodiversity, which is essential for a range of ecosystem processes such as decomposition, mineralisation, and nutrient cycling, serves as a repository for the carbon and nutrient elements that sustain life, retains the water for plants growth and soil organisms and limits the soil loss, contributes to the composition of the atmosphere and impact climate (FAO, 2015; Nielsen et al., 2015; Silver et al., 2021) (Figure 1). Also, soils can provide cultural ecosystem services (i.e. recreation, spirituality, knowledge, aesthetics etc.) (Power, 2010).

Soil functions are strongly interrelated and they are used to assess soil ecosystem services (Prado et al., 2016; Pereira et al., 2018).

Agricultural ecosystems cover approximatively 40% of the Earth land area and are providers of ecosystem services such as pollination, pest control, genetic diversity for future agricultural use, soil retention, soil fertility maintenance and nutrient cycling that support the provisioning services (Power, 2010).

As economy developed and human production activities increased, the structure and functions of agricultural ecosystems changed, resulting in a series of ecological and environmental problems (e.g. cropland quality decline and its overall function) (Tao et al., 2022).

Intensive agriculture focusses on profit maximization achieved by high yields, the technologies applied being based on high consumption of industrial resources (Luty et al., 2021). The Green Revolution of the 1950s and 1960s led to tripled cereal crop production with just a 30% increase in land area cultivated due to crop genetic improvement, combined with enhanced inputs and irrigation. Intensification of the agricultural system did not end with the Green Revolution. From 1985 to 2005, global crop production increased by another 28% (Bennet et al., 2021).

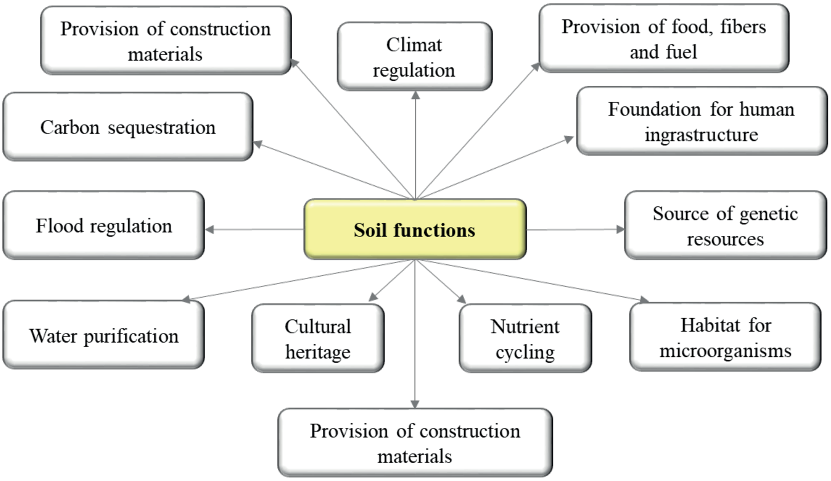

Figure 1. Soil functions diagram (modified after FAO, 2015)

In conventional agriculture, agroecosystems are "often maintained in a state of nutrient saturation and are inherently leaky as a result of chronic surplus additions of nitrogen and phosphorus" (Power, 2010). From 1965 to 2000, nitrogen fertilizers use increased 6.87 times and phosphorous fertilizers use increased 3.48 times. Thus, the increasing agricultural intensity generates pressure not only on land resources but also across the whole environment (Tilmann, 1999; Kanianska, 2016).

Nitrogen chemical fertilizers raise a series of issued related to the potential effects on biodiversity and ecosystem functioning (Socolow, 2016). More than half of the nitrogen in agriculture is not properly used and is lost to the environment by nitrate leaching and emissions of ammonia (NH_3), nitrous oxide (N_2O) and nitrogen oxide (NO), out of which the volatilization loss of ammonia represents 10 to 60% of the total nitrogen intake (Sun et al., 2019). Also, different practices within intensive agriculture (monoculture or short crop rotation, conventional tillage - CT, use of pesticides, intensive grazing and livestock production) are known for their negative impact on soil ecosystem services in the agricultural areas (e.g. acidification, salinization, erosion, compaction, water use increase, soil fertility loss, greenhouse gas emissions and increased pollution) (Gomiero et al., 2011; Pereira et al., 2018).

A response to the contrast between sustaining human population growth through agricultural production and maintaining the ecosystem functions within conventional agriculture could be the promotion of alternative agricultural production systems, which were brought to global attention in the mid 80's and are closely linked to the idea of sustainability (O'Donoghue et al., 2022).

Conservation agriculture practices, which include reduced tillage or no-tillage, retention of crop residues on soil, and crop rotations, including cover crops, aim to increase crop yields by enhancing several regulating and supporting ecosystem services (Palm et al., 2013). They can reduce erosion due to residues retention on soil surface and increase water infiltration and decrease runoff with no-till. The benefits of conservation agriculture on ecosystem services (nutrient cycling, C sequestration, and pest and disease control) can vary depending on soil management, soil type, and climate (Palm et al., 2013). Conservation agriculture practices can limit the soil fertility and agroecosystem functioning by increasing water deficiency for crops in drought periods, pest infestation due to entire maintenance of crop residue on soil surface and the risk of off-site water source contamination because of organic nutrient management (Stavi et al., 2016).

Organic agriculture system is subordinated to the rhythm of natural processes (Luty et al., 2021). Its practices rely on and benefit from biological cycles (i.e. appropriate selection of crop rotations or cover crops, biological control etc.) (Boone et al., 2019), may lead to the reduction of greenhouse gases emissions, and a better biodiversity, water use efficiency, soil, and air quality (Gomiero et al., 2011), but “require more land to produce the same amount of output and therefore, their better environmental results might be cancelled” (Boone et al., 2019).

The concept of integrated farming systems appeared in Western Europe in the 1980s and combines natural processes with agricultural activity. Integrated farming includes the application of phytosanitary products and organic and chemical fertilizers, but at minimum levels to prevent the spread of nutrients outside the agroecosystems. Also, it promotes crop rotation, especially with leguminous species and intercrops, which addresses the concept of ecosystem services (Luty et al., 2021).

The negative effects of agricultural production on ecosystem services can be avoided through the adoption of sustainable agricultural practices that include soil conservative tillage (conservation tillage - CsvT, reduced tillage - RT, minimum tillage - Mt and no-tillage - NT), crop diversity practices (e.g. intercropping or the use of multi-year crop rotations), returning of organic matter to soil, cultivation of carefully selected cover crops, mulching - which protects soil and increase its fertility, integrated pest management (Valieva et al., 2010). Also, a constant and balanced use of fertilizers and organic amendments (compost, biochar etc.) can contribute to the soil structural stability and quality restoring (Siedt et al., 2021). The sustainable practices we focused on in this study were the use of organic fertilisers, various crop rotations and conservation tillage.

Sustainable agricultural practices can improve the efficiency of resources in agriculture and the sustainability of agroecosystems, but more research is needed to identify ways to strengthen the resilience of systems as well as their sustainable performance, with high productivity, stable yields, maximum resistance to stressors and a positive response to favourable conditions, leading at the same time to long-term economic and social sustainability, multiple ecosystem services and a minimal impact on the environment (Peterson et al., 2018).

The main objective of the study is to assess the evolution of the soil ecosystem services under different cropping systems such as certain crop species, monoculture, or various types of crop rotation, organic or mineral fertilization, soil tillage etc. and to understand the interrelation between soil and ecosystem services, focusing only on soil structure, soil organic matter and organic carbon contents under different cropping systems.

MATERIALS AND METHODS

A number of 114 research papers published between 1990-2022 in different multinational indexed open access journals like *Elsevier, Springer, Taylor & Francis, MDPI* or research networking sites such as *Wiley Online Library*, *Web of Science, ResearchGate* were used for this review. A search query was applied for titles that included the following terms: “*soil ecosystem services*”, “*monoculture*”, “*crop rotation*”, “*organic amendments*”, “*chemical fertilisers*”, “*conventional tillage*”, “*conservation tillage*”, “*reduced tillage*”, “*no-tillage*”, “*soil structure*”, “*soil physical properties*”, “*organic matter*” or “*organic carbon*”.

There are many research papers that focus on the relationship between soil and ecosystem services, but this subject cannot be exhausted since, at the global level, there is a wide range of ecological conditions in which agriculture is performed and at the same time there is a wide range of agricultural practices whose impact on the environment is very variable.

This study focusses on the current knowledge on: i) cropping systems (monoculture, 2-3 years crop rotations, long-term crop rotation); ii) soil tillage systems (conventional, conservation, reduced or no-tillage); iii) fertilisation methods (chemical and organic fertilisers) and their effects on the ecosystem services.

RESULTS AND DISCUSSIONS

Overview

Monoculture or the practice of growing one crop species at a time year after year (Aman, 2020) emerged a couple of centuries ago as a cropping system that allow farmers for a more efficient planting and harvesting, use of fewer types of expensive equipment and labour. After 1945, monoculture evolved globally and currently supplies most of our food and a significant share of non-food crops. Despite its advantages, monoculture is amongst the most controversial features of today's agriculture (Balogh, 2021). Over the years, in monoculture system, standard and persistent agronomic practices were employed (i.e. the use of similar pesticides, fertilizers, farm machinery, tillage depth, etc), which led to the evolution of certain weeds, pests, and diseases, depletion of nitrogen, phosphorus, and potassium from soil, the reduction of essential nutrients content in the agricultural soils, the alteration of soil physico-chemical and biological properties (Pervaiz et al., 2020).

Crop rotation is a practice that farmers have been using for centuries. It can be simple, where two crops are alternated every year or can follow a more complex pattern, several crops being rotated (Plourde et al., 2013). Simplified corn-soybean rotation is under expansion during the past several decades in the U.S., due to "increased food and industrial uses, economic and world trade benefits, and tremendous efforts devoted to genetic improvement and infrastructure development" (Wang et al., 2021). In the European Union (EU), crop rotations last 3 to 5 years in conventional agriculture and 5 to 10 years in organic agriculture and can include different species and strategies to achieve the desired outcome (Mudgal et al., 2010). For example, 3-year rotations were recently studied under the conditions of a stagnant argic faeoziom type soil (Moraru and Rusu, 2013), as well as under the specific climatic conditions of the sylvosteppe area in the south-est of Romania (Figure 2), on a red preluvosoil (Dușa M., 2022). Different socio-economic and technological factors influenced the abandonment and rediscovery of crop rotation over time. Since the Green Revolution, farmers have been choosing simplified rotation because of innovations in machinery, better performing varieties, chemical fertilisers, efficient pest and weed control as well as market opportunities. Breeding and the improvement of watering practices allowed the development of more diversified crop rotations (Mudgal et al., 2010). From 1950 to 1970, the choices of crop rotation were greatly influenced by the changes in the world economic situation. The economic factor that had an impact on the crop rotations was the good market prices for maize and wheat, with dropping demands on grain leguminous crops which were taken out from crop rotations in Europe. The energetic crisis in 1970 increased fuel prices, the imported crops from other continents became more expensive and farmers had to diversify the production and to implement crop rotation in their management practices (Mudgal et al., 2010).

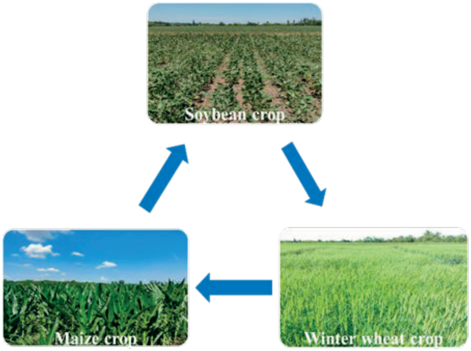

Figure 2. Winter wheat - maize - soybean crop rotation diagram in Moara Domneasca Experimental Field for 2021-2023 period

Diversified crop rotations have positive effects on ecosystem services: they suppress weeds and pests thus reducing the costs of chemical fertilisers and pesticides, reverse soil degradation by increasing the soil microbial biomass C and N pools, reduce soil erosion (Wang et al., 2021) by improving soil structure (Hoss et al., 2018). Long-term crop rotations also reduce the risks of eutrophication due to runoff and leaching and improve crop yield (Hunt et al., 2019). There are also some disadvantages of crop rotations but those are low compared to benefits: less profitability (when farmers are forced to reduce the area cultivated with the most profitable crop), sometimes decreased crop flexibility and some rotations involve high inputs (Selim M., 2019).

Crop rotation and soil physical properties

The sustainability of an ecosystem can be estimated by assessing and monitoring soil properties, which are sensitive, over time, to various changes that occur and through which the quality of soil can be evaluated (Novak et al., 2019). Soil physical quality affects the conditions under which plants absorb nutrients and how chemical reactions or biochemical and microbiological transformations take place (e.g.

oxidation and reduction processes, transfer, or immobilisation of pollutants in soil, etc.) (Pranagal et al., 2021). Also, high quality soils should be resistant to degradation and resilient in their ability to recover from unfavourable conditions (Larkin et al., 2021).

There are not many studies on the evolution of soil physical properties under long-term *monoculture* and under the conditions of typical agricultural production. However, according to Pranagal et al. (2021), long-term wheat monoculture didn't have a significant negative impact on soil physical properties. For instance, the values for field air capacity of soil (which provides information on soil oxygenation, gas exchange, soil organisms activity, oxidation and reduction processes) under monoculture were higher than those for the soil under crop rotation (under wheat monoculture, the soil contained more air - 0.144 $m^3 m^{-3}$ - compared to the soil under crop rotation - 0.117 $m^3 m^{-3}$). It is important to say that the changes in the field air capacity caused by long-term wheat monoculture didn't led to significant deterioration of soil aeration. Also, under monoculture, soil bulk density was lower (1.69 Mg m^{-3}) than in crop rotation (1.75 Mg m^{-3}) (Pranagal et al., 2021).

A long-term experiment with winter wheat monoculture on a Spolic technosol from Poland showed that soil had visible large pores, developed mainly due to the presence of wheat stalks and roots which were mixed each year during ploughing, and the highest values of bulk density or total porosity (Kofodziej et al., 2016). An increase of soil bulk density and a decrease of porosity under monoculture can be explained by the deep plants root distribution in soil, the decrease of water content around root system and thus the intensification of soil compaction (Wu et al., 2021).

Crop rotation can be an eco-friendly measure, providing diversification in crop management systems and modifying the high pressure on the agricultural ecosystem (Saulic et al., 2022). There is a strong correlation between the species included in the crop rotation system and soil properties. So, "deep-rooted crops should ideally follow shallow-rooted ones to preserve subsoil structure" (Lampkin, 1990). This alternation of crops leads to uniform root distribution, good soil structure, increased soil porosity and permeability, reduced soil bulk density, improved soil aggregate stability, increased water retention and stability, and increased resistance to soil erosion (Yu et al., 2022).

Crop rotation with grain leguminous and perennial forage species can have beneficial effects on soil physical properties by increasing microporosity, hydraulic conductivity and aggregate stability and decreasing bulk density and penetration resistance (Gotze et al., 2016). Under a crop rotation with lupin and canola, soil had a lower shear strength and a greater porosity than those with cultivated field pea and barley (Ball et al., 2005). Also, a crop rotation practiced in an organic farming system that included red clover had a strong influence on soil pore-size distribution. Here, the highest soil meso-porosity (0.2-30 μm) and the lowest microporosity (< 0.2 μm) were registered compared to other crop rotations (spring barley - buckwheat or buckwheat - white mustard - buckwheat - rye -spring wheat) (Feiziene et al., 2016).

However, some authors showed that short crop rotations, such as corn-soybean or wheat-soybean reduce macro-aggregation because of low residue input by soybean (Agomoh et al., 2021). Zuber et al. (2015) reported that the inclusion of soybean in rotation with corn led to reduced water aggregate stability as compared to corn monoculture. This can be explained by the low residue accumulation and soil organic matter depletion. Also, in corn-soybean rotation, the soil remains uncovered over-winter and this can increase the risk of erosion (Blanco-Canqui, 2018).

A 3-year wheat-soybean-maize crop rotation significantly reduced the bulk density in the 0-20 cm and 20-40 cm soil layers and increased soil porosity (Wu et al., 2021). In crop rotation, maize can be considered a suitable species due to its fibrous roots that produce high levels of macro-aggregation (Bronick and Lal, 2005). Diversification of crop rotations by including cereals, cover crops or overwinter crops can be a strategy to imitate the structure of natural ecosystems, and may improve soil ecosystem services (Taveira et al., 2020). Complex crop rotations which include alfalfa improve soil saturated water content and aggregation compared to simple rotations because perennial leguminous have deep tap roots that lift the soil for better water holding capacity. As a result of improved soil aggregation, the abundance of larger soil pores increases and this contributes to a higher saturated water content and hydraulic conductivity (Kiani et al., 2015).

Making a comparison with an annual crop rotation without grassland, Van Eekeren et al. (2008) showed that a 3-year annual crop rotation preceded by 3-year of grassland lead to an improved soil structure (i.e. higher percentage of crumbs and sub-angular blocky elements), and a lower bulk density.

Within an experiment with two crop rotations which included corn-corn-oats-spring barley (with red clover under-seeded in oats and spring barley) and corn-corn-soybean-soybean and 4-year corn monoculture, the poorest soil structure was recorded in monoculture and a good soil structure in corn-corn-oats-spring barley rotation. Also, the topsoil structural quality was better preserved in the diverse rotation compared to monoculture or corn-corn-soybean-soybean rotation (Munkholm et al., 2013).

The influence of crop rotation on soil structure depends both on the chosen species for rotation as well as on soil management practices (Ball et al., 2005).

Tillage systems and soil physical properties

The need to minimize the impact of agricultural practices on soil structure is one of the main purposes of land management (Pagliai et al., 2004). But tillage systems can have a different effect on soil physical properties because of the variation of tillage intensities (Bhattacharyya et al., 2008).

According to Pagliai et al. (2004), *conventional tillage* modifies the most, soil physical properties having a negative impact on soil structure due to surface crust. Also, the elongated transmission pores decreased significantly, thus indicating that the soil structure became compact, and a plough pan was developed at the lower limit of cultivation.

Conservation tillage (which includes reduced tillage and no-tillage) is a sustainable management practice associated with improved water infiltration and conservation, reduced erosion and improved soil structure (Žurovec et al., 2017).

Reduced tillage can have a strong influence on the soil aggregates stability compared to conventional tillage (Pagliai et al., 2004; Daraghmeh et al., 2009; Obalum et al., 2019) but its positive effect on soil depends on climatic conditions and soil type (Daraghmeh et al., 2009).

Within an experiment with different tillage practices conducted in Germany over a period of 37-40 years, Jacobs et al. (2009) reported that reduced tillage improved the aggregate stability and increased the concentrations of soil organic carbon and nitrogen within the aggregates in the upper soil compared to conventional tillage. Also, compared to CT, RT decreased the soil bulk density and increased the proportion of larger aggregates, thus increasing soil structure (Daraghmeh et al., 2009).

However, Schluter et al. (2018) observed that under CT and RT, differences in soil structure were determined only in a shallow depth. Thus, ploughing led to soil loosening and increase of macroporosity and macropore connectivity. Instead, the absence of ploughing caused compaction and a decrease of hydraulic conductivity that wasn’t recovered even if the earth-worms population from the soil increased (Figure 3).

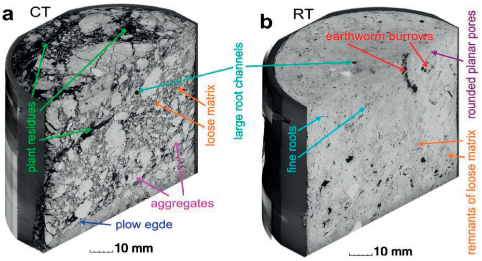

Figure 3. Microstructure of soil at a depth of 13-23 cm, in a) conventional tillage and b) reduced tillage (reprinted after Schluter et al., 2018)

Regarding the soil pore system, Pagliai et al. (2004) reported that under minimum tillage, there was an increase of the storage pores (0.5-50 μm) and of the amount of elongated transmission pores (50-500 μm) mainly due to the improvement of soil water content and to the increase of available water for plants.

Under certain environmental conditions, *no-tillage systems* (NT) may have some advantages over CT such as the improvement of soil aggregate stability and reduction of soil loss, increasing soil water availability and the number of bio-pores that can facilitate root growth (Martinez et al., 2008). Thus, comparing the effects of CT and NT treatments on the soil physical properties it was observed that NT systems enhanced the soil aggregate stability and decreased soil water infiltration and coarse porosity (Martinez et al., 2008). Also, the values obtained by Moreira et al. (2016) for bulk density and pore size distribution under NT system indicated an improvement of soil physical properties and showed a physical balance condition, which can be modified only by short term events like weather conditions variability, intensive machinery traffic or changes in crops grown in the crop rotation system.

Even if NT system has some environmental advantages compared to the conventional one, there are also some important negative effects of this system on soil physical properties such as surface compaction through the reduction of macropores, mainly when heavy machineries are used in high soil moisture conditions (Sokolowski et al., 2020).

Conservation tillage can be applied depending on soil conditions. For instance, in soils with fine texture and poorly drained, minimum tillage (MT) is encouraged, while in light-medium texture and well drained soils, NT will be beneficial (Bussari et al., 2015).

Soil organic matter under different cropping system

Crop rotation and soil organic matter

Soil organic matter (SOM) is a key element of soil properties and processes (bulk density, structure, temperature, water relations, nutrient availability, and biological activity) (Miles et al., 2008) that can be affected by agricultural practices (Liu et al., 2006). Therefore, improving the content of organic matter in the soil could be a strategy to make resilient agroecosystems (Allam et al., 2022). Dynamics and the quantity of SOM are affected by the land use changes and management and this can be measured in practice as soil total organic carbon (TOC) (Apezteguia et al., 2009). Plant diversity can influence the ecosystem processes including SOM dynamics (McDaniel et al., 2014). The crops included in rotation can have different effects on the quantity and quality of SOM through their biomass, plant residues characteristics, root system and their influence on the soil microbial community (Raphael et al., 2016). The studies conducted over time showed that crop rotation can decrease, increase, or have no effect on SOM concentration (McDaniel et al., 2014).

Within an experiment which focused on the assessment of the SOM stratification under 3 crop rotations namely continuous corn, 2-year corn-soybean and 3-year corn-oat-alfalfa combined with three levels of tillage intensity, Deiss et al. (2021) showed that, under NT, crop rotation with oat and alfalfa maintained or increased SOM accumulation. The high root biomass produced by perennials can lead to increased SOM accumulation. Moreover, corn-soybean crop rotation decreased SOM accumulation compared to continuous-corn and corn-oat-alfalfa.

Regarding the soil organic carbon (SOC) content, lower values were also obtained when soybean was included in a short crop rotation with corn compared to a corn monoculture because soybean produce lower residue and those are decomposed more quickly. Even if SOC was higher in corn monoculture than in corn-soybean crop rotation, more complex rotations can lead to a greater SOC accumulation (Zuber et al., 2015).

Within an experiment carried out in Poland on a luvisoil including 2 long-term crop rotations with potato-oat-flax-winter/rye-faba bean-winter triticale and sugar beet-maize-spring/ barley-pea-winter rape-winter wheat as well as a long-term monoculture with each species included in crop rotation, the organic carbon content slightly increased in both crop rotations, being greater in the first one. In monoculture conditions, the lowest amount of organic carbon was registered in maize (0.57%), pea (0.63%) and potato (0.66%) and the highest content was registered in winter triticale (0.81%), winter wheat (0.80%) and faba bean (0.80%) (Rychcik et al., 2006).

Liu et al. (2006) reported that 11-year continuous maize, soybean, and wheat led to soil organic carbon decline, compared to all crops in rotation. SOC decline in deeper soil profile in continuous soybean may be due to the tap root system of this or the impact of monoculture on soybean root nodules and nitrogen fixation. Also, under continuous cropping, the SOC loss reported by Salvo et al. (2010) in the Ap horizon was in average of 540 kg/ha/year while in crop-pasture rotation, the average loss was only of 80 kg/ha/year.

Gregorish et al. (2001) found a large increase in SOC level in maize-oat-alfalfa-alfalfa crop rotation than under maize monoculture. However, the species included in the crop rotation may have different effects on the quantity and quality of C inputs and further on the mineralisation rates and the growth of subsequent crops (Huggins et al., 2007). Plant species that return greater amounts of residues to the soil can be included into crop rotation and can be associated with greater SOC contents (Page et al., 2020).

Rotations which include grain legumes such as mung bean, pigeon pea, cowpea, chickpea, soybean etc., can maintain higher organic matter levels in the soil than non-leguminous crops grown in monoculture systems (Kamanga et al., 2014). After long-term continuous cropping of cereals, the inclusion of grain leguminous species (i.e. pigeon-pea, mung-bean or chickpea in crop rotations with maize or wheat brought significant changes in SOC, the increase being probably due to the addition of C-input through above- and belowground crop biomass (Venkatesh et al., 2017). Also, wheat-lentil crop rotation resulted in higher soil C levels than other wheat cropping systems, which is attributed to more efficient conversion of residue C to soil C in grain legume rotation systems than in monoculture wheat (Campbell et al., 1999).

Crop rotations that include perennial forage crops can be considered very important for SOC because, compared to annual crops, there is a lower soil disturbance from tillage and they have a higher root biomass (Bolinder et al., 2012). A 38-years experiment carried out on a silty clay loam soil in Uruguay was used to observe the effect of a 4-year cycle annual crop rotation with sorghum-flax-wheat-sunflower followed by 4-year periods of pasture on TOC at 20-40 and 40-60 cm soil depths. In both depths, TOC was higher in pasture (15.39 and 9.26 g C/kg soil) than in annual crop rotation (11.39 and 7.26 g C/kg soil) (Gentile et al., 2004).

Tillage systems and soil organic matter

Land management practices including different tillage systems influence the quantity and composition of SOM (Šimon et al., 2009) and its turnover due to different quantity and quality of plant residues, ratio between above- and belowground inputs and changes in soil disturbance (Machado-Pinheiro et al., 2015).

Conventional tillage can increase soil erosion process and carbon mineralization rate which further can cause significant losses of SOM content (Salvo et al., 2010; Pantani et al., 2022). Under intense tillage, SOM is exposed to oxidation, this process stimulating its decomposition by soil microbes (Hussain et al., 2021).

The loss of organic matter and structure degradation that is potentially produced by CT (ploughing) could be prevented using conservation tillage (Hazarika et al., 2009). Adopting CsvT or NT could be a solution for farmers to preserve soil fertility (Pantani et al., 2022) and to reduce the soil carbon loss (Haddaway et al., 2017).

Using different tillage methods (i.e. CvsT, CT, NT, MT) on a clay-loam texture soil Šimon et al. (2009) noted that SOM content was greater under CvsT where plant residues remained on the soil surface compared with CT, where SOM was distributed in the soil profile. Hussain et al. (2021) noted also that CvsT can improve SOC and organic matter content and can have a big contribution to SOC sequestration.

Under NT system, the percentage of SOM of a sandy loam soil from central Italy was higher (3.31%) than under CT (2.19%) (Sapkota et al., 2012). Also, SOC gains under NT were about 250 kg/ha/year higher than in tilled systems regardless of the cropping frequency in semiarid climate conditions. In the surface layer, NT system had 7.28 Mg/ha more SOC and 4.98 more particulate organic matter carbon than CT (Liu et al., 2006).

In NT system, the crop residues are left on the soil surface and thus a higher amount of organic matter mineralization rate (Hussein et al., 2021). Compared to CT, RT or NT increased SOC in the topsoil (9.8% in NT and 16.7% in RT). This increase could be explained through the retention of crop residues on the soil surface which created a barrier and reduced the contact with soil microorganisms, thus protecting the microbial decomposition (Allam et al., 2022).

The adaptation of long-term conservation tillage practices, including NT or RT favours higher organic carbon concentrations, especially in upper soil profiles but a continuous monitoring of soil quality and SOC changes is essential (Liu et al., 2006).

Fertilisation methods and soil properties

Fertilisation contributes to crop yield increase, soil fertility improvement and agricultural ecosystem functioning (Jaskulska et al., 2020; Wen et al., 2020), but also can produce changes in soil properties soon after their application or after many years. The effect on soil depends on the type and dose of fertilisers, the methods of application, the climate conditions, or other agricultural technologies (Jaskulska et al., 2020).

Fertilisation and soil physical properties

The impact of mineral or organic fertilizers on soil environment can be assessed by quantifying the modifications of soil structure (Naveed et al., 2014). Nitrogen fertilization could increase (Bronick et al., 2005; Naveed et al., 2014) or reduce the soil aggregate stability (Plaza-Bonilla et al., 2013) or there is no effect of inorganic fertilizer on soil structure (Plaza-Bonilla et al., 2013; Zhou et al., 2013).

Zhang et al. (2021) noted that fertilisation with N and P separately didn’t significantly affect the aggregate stability as compared to the combination of N and P fertilizers (at high doses of N - 540 kg N/ha/year and P - 67.5 kg P/ha/year). Also, the decrease of aggregate stability was found to be larger when higher amounts of N and P fertilizers were applied (e.g. at rates bigger than 100 kg N/ha/year or than 40 kg P/ha/year) than when N and P were applied alone or in smaller doses (Blanco-Canqui et al., 2013). In an experiment carried out by Tuo et al. (2016), the mean weight diameter (MWD) values of soil aggregates were lower when chemical fertilizers with N and P were applied alone or in combination as compared to non-fertilised variant.

Applying organic fertilizers could be an option to reduce the negative impacts of chemical fertilizers by stagnating soil degradation (Li et al, 2021). Some authors reported that organic manure can increase aggregate stability and soil porosity and decrease the bulk density (Haynes et al., 1998; Pagliai et al., 2004). However, Yu et al. (2012) found out that farmyard manure significantly reduced the proportion of microaggregates, while Zhang et al. (2018) found out that this type of fertiliser had no significant effects on the microaggregates. Those different effects of organic fertiliser on the distribution of microaggregates may be associated to the specific soil characteristics and climatic conditions (Yu et al., 2012).

Research carried out in a semi-humid or arid region in China revealed that swine manure has a negative impact on soil aggregation, which can be explained by the accumulation of exchangeable Na^+ on the topsoil in these areas (Guo et al., 2019). Compared to chemical fertilisation, manure or the combination of manure and chemical fertilizers increased the proportion of small macroaggregates and decreased the proportion of microaggregates (Xie et al., 2015). Naveed et al. (2014) reported an improvement of soil structure and related soil functions (water holding capacity, total porosity, wider pore size distribution, higher pore connectivity) with increasing animal manure in combination with NPK fertilizer applications.

Compost application increase soil properties like porosity, available water, organic matter, and decrease bulk density (Ejigu et al., 2021). For instance, Bouajila and Sanaa (2011) showed that the application of 120 t/ha manure and household waste compost led to an increase of structural stability, a better soil permeability, an increase of organic carbon and organic matter in the soil when compared to control. Those results can be due to the presence of a great amount of organic matter which is associated to a greater microbiological activity.

The effect of chemical and organic fertilizers on soil structure (Table 1) is a complex process which can be affected by many factors (soil type, crops, fertilizer rates, etc.).

Table 1. The impact of chemical and organic fertilization on soil structure

Soil type	Crop	Fertilization rate/year	Impact on soil structure	References
ns	ns	N fertilisation - no rates specified	Increased soil aggregation	Bronick and Lal, 2005 - review; Naveed et al., 2014
Loess	Soybean-maize rotation	Manure - 500 kg/ha, N -100 kg/ha and P_2O_5 - 50 kg ha alone or in combination	Manure alone or with N and/or P can increase WSA, MWD and AS. Long-term application of N and P alone or NP results in lower values of properties above.	Tuo et al., 2016
Mollic Andosol Luvisol	Grassland Maize-wheat rotation	164-184 kg N/ha/ year 0, 60, 120 mg N/kg dry soil Crop residue input	Higher SOC mineralisation and worse structural state of soils	Shimizu et al., 2009 Le Guillou et al., 2011
Aridic Haplustoll	Maize	0, 45, 90, 134, 179, 224 kg N/ha; 0, 20, and 40 kg P_2O_5/ha	Decrease of aggregate stability and macropore reduction	Blanco-Canqui et al., 2013
Brown soil	Maize	Composted swine manure: 13.5 and 27 Mg hm^{-2} yr^{-1}; NPK fertiliser (urea, multiple phosphate, and potassium sulphate) rates: 135, 29, 56 kg hm^{-2} yr^{-1}	NPK treatment decreased the proportion of small macroaggregates, but manure or manure plus chemical fertilizers increased the same size aggregate. NPK increased the proportion of microaggregates, but manure or manure plus chemical fertilizers decreased the same size aggregate.	Xie et al., 2015
Vertisol	Wheat-maize crop rotation	12-year N fertilisation with 0, 360, 450, 540, 630, 720 kg/ha/year	Reduced soil aggregate stability by 12-18% at rates of 0-720 kg/ha/year (because of the increases in monovalent ions (H$^+$ and NH$_4^+$).	Guo et al., 2022
Vertisols Luvisols	Maize	Urea-0, 50 and 100 kg/ha Compost - 0, 5 and 10 t/ha	Compost alone or combined with mineral fertilizer decreased soil BD hence improving total porosity, water infiltration and aeration of the soil. Low BD value (1.22 g/cm^3) -in compost 10 t/ha	Ejigu et al., 2021
Ns Loam soil	Ns Maize	Organic manure Compost: 0, 40 and 10 Mg/ha and livestock manure – 10 Mg/ha	Increased water holding capacity, porosity, infiltration capacity, WSA and decreased BD	Haynes et al., 1998 - review; Pagliai et al., 2004

Ns - unspecified; MWD - mean weight diameter; WSA - water stable aggregates; AS - aggregate state; BD - bulk density

Fertilisation methods can also influence the soil organic matter content. Synthetic N fertilizer can reduce the SOM stocks due to a greater mineralization (Russel et al., 2009) or can increase the amount of SOM, mainly at optimum N fertilizer rate because it increases net primary productivity (Poffenbarger et al., 2017). The application of mineral fertilizer in combination with composted farmyard manure improved SOM contents compared to non-fertilised treatment (Guo et al., 2014). Also, one way of restoring SOM content is to increase the organic inputs by applying organic fertilisers. The effect of organic fertilisers may be related to the amount and quality of the organic matter applied and to the stabilisation capacity of the soil. The stabilisation of SOM depends on its interaction with mineral surfaces, which make it less available to microorganisms. Thus, long-term utilisation of compost as fertiliser led to higher amounts of soil organic matter in the 30 cm layer than in soils treated with mineral fertilisers, with an average difference of 46% in soil C stocks (Garcia-Pausas et al., 2017).

The excessive use of chemical fertilizers can result in 7 to 11% SOC loss from soil (Zhang et al., 2021). Long-term organic fertilisation can lead to higher organic C content in soils than in those that are receiving only mineral fertilisers, which is observed mainly in the upper soil (Garcia-Pausas et al., 2017; Zhang et al., 2018). A positive impact on SOC was observed when organic fertilizers were applied alone or in combination with mineral fertilizer (Allam et al., 2022). Organic fertilizers supply the substrate for soil microorganisms which are converting it into soil organic matter (Yang et al., 2016). Even if the high rates of nitrogen fertilisers stimulate the decomposition process and determine the depletion of SOM, their application may lead to a SOC increase, favouring the accumulation of plant biomass (Allam et al., 2022).

CONCLUSIONS

Soils represent an important component of the ecosystem, and its functions are strongly interrelated. Soil structure and fertility provide essential ecosystem services to agroecosystems. Changes in soil quality are gradual and the measurements regarding the effect of different cropping systems cannot be observed on short-term. Thus, the long-term experiments are of great importance.

Some management practices have negative or no effects on soil properties (i.e monoculture, intensive tillage, or chemical fertilisation). Differences in the tillage practices can determine changes in soil physical properties and its fertility, thus affecting the soil function and its capacity to provide ecosystem services (Bai et al., 2018).

Soil organic matter is related to various key soil functions that are relevant to soil ecosystem resilience and recovery (Grandy et al., 2012). Organic fertilisers can improve soil structure and soil organic matter content, both alone and in combination with mineral fertilisers, but increased soil organic matter contents depend on the amount and type of organic matter applied as well as on the period of application. Agricultural management practices are important elements in obtaining the benefits of ecosystem services and reducing disservices from agricultural activities, but future research is needed to estimate the value of various ecosystem services related to agriculture and to analyse the interactions between soil functions.

ACKNOWLEDGEMENTS

This work was supported by a grant of the University of Agronomic Sciences and Veterinary Medicine of Bucharest, project number 1258/30.07.2021, acronym SustenRo, within IPC 2021.

REFERENCES

Agomoh, I.V., Drury, C.F., Yang, X., Phillips, L.A. (2021). Crop rotation enhances soybean yields and soil health indicators. *Soil Sci. Soc. Am. J.,* 85, 1185–1195.

Allam, M., Radicetti, E., Quintarelli, V., Petroselli, V., Marinari, S., Mancinelli, R. (2022). Influence of Organic and Mineral Fertilizers on Soil Organic Carbon and Crop Productivity under Different Tillage Systems: A Meta-Analysis. *Agriculture*, 12, 464.

Aman, M. (2020). Impact of monocropping for crop pest management: Review. *Acad. Res. J. Agri. Sci. Res.* 8(5), 447-452.

Apezteguıa, H.P., Izaurralde, R.C, Sereno, R. (2009). Simulation study of soil organic matter dynamics as affected by land use and agricultural practices in semiarid Córdoba, Argentina. *Soil and Tillage Research*, 102(1), 101-108.

Bai, Z., Caspari, T., Ruiperez Gonzalez, M., Batjes, N., Mader, P., Bunemann, E. et al. (2018). Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agriculture, Ecosystem and Environment,* 265, 1-7.

Ball, B.C., Bingham, I., Rees, R.M., Watson, C.A., Litterick, A. (2005). The role of crop rotations in determining soil structure and crop growth conditions. *Can. J. Soil Sci*. 85, 557–577.

Balogh, A. (2021). The rise and fall of monoculture farming. Horizon, The EU Research & Innovation Magazine.

Bennet, E., Baird, J., Baulch, H., Chaplin-Kramer, R., Fraser, E., Loring, P. et al. (2021). Ecosystem services and the resilience of agricultural landscapes. *Advances in Ecological Research*, vol. 64, Elsevier Ltd, ISSN 0065-2504.

Bhattacharyya, R., Kundu, S., Pandey, S.C., Singh, K.P., Gupta, H.S. (2008). Tillage and irrigation effects on crop yields and soil properties under the rice-wheat system in the Indian Himalayas. *Agric Water Management*, 95, 993-1002.

Blanco-Canqui, H. (2018). Cover Crops and Water Quality. *Agronomy Journal*, vol.110, pp.1633–1647.

Bolinder, M.A., Katterer, T., Andren, O., Parent, L.E. (2012). Estimating carbon inputs to soil in forage-based crop rotations and modeling the effects on soil carbon dynamics in a Swedish long-term field experiment. *Can. J. Soil Sci*., 92, 821-833.

Boone, L., Roldan-Ruiz, I., Van Linden, V., Muylle, H., Dewulf, J. (2019). Environmental sustainability of conventional and organic farming: Accounting for ecosystem services in life cycle assessment. *Science of The Total Environment,* 695, 133841.

Bouajila, K., Sanaa, M. (2011). Effects of organic amendments on soil physico-chemical and biological properties. *J. Mater. Environ. Sci*. 2, 485- 490.

Breure, A.M., DeDeyn, G.B., Dominati, E., Eglin, T., Hedlund, K., Van Orshoven, J., Posthuma, L. (2012). Ecosystem services: a useful concept for soil policy making! *Current Opinion in Environmental Sustainability*, 4, 578–585.

Bronick, C.J., Lal, R. (2005). Soil structure and management: a review. *Geoderma*, 124, 3-22.

Busari, M.A., Kukal, S.S., Kaur, A., Bhatt, R., Dulazi, A.A. (2015). Conservation tillage impacts on soil, crop and the environment. *International Soil and Water Conservation Research*, 3, 119-129.

Campbell, C.A., Zentner, R.P., Selles, F., Biederbeck, V.O., McConkey, B.G. et al. (1999). Quantifying short-term effects of crop rotations on soil organic carbon in southwestern Saskatchewan. *Can. J. Soil Sci*., 80, 193–202.

Daraghmeh, O.A., Jensen, J.R., Petersen, C.T. (2009). Soil structure stability under conventional and reduced tillage in a sandy loam. *Geoderma*, 150, 64-71.

Deiss, L., Sall, A., Demyan, S., Culman, S. (2021). Does crop rotation affect soil organic matter stratification in tillage systems? *Soil and Tillage Research*, 209, 104932.

Dușa, M. (2022). Interimar report of internal project competition, acronim *SustenRo. Project no. 1258/30.07.2021*, University of Agronomic Sciences and Veterinary Medicine from Bucharest.

Ejigu, W., Selassie, Y., Elias, E., Damte, M. (2021). Integrated fertilizer application improves soil properties and maize (*Zea mays* L.) yield on Nitisols in Northwestern Ethiopia. *Helyion*, 7(2), e06074.

Feiziene, D., Feiza, V., Povilaitis, V., Putramentaite, A., Janusauskaite, D. et al. (2016). Soil sustainability changes in organic crop rotations with diverse crop species and the share of legumes. *Acta Agriculturae Scandinavica, Soil & Plant Science*, 66(1), pp.36-51.

FAO (2015). Status of the world's soil resources, pp. 123–126. Intergovernmental Technical Panel on Soils.

FAO (2015). Soil functions: www.fao.org/resources/infographics/infographics-details/en/c/284478

Ferrarini, A., Bini, A., Amaducci, S. (2018). Soil and ecosystem services: Current knowledge and evidence from Italian case studies. *Applied Soil Ecology*, 123, 693-698.

Garcia-Pausas, J., Rabissi, A., Rovira, P., Romanya, J. (2017). Organic fertilization increases C and N stocks and reduced soil organic matter stability in Mediterranean vegetable gardens. *Land Degrad. Develop*., 28, 691–698.

Gentile, R.M., Martino, D.L., Entz, M.H. (2005). Influence of perennial forages on subsoil organic carbon in a long-term rotation study in Uruguay. *Agriculture, Ecosystems and Environment*, 105, 419–423.

Gomiero, T., Pimentel, D., Paoletti, M.G. (2011). Is There a Need for a More Sustainable Agriculture? *Critical Reviews in Plant Sciences*, 30(6), 23.

Gotze, P., Rucknagel, J., Jacobs, A., Marlander, B., Koch, H-I., Christen, O. (2016). Environmental impacts of different crop rotations in terms of soil compaction. *Journal of Environmental Management*, 181, 54-63.

Grandy, S., Fraterrigo, J.M., Billings, S.A. (2012). Soil Ecosystem Resilience and Recovery. Soil ecology and ecosystem services. Oxford University Press.

Gregorish, E.G., Drury, C.F., Baldock, J.A. (2001). Changes in soil carbon under long-term maize in monoculture and legume-based rotation. *Can. J. Soil Sci*., 81, 21–31.

Guo, Z., Hua, K., Wang, J., Guo, X., He, C., D. (2014). Effects of different regimes of fertilization on soil organic matter under conventional tillage. Spanish *Journal of Agricultural Research*, 12(3), 801-808.

Guo, Z., Zhang, J., Fan, J., Yang, X., Yi, Y. et al. (2019). Does animal manure application improve soil aggregation? Insights from nine long-term fertilization experiments. *Science of The Total Environment*, 660, 1029-1037.

Haddaway, N.R., Hedlund, K., Jackson, L.E., Katterer, T., Lugato et al. (2017). How does tillage intensity afect soil organic carbon? A systematic review. *Environmental Evidence*, 6, 30.

Haynes, R., Naidu, R. (1998). Influence of Lime, Fertilizer and Manure Applications on Soil Organic Matter Content and Soil Physical Conditions: A Review. *Nutrient Cycling in Agroecosystems*, 51, 123-137.

Hazarika, S., Parkinson, R., Bol, R., Dixon, L., Russell, P., Donovan, S., Allen, D. (2009). Effect of tillage system and straw management on organic matter dynamics. *Agron. Sustain. Dev*., 29, 525–533.

Hoss, M., Behnke, G.D., Davis, A.S., Nafziger, E.D., Villamil, M.B. (2018). Short Corn Rotations Do Not Improve Soil Quality, Compared with Corn Monocultures. *Agronomy Journal*, 110, 1274-1288.

Huggins, D.R., Allmaras, R.R., Clapp, C.E., Lamb, J.A., Randall, G.W. (2007). Corn-Soybean Sequence and Tillage Effects on Soil Carbon Dynamics and Storage. *SSSAJ*, 71(1), 145-154.

Hunt, Natalie, Hill, J., Liebman, M. (2019). Cropping System Diversity Effects on Nutrient Discharge, Soil Erosion, and Agronomic Performance. *Environmental Science & Technology*, 53(3), 1344-1352.

Hussain, S., Hussain, S., Guo, R., Sarwar, M., Ren, X. et al. (2021). Carbon Sequestration to Avoid Soil Degradation: A Review on the Role of Conservation Tillage. *Plants*, 10, 2001.

Jacobs, A., Rauber, R., Ludwig, B., 2009. Impact of reduced tillage on carbon and nitrogen storage of two Haplic Luvisols after 40 years. *Soil and Tillage Research*, 102, 158-164.

Jaskulska, I., Lemanowicz, J., Breza-Boruta, B., Siwik-Ziomek, A., Radziemska, M. et al. (2020). Chemical and biological properties of sandy loam soil in response to long-term organic–mineral fertilisation in a warm-summer humid continental climate. *Agronomy*, 10, 1610.

Jónsson, J,O.G., Davíðsdóttir, B. (2016). Classifification and valuation of soil ecosystem services. *Agricultural Systems*, 145, 24–38.

Kamanga, B.C.G., Kanyama-Phiri, G.Y., Waddington, S.R., Almekinders, C.J.M., Giller, K.E. (2014). The evaluation and adoption of annual legumes by smallholder maize farmers for soil fertility maintenance and food diversity in central Malawi. *Food* Security, 6, 45–59.

Kanianska, R. (2016). Agriculture and Its Impact on Land-Use, Environment, and Ecosystem Services. Book Landscape Ecology - The Influences of Land Use and Anthropogenic Impacts of Landscape Creation. *InTech Publishing house.*

Kiani, M., Hernandez-Ramirez, G., Quideau, S., Smith, E., Janzen, H., Larney, F., Puurveen, D. (2015). Quantifying sensitive soil quality indicators across contrasting long-term land management systems: Crop rotations and nutrient regimes. *Agriculture, Ecosystems and Environment*, 248, 123–135.

Kołodziej, B., Bryk, M., Słowińska-Jurkiewicz, A., Otremba, K., Gilewska, M. (2016). Soil physical properties of agriculturally reclaimed area after lignite mine: A case study from central Poland. *Soil and Tillage Research*, 163, 54-63.

Lampkin, N. H. 1990. Organic farming. *Farming Press Books*, Ipswitch, UK.

Larkin, R.P., Griffin, T.S., Honeycutt, C.W., Olanya, O.M., He, Z. (2021). Potato cropping system management strategy impacts soil physical, chemical, and biological properties over time. *Soil and Tillage Research*, 213, 105148.

Le Guillou, C., Angers, D.A., Leterme, P., Menasseri-Aubry, S. (2011). Differential and successive effects of residue quality and soil mineral N on water-stable aggregation during crop residue decomposition. *Soil Biology and Biochemistry*, 43(9), 1955–1960.

Li, P., Kong, D., Zhang, H., Xu, L., Li, C., Wu, M. et al. (2021). Different regulation of soil structure and resource chemistry under animal and plant-derived organic fertilizers changed soil bacterial communities. *Applied Soil Ecology*, 165, 104020.

Liu X., Herbert S.J., Hashemi, A.M., Zhang, X., Ding, G. (2006). Effects of agricultural management on soil organic matter and carbon transformation – a review. *Plant Soil Environ*., 52(12), 531–543.

Luty, L., Musial, K., Ziolo, M., (2021). The Role of Selected Ecosystem Services in Different Farming Systems in Poland Regarding the Differentiation of Agricultural Land Structure. *Sustainability*, *13*, 6673.

Machado-Pinheiro, É.F., de Campos, D.V.B., Balieiro, F.C., Cunha dos Anjos, L.H., Pereira, M.G. (2015). Tillage systems effects on soil carbon stock and physical fractions of soil organic matter. *Agricultural Systems*, 132, 35–39.

Martinez, E., Fuentes, J.P., Silva, P., Valle, S., Acevedo, E. (2008). Soil physical properties and wheat root growth as affected by no-tillage and conventional tillage systems in a Mediterranean environment of Chile. *Soil & Tillage Research*, 99, 232–244.

McDaniel, M.D., Tiemann, L.K., Grandy, A.S. (2014). Does agricultural crop diversity enhance soil microbial biomass and organic matter dynamics? A meta-analysis. *Ecological Applications*, 24(3), 560–570.

Miles, N., Meyer, J.H., Van Antwerpen, R. (2008). Soil organic matter data: what do they mean? *Proc. S. Afr. Sug. Technol.Ass.*, 81, 324 – 332.

Moraru, P.I., Rusu, T. (2013). Effect of Different Tillage Systems on Soil Properties and Production on Wheat, Maize and Soybean Crop. *Engineering and Technology International Journal of Agricultural and Biosystems Engineering*, 7(11), 1027–1030.

Moreira, W.H., Tormena, C.A., Karlen, D.L., da Silva, A.P., Keller, T., Betioli Jr., E. (2016). Seasonal changes in soil physical properties under long-term no-tillage. *Soil & Tillage Research*, 160, 53-64.

Mudgal, S., Lavelle, P., Cachia, F., Somogyi, D., Majewski et al. (2010). Environmental impacts of different crop rotations in the European Union. *Final Report, European Commission*.

Munkholm, L.J., Heck, R.J., Deen, B. (2013). Long-term rotation and tillage effects on soil structure and crop yield. *Soil and Tillage Research*, 127, 85–91.

Naveed, M., Moldrup, P., Vogel, H.J., Lamande, M., Wildenschild, D., Tuller, M., de Jonge, L.W. (2014). Impact of long-term fertilization practice on soil structure evolution. *Geoderma* 217-218, pp.181-189.

Nielsen, U., Wall, D., Six, J. (2015). Soil Biodiversity and the Environment. *Annu. Rev. Environ. Resour.,* 40, 63–90.

Novak, Elaine, de Carvalho, L.A., Santiago, E.F., Tomazi, M. (2019). Changes in the soil structure and organic matter dynamics under different plant covers. *Cerne*, 25(2), 230–239.

Obalum, S.E., Uteau-Puschmann, D., Peth, S. (2019). Reduced tillage and compost effects on soil aggregate stability of a silt-loam Luvisol using different aggregate stability tests. *Soil and Tillage Research*, 189, 217–228.

O'Donaghue, T., Minasny, B., McBratney, A. (2022). Regenerative Agriculture and Its Potential to Improve Farmscape Function. *Sustainability*, *14*, 5815.

Page, K.L., Dang, Y.P., Dalal, R.C. (2020). The Ability of Conservation Agriculture to Conserve Soil Organic Carbon and the Subsequent Impact on Soil Physical, Chemical, and Biological Properties and Yield. Front. Sustain. *Food Syst*., 4, 31.

Pagliai, M., Vignozzi, N., Pellegrini, S. (2004). Soil structure and the effect of management practices. *Soil & Tillage Research*, 79, 131–143.

Palm, C., Blanco-Canqui, H., DeClerck, F., Gatere, L., Grace, P. (2013). Conservation agriculture and ecosystem services: An overview. *Agriculture, Ecosystems & Environment*, 187, 87–105.

Pantani, O.L., Ferretti, L., Santoni, M., Massenzio, S., D'Acqui, L.P., Pacini, G.C. (2022). Assessment of the impact of conventional and organic agroecosystems management options and conservation tillage on soil fertility at the Montepaldi Long Term Experiment, Tuscany. *European Journal of Agronomy*, 140, 126575.

Pereira, P., Bogunovic, I., Muñoz-Rojas, Miriam, Brevik, E.C. (2018). Soil ecosystem services, sustainability, valuation and management. *Current Opinion in Environmental Science & Health*, 5, 7–13.

Pervaiz, Z.H., Iqbal, j., Zhang, Q., Chen, D., Wei, H., Saleem, M. (2020). Continuous Cropping Alters Multiple Biotic and Abiotic Indicators of Soil Health. *Soil Syst., 4*, 59.

Peterson, C., Eviner, V., Gaudin, A. (2018). Ways forward for resilience research in agroecosystems. *Agricultural Systems*, 162, 19–27.

Plourde, J.D., Pijanowsky, B.C., Pekin, B.K. (2013). Evidence for increased monoculture cropping in the Central United States. *Agriculture, Ecosystems & Environment*, 165, 50–59.

Plaza-Bonilla, D., Alvaro-Fuentes, J., Cantero-Martinez, C. (2013). Soil Aggregate Stability as Affected by Fertilization Type under Semiarid No-Tillage Conditions. *Soil Science Society of America Journal,* **77**(1), 284–292.

Poffenbarger, H. J., Barker, D. W., Helmers, M. J., Miguez, F. E., Olk, D. C., Sawyer, J. E., et al. (2017). Maximum soil organic carbon storage in Midwest US cropping systems when crops are optimally nitrogen fertilized. *PLoS ONE*, 12, e0172293.

Power, Alison (2010). Ecosystem services and agriculture: tradeoffs and synergies. *Phil. Trans. R. Soc*. B, 365, 2959–2971.

Prado, Rachel Bardy et al. (2016). Current overview and potential applications of the soil ecosystem services approach in Brazil. *Pesquisa Agropecuária Brasileira*., 51(9), 1021–1038.

Pranagal, J., Wozniak, A. (2021). 30 years of wheat monoculture and reduced tillage and physical condition of Rendzic Phaeozem. *Agricultural Water Management,* 243, 106408.

Pulleman, M., Creamer, R., Hamer, U., Helder, J., Pelosi et al. (2012). Soil biodiversity, biological indicators and soil ecosystem services—an overview of European approaches. *Current Opinion in Environmental Sustainability*, 4, 529–538.

Raphael, J.P.A., Calonego, J., Milori, D.B., Rosolem, C.A. (2016). Soil organic matter in crop rotations under no-till. *Soil and Tillage Research,* 155, 45–53.

Rychcik, B., Adamiak, J., Wójciak, H. (2006). Dynamics of the soil organic matter in crop rotation and long-term monoculture. *Plant Soil Environ*ment, 52, 15–20.

Russell, A.E., Cambardella, C.A., Laird, D.A., Jaynes, D.B., Meek, D.W. (2009). Nitrogen fertilizer effects on soil carbon balances in Midwestern U.S. agricultural systems. *Ecol. Appl*., 19, 1102–1113.

Salvo, L., Hernandez, J., Ernst, O. (2010). Distribution of soil organic carbon in different size fractions, under pasture and crop rotations with conventional tillage and no-till systems. *Soil&Tillage Research*, 109, 116–122.

Sapkota, T.B., Mazzoncini, M., Barberi, P., Antichi, D., Silvestri, N. (2012). Fifteen years of no till increase soil organic matter, microbial biomass and arthropod diversity in cover crop-based arable cropping systems. *Agronom. Sustain. Dev.*, 32, 853–863.

Saulic, M., Oveisi, M., Djalovic, I., Bozic, D., Pishyar, A., Savi´c, A., Prasad, P.V., Vrbnicanin, S. (2022). How Do Long Term Crop Rotations Influence Weed Populations: Exploring the Impacts of More than 50 Years of Crop Management in Serbia. *Agronomy*, 12, 1772.

Schlüter, S., Großmann, C., Diel, J., Wu, G.M., Tischer, S., Deubel, A., Rücknagel, J. (2018). Long-term effects of conventional and reduced tillage on soil structure, soil ecological and soil hydraulic properties. *Geoderma*, 332, 10-19.

Selim, M. (2019). A Review of Advantages, Disadvantages and Challenges of Crop Rotations. *Egypt. J. Agron*., 41(1), 1–10.

Shimizu, M., Marutani, S., Desyatkin, A.R., Jin, T., Hata, H., Hatano, R. (2009). The effect of manure application on carbon dynamics and budgets in a managed grassland of Southern Hokkaido, Japan. *Agriculture, Ecosystems and Environment*, 130, 31–40.

Siedt, M., Schaffer, A., Smith, K.E.C., Nabel, M., Rob-Nickoll, M., van Dongen, J.T. (2021). Comparing straw, compost, and biochar regarding their suitability as agricultural soil amendments to affect soil structure, nutrient leaching, microbial communities, and the fate of pesticides. *Science of the Total Environment*, 751, 141607.

Silver, W.L., Perez, T., Mayer, A., Jones, A.R. (2021). The role of soil in the contribution of food and feed. *Phil. Trans. R. Soc*. B 376, 20200181.

Simon, T. S., Javurek, M., Mikanova, O., Vach, M. (2009). The inflfluence of tillage systems on soil organic matter and soil hydrophobicity. *Soil & Tillage Research*, 105, 44–48.

Socolow, R. (2016). Fitting on the Earth: Challenges of Carbon and Nitrogen Cycle to Preserve the *Habitability of the Planet. Engineering*, 2.

Sokolowski, A.C., McCormick, B.P., De Grazia, J., Wolski, J.E., Rodríguez-Frers, E.P. et al. (2020). Tillage and no-tillage effects on physical and chemical properties of an Argiaquoll soil under long-term crop rotation in Buenos Aires, Argentina. *International Soil and Water Conservation Research,* vol. 8 (2), 185–194.

Stavi, I., Bel, G., Zaady, E. (2016). Soil functions and ecosystem services in conventional, conservation, and integrated agricultural systems. A review. *Agron. Sustain. Dev.*, 36–32.

Sun, X., Zhong, T., Zhang, L., Zhang, K., Wu, W. (2019). Reducing ammonia volatilization from paddy field with rice straw derived biochar. *Science of The Total Environment*, 660, 512–518.

Tao, J., Lu, Y., Ge, D., Dong, P., Gong, X., Ma, X. (2022). The spatial pattern of agricultural ecosystem services from the production-living-ecology perspective: A case study of the Huaihai Economic Zone, China. *Land Use Policy*, 122, 106355.

Taveira, C.J., Farrel, R.E., Wagner-Riddle, C., Machado, P.V.F., Deen, B., Congreves, K.A. (2020). Tracing crop residue N into subsequent crops: Insight from long-term crop rotations that vary in diversity. *Field Crop Research*, 255, 107904.

Tilmann, D. (1999). Global environmental impacts of agricultural expansion: The need for sustainable and efficient practices. *Proc. Natl. Acad. Sci. USA,* 96, 5995–6000.

Tuo, D., Xu, M., Li, Q., Liu, S. (2016). Soil Aggregate Stability and Associated Structure Affected by Long-Term Fertilization for a Loessial Soil on the Loess Plateau of China. *Pol. J. Environ. Stud*., 26(2), 827–835.

Valieva, S. (2010). Enhancing Agronomic Practices for Improved Ecosystem Resilience in I&D Operations. Water Stewardship in Agriculture workstream of the Water in Agriculture Global Solutions Group.

Van Eekeren, N., Murray, P.J., Smeding, F.W. (2007). Soil biota in grassland, its ecosystem services and the impact of management. *Grassland Science in Europe*, 12, 247–258.

Venkatesh, M.S., Hazra, K.K., Ghosh, P.K., Khuswah, B.L., Ganeshamurthy, A.N. et al. (2017). Long–term effect of crop rotation and nutrient management on soil–plant nutrient cycling and nutrient budgeting in Indo–Gangetic plains of India. *Archives of Agronomy and Soil Science*, ISSN: 0365-0340.

Wang, T., Jin, H., Fan, Y., Obembe, O., Li, D. (2021). Farmers' adoption and perceived benefits of diversified crop rotations in the margins of U.S. Corn Belt. *Journal of Environmental Management*, 293, 112903.

Wen, Y.C., Li, H.Y., Lin, Z.A., Zhao, B.Q., Sun, Z.B. et al. (2020). Long-term fertilization alters soil properties and fungal community composition in fuvo-aquic soil of the North China Plain. Nature. *Scientific Reports*, 10, 7198.

Wu, P., Zhao, G., Liu, F., Ahmad, S., Fan, T. et al. (2021). Agronomic system for stabilizing wheat yields and enhancing the sustainable utilization of soil: A 12-year *in-situ* rotation study in a semi-arid agro-ecosystem. *Journal of Cleaner Production*, 329, 129768.

Xie, H., Li, J., Zhang, B., Wang, L., Wang, J., He, H., Zhang, X. (2015). Long-term manure amendments reduced soil aggregate stability via redistribution of the glomalin-related soil protein in macroaggregates. *Nature. Scientific Reports*, 5, 14687.

Yang, R., Su, Y.Z., Wang, T., Yang, Q. (2016). Effect of chemical and organic fertilization on soil carbon and nitrogen accumulation in a newly cultivated farmland. *Journal Integrated Agriculture*, 15, 658–666.

Yu, H., Ding, W., Luo, J., Geng, R., Cai, Z. (2012). Long-term application of organic manure and mineral fertilizers on aggregation and aggregate-associated carbon in a sandy loam soil. *Soil & Tillage Research*, 124, 170–177.

Yu, T., Mahe L., Li, Y., Wei, X., Deng, X., Zhang, D. (2022). Benefits of Crop Rotation on Climate Resilience and Its Prospects in China. *Agronomy*, 12(2), 436.

Zhang, J., Sun, C., Liu, G., Xue, S. (2018). Effects of long-term fertilisation on aggregates and dynamics of soil organic carbon in a semiarid agro ecosystem in China. *PeerJ*, 6, e4758.

Zhang, H., Niu, L., Hu, K., Hao, J., Li, F., Wang, X., Chen, H. (2021). Long-term effects of nitrogen and phosphorus fertilization on soil aggregate stability and aggregate-associated carbon and nitrogen in the North China Plain. *Soil Sci. Soc. Am. J.*, 85, 732–745.

Zhou, H., Peng, X.H., Perfect, E., Xiao, T.Q., Peng, G.Y. (2013). Effects of organic and inorganic fertilization on soil aggregation in an Ultisol as characterized by synchrotron-based X-ray microcomputed tomography. *Geoderma*, 195-196, 23–30.

Zuber, S.M., Behnke, G., Nafziger, E.D., Villamil, M.B. (2015). Crop Rotation and Tillage Effects on Soil Physical and Chemical Properties in Illinois. *Agron. J.*, 107, 971–978.

Žurovec, O., Sitaula, B.K., Čustović, H., Žurovec, J., Dörsch, P. (2017). Effects of tillage practice on soil structure, N_2O emissions and economics in cereal production under current socio-economic conditions in central Bosnia and Herzegovina. *PLOS ONE,* 12(11), e0187681.