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SOIL: A RESOURCE AT RISK

Soil Degradation

"The soil is the great connector of lives, the source and destination of all. It is the healer and restorer and resurrector, by which disease passes into health, age into youth, death into life. Without proper care for it we can have no community, because without proper care for it we can have no life"

Wendell Berry

"The nation that destroys its soil destroys itself"

Franklin D. Roosevelt

Michaela Oriolo – FEEM

Francesca Morigi - FEEM

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1. SOIL: A FUNDAMENTAL RESOURCE FOR LIFE

Soil is an irreplaceable resource and provides a disparate range of ecosystem goods and services of vital importance for all terrestrial species, but it has not always received appropriate and notable consideration. It occupies 1/6 of the Earth's surface net of seas, lakes, deserts, ice and bare rocks and, in terms of thickness, is a surface layer of a few decimeters of depth. To better understand, "*if the Earth were the size of a football, the soil would be a coating of 20 millionths of a millimeter*" [1].

Moreover, in the next few years the portion of land per capita used for the production of food, is destined to further reduce because of the demographic increase, the effects of climate change and those related to anthropogenic factors (unsustainable soil management, pollution, contamination).
Surely, many of our habits will have to change, but the extent of the emerged land will remain the same! The sustainable management and protection of the soil resource from degradation and destruction becomes, therefore, a challenge that no one can and must avoid because the soil is a fundamental, vulnerable, limited, and non-renewable resource.

In this e-library we will talk about the soil resource, outlining its formation processes and main characteristics. particular emphasis will be placed on the functions and ecosystem services that it provides to all living beings of the Earth. Soil degradation will be the focal point: its extension in Europe and the main drivers that have facilitated its dissemination will be analyzed to provide a snapshot of the current state of European soils.

1.1 What is soil?

First of all, the soil and land terms differ from each other because:

- Land commonly refers to the planet's surface not covered by seas, lakes or rivers and includes the total land mass with continents and islands. The term land is used to indicate limited portions of the Earth's surface, formed by rocks, soil, pools of water and much more and covered by different types of vegetation and artificial surfaces (e.g. roads and buildings) [2];

- Soil is one of the essential components of land and it is the thin porous and biologically active medium[1] that represents the upper layer of the Earth's crust [3].

There are many different definitions of soil which, although often coinciding, tend individually to highlight some aspects rather than others. For example, "*an engineer may view soils as a material upon which infrastructure is built, while a diplomat may refer to "soil" as a nation's territory. From a soil scientist's perspective, the soil is the surface mineral and/or organic layer of the Earth that has experienced some degree of physical, biological and chemical weathering*" [4].

Therefore, considering the complexity of soil system and the variability of the atmospheric and environmental conditions that characterize its genesis, it is very difficult to provide a brief, exhaustive and unique definition of the soil [5], [6].

In general, we can agree on the following definition [2], [6]–[8]:

Soil is an open, dynamic, complex and diversified natural system that is located at the interface between land, air, water and life. It envelops a large part of the Earth's surface like a thin film and is referred to as the pedosphere. Furthermore, it is the result of numerous physical, chemical and biological processes that act simultaneously or in sequence due to climatic events, geomorphology, passing time and vegetation.

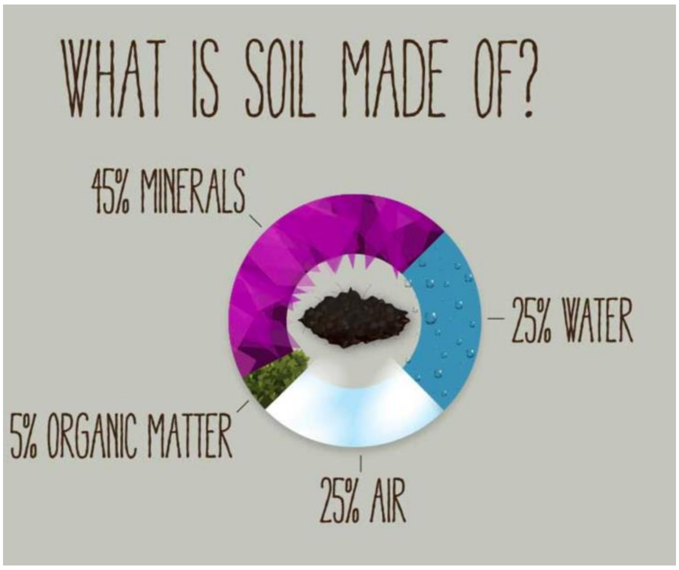
[1] The biologically active layer, also known as *topsoil*, "*is the layer closest to the surface (usually the densely rooted zone or plough layer, down to 20-30 cm)*" [2], p. 6.

1.2 Soil composition

Soils are composed of rocks, roots, animals, and other biotic entities. In general, soils are made up of three distinct phases (see Figure 1):

1. Solid-phase (50%). It has a [8]:
    a. Organic nature (5%), consisting of living organisms and more or less decomposed plant and animal residues.
    b. Inorganic nature (45%), consisting mainly of primary and secondary minerals, divided into clay, silt and sand according to their size.
2. Liquid phase (25%). It is represented by water, within which inorganic and organic substances are dissolved and collodions of different nature are dispersed.
3. Gas-phase (25%). It appears like a mixture of gases and vapours with a composition similar to that of atmospheric air but characterized by a higher content of water vapour and carbon dioxide (CO_2).

***Figure 1**. Soil as a polyphasic system. Retrieved from* [9].



The composition and nature of the soils strongly depend on the interactions between chemical, physical, and biological environmental factors.

1.3 The soil process formation

Soil is a non-renewable, limited and fragile resource because its processes of formation and regeneration are often characterized by very long times; just think that it takes more than 1,000 years to produce 2-3 cm of soil! [3].

<u>But how is the soil formed?</u>

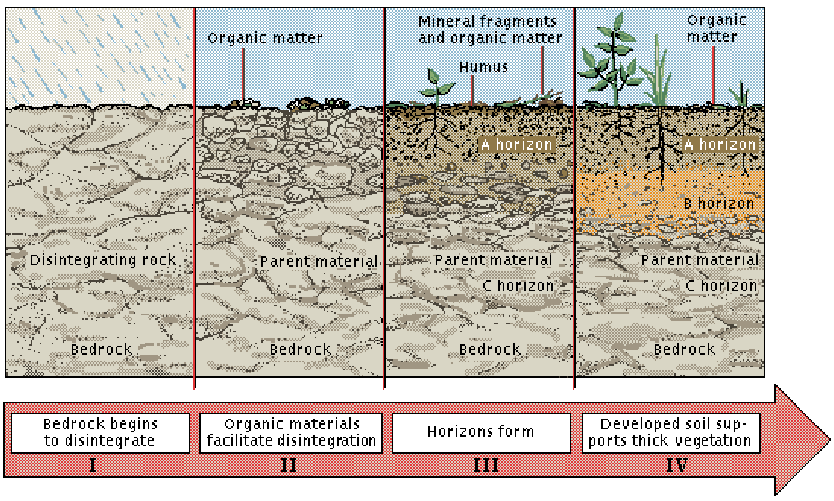
The process of soil formation is called pedogenesis and it is the result of a succession of physical and chemical phenomena, which, occurring simultaneously, cause the alteration and decomposition of the solid phases of the soil and the consequent formation of new minerals and molecules [10].

Pedogenesis depends on the so-called soil formation factors (see Figure 2); namely:

Figure 2. How soil is formed. Retrieved from [11].

– Parental material. It is the source material (e.g. rocks, clays, limestones, etc.) of the soil;
– Climate (intensity and frequency of rain, evaporation, wind, and sun exposure). It is responsible for the formation and definition of soil characteristics and properties;
– Action of biotic entities (e.g. vegetation, micro and macrofauna, flora) and human activities (e.g. construction, deforestation and agriculture);
– Topography. The slope of the land strongly affects soil thickness; think, for example, of the rocky walls of the mountains, where rock debris does not accumulate on the spot, but descends downwards due to the force of gravity;
– Time.

Figure 3. Pedogenesis steps. Retrieved from [12].

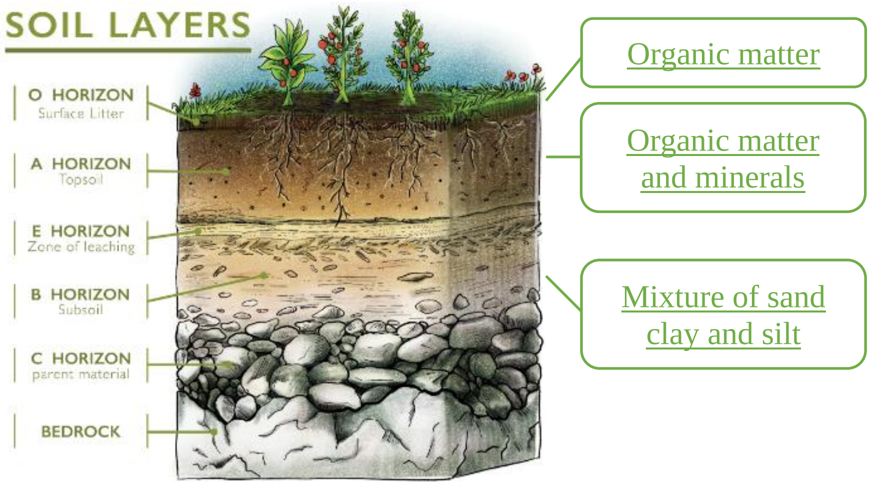


During the pedogenesis process, layers of different thickness (horizons) gradually form (Figure 3) and their succession gives rise to what is now well known as soil profile. This profile is strongly influenced by the climatic conditions in which the soil develops, as well as by lithological and geomorphological factors (e.g. steepness).

Figure 4. a) Main pedogenetic horizons. Retrieved and adapted from [13]. *b) Soil layer and brief description of their content. Retrieved and adapted from* [13].

(a)

b)



The horizons (Figure 4) differ in consistency, colour, biological activity, and structure, depending on soil depth.

The more superficial horizons are generally more affected by the formation factors and have very different characteristics from the parental material; on the contrary, the deeper ones are little affected by the action of the climate and organisms and have characteristics similar to the parental material.

The main pedogenetic horizons are generally indicated by a single capital letter, but to provide further information one or more lowercase letters can be added as suffixes or prefixes [8].

On our planet there are many types of soils thanks to the fluctuations over time and during the changing seasons of all the factors that occur during their pedogenesis process. Thus, several classification systems have been developed considering soil similar properties and their relationships with the factors that define their peculiar qualities. The most famous classification systems are [5], [8]:

1. **The US system - Soil Taxonomy**. It is a hierarchical and objective classification system based on six categories that distinguish soil considering both pedogenetic processes (genetic level) and practical aspects according to the response to use (pragmatic level);
2. **World Reference Base (WRB) System** developed by the International Union of Sciences and officially adopted by the European Commission. It has become an international reference point and has two levels of categorical detail: the “reference base” with 32 reference soil groups (RSG)

and the "reference soil units" consisting of combinations of prefixes (179 in total) to be added to the RSG to exactly characterize and classify the soil individual profiles.

1.4 Why is soil vital?

1.4.1 Ecosystem functions

Soils are fundamental chemical-biological laboratories [3] and great essential services providers for life on Earth [14].

These services are known as ecosystem services and are defined as the benefits (or contributions) that humans obtain, directly or indirectly, from ecosystems. They are divided into [3]:

- Supply services;
- Regulation and maintenance services;
- Cultural services.

Table 1 and Figure 5 summarize the main functions and ecosystem services made available by the soil for life.

***Table 1**. Soil functions and ecosystem services* [2], [3], [14]–[16].

FUNCTION	TYPE OF FUNCTION	DESCRIPTION
Production of food, fiber and fuels	Supply service	Soil provides nutrients, air, water and a medium in which plants can penetrate with their roots
Foundation for human infrastructures	Cultural service	Soil provides ground for the building of houses, industries, roads, recreational facilities and waste disposal
Biodiversity and gene reserve and protection	Regulation and maintenance service	Soil is the living skin of the Earth because it hosts very different microhabitats and several living organisms[2] in the so-called soil biome
Filtering, buffering and transforming	Regulation and maintenance service	Soil prevents the transfer of harmful substances to groundwater or food-chain
Source of raw materials	Supply service	Soil provides water, clay, sand, gravel, minerals and also fuels (coal and oil)
Cultural heritage	Cultural service	Soil forms an essential part of the landscape and is relevant to understand the evolution of the earth
Regulation of the water cycle	Regulation and maintenance service	Soil, thanks to its structure, regulates, modulates, absorbs, retains and purifies the water that permeates through its pores
Regulation of biogeochemical cycles of nutrients[3]	Regulation and maintenance service	Soil is crucial in nature's cycles, especially in the nutrient cycle (Figure 6) which regulate the quantity of soil organic matter taken up and stored in soil
Source of pharmaceutical resources	Regulation and maintenance service	Some soil microorganisms produce antibiotics and medicines (e.g. penicillin and streptomycin) and plants grown on it contain one or more active ingredients
Atmospheric carbon capture and climate mitigation	Regulation and maintenance service	Soil is the most important terrestrial carbon reservoir and play a key role in climate change mitigation because it stores carbon and inhibits its release into the atmosphere in the form CO_2

[2] From 1/3 to 1/4 of all those present on Earth.
[3] Carbon, nitrogen, phosphorus.

Figure 5. *Ecosystem services provided by the soil. Retrieved from* [3], *p.3.*

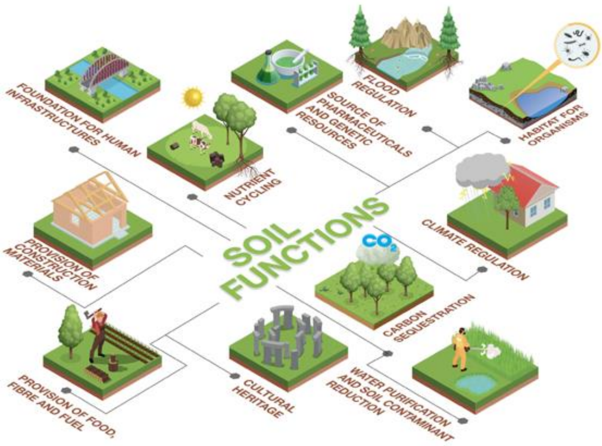
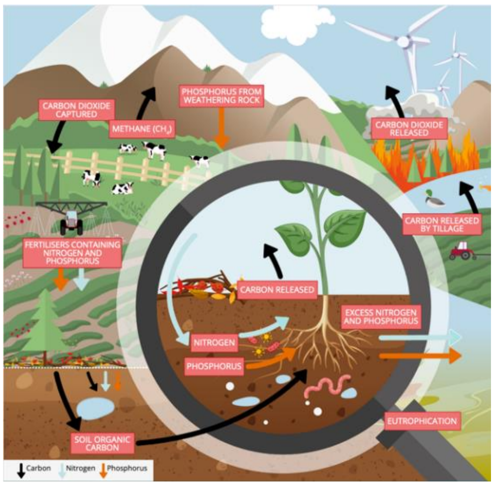


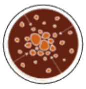
Figure 6. *Nature's nutrient cycle. Retrieved from* [2], *p.43*



1.4.2 Soil physical properties

Soil physical properties (Table 2) are extremely important because they affect all the three soil phases, regulate their relationship and allow to provide the ecosystem services listed in Table 1.

Table 2*. Physical properties of soil* [17]. *Images retrieved from* [17].

PROPERTY	DEFINITION	RELEVANCE
Texture 	Percentage composition, in terms of size and proportions, of the three mineral soil particles (sand, silt and clay)	Definition of soil behavior and its retention capacity for nutrients and water
Structure 	Association of aggregates of sand, silt and clay in larger units called pets	Effect on aeration, water movement, conduction of heat, plant root growth and resistance to erosion
Porosity 	Pore space is the open part of the bulk volume occupied by either air or water	Supply of oxygen to plant roots and soil organisms and effect on movement and storage of water and dissolved nutrients
Water infiltration 	It is the downward entry of water into the soil	Supply of water for soil living organism and plant growth
Color 	It is due to the minerals present and the organic matter content	Clues on the composition of the soil and the conditions that the soil is subjected to
Soil moisture 	It is the quantity of water contained in soil	Transport of nutrients for plants, regulation of soil temperature, help with microbial activity and many other crucial and essential activities for plant growth
Compaction 	Refers to the increase in soil bulk density/decrease in soil porosity	Impairs soil functions and impedes roots penetration and water and gas exchange

2. SOIL DEGRADATION IN EUROPE

2.1 Introduction

In recent decades, soil and land natural resources have undergone, and still suffer, increasing pressures (Figure 7), also aggravated by unsustainable models of land use and management [2].
In the long term, these pressures have caused the overuse, rapid depletion, and deterioration of these vital resources. Experts define the loss of high-quality soil as **soil degradation**.

Soil degradation is a broad, varied and extensive process and, thus, it can be considered as a global pandemic [18], [19]. Indeed, the impacts of degradation extend beyond the land surface itself, affecting marine and freshwater systems, as well as people and ecosystems far away from the local sites of degradation [20].

Figure 7. Pressures on soil. Retrieved from [2], *p. 25.*

Soil degradation can be caused by direct and indirect human-induced processes [20] or by highly diversified and interconnected natural phenomena. Furthermore, it refers to a subset of land degradation processes that, occurring simultaneously, can directly affect soil and induce combined effects that are likely to aggravate the problem [20], [21].

Degradation of soil also results in the loss of critical functions and ecosystem services, [19], [22]. Thus, it affects humans in multiple ways, interacting with social, political, cultural and economic aspects (e.g. markets, technology, inequality and demographic change) [20].

Soil degradation hides, however, a paradox: the driving forces that directly and indirectly contribute to this phenomenon, at the same time, need and require healthy and high-quality soils to ensure the sustainability of society [18].

Unfortunately, soil degradation is a particularly complex phenomenon, considering that it is neither a new problem for humans nor a theoretical one [18].
Soils are in an increasingly drastic situation: globally 33% of them are moderately or severely degraded and more than 50,000 km^2 of soil, an extension equal to Costa Rica, are lost every year [9]. Furthermore, more than 50% of agricultural soils are affected by moderate or high degradation and less than one-third of natural soils are exposed to degradation phenomena [22]. Finally, the experts estimate that we only have 60 years of topsoil left [9].

2.2 Current state of degradation in Europe

For some decades the situation in which European soils are concerned has been deteriorating, and soil formation and protection are among the ecosystem services most affected by a decline in Europe [23], [24]. Sector experts also predict further worsening for the next few years if a reversal of direction will not be implemented.

In Europe, soil degradation is a serious and widespread problem [15]: it involves all Member States [24] in several ways with an irregular and fragmented extension [21], [25] and, in addition to causing environmental and ecosystem damage, it also severely affects the European economic system [21].

What is the actual extent of soil degradation in Europe?

Nearly 33% of the total European land is affected by soil degradation. The countries more exposed are Portugal, Spain, Italy, Greece, Albania, Bosnia and Herzegovina, Croatia, Cyprus, France, Malta, Slovenia and Turkey [26].
Overall, however, approx. 37 million hectares of land are particularly vulnerable due to irreversible degradation processes [26]. Moreover, the European Environmental Bureau states that "1*,000 km^2 of agricultural and natural land disappear every year in Europe*" [27].

Quantifying the area affected by degradation and defining the spatial distribution of the phenomenon within the entire European territory present considerable difficulties due to the adoption of different survey approaches and methodologies, the absence of continuous monitoring campaigns in some Member States, the lack of an European-wide monitoring network for soil and, consequently, the unavailability of data [15], [19], [28]. Finally, key uncertainties remain concerning land degradation severity and connections to its driving forces [20].

2.3 Driving forces of soil degradation

Soil degradation is the result a complex chain of causes and factors called soil degradation drivers since they directly or indirectly may drive land degradation by interacting differently with each other in multiple ways [20].

Soil degradation drivers can be of both natural and anthropogenic origin [20] and are listed in Table 3. Today, the anthropogenic pressures represent the main cause for soil degradation in many parts of Europe [25].

Table 3. *Main soil degradation drivers* [19].

SOIL DEGRADATION DRIVING FORCES	
Natural drivers	***Anthropogenic drivers***
	Land-use change and land cover change (e.g. clearing and deforestation)
Earthquakes	Urban sprawl and land take
Tsunamis	Commercial/industrial development
Droughts	Excessive tillage
Avalanches	Use of heavy machinery
Landslides	Overuse of inorganic fertilizers and pesticides
Volcanic eruptions	Poor irrigation and inappropriate water management techniques
Floods	Inadequate crop residue and/or organic carbon inputs
Tornadoes	Poor crop cycle planning
Wildfires	Improper management of industrial effluents and wastes
	Over-grazing
	Surface mining

It is important to stress that there are no simple or direct relationships between underlying drivers and land degradation and that all the drivers need to be evaluated in spatial, temporal, economic, environmental and cultural contexts [20]. The main drivers listed above will be analyzed individually in the next paragraphs, emphasizing their impacts at the European level.

2.3.1 Land cover change and land use change

Land cover indicates the physical land type (forest, wetlands) while land use documents how people are using the land. The different types of land cover can be managed or used quite differently, for development or agriculture, for conservation. Land-use change and land cover change generally entail

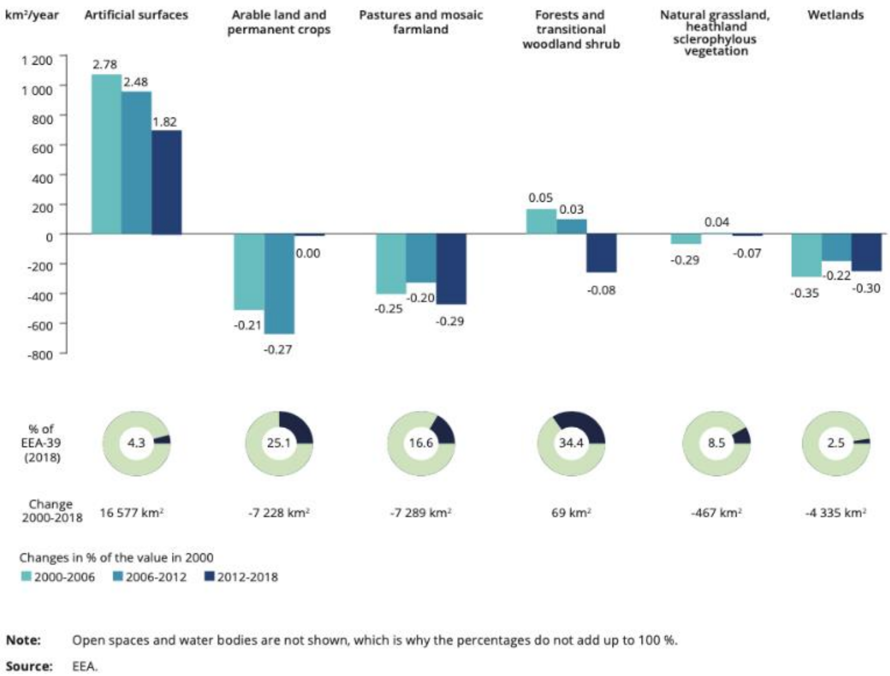
the transition from one type of vegetative cover to another (e.g. forest to pasture, natural grassland to cropland) [25].
They strongly affect the fertility and security of soils, reducing the accumulation of Soil Organic Carbon (SOC). Some studies [25], [29] showed that for 98% of the sites considered (especially in temperate regions) there is a reduction in SOC stocks following land-use change [25].

Land-use change has been accelerated by urban and industrial growth, migration and the demographic increase [25], [30]. Initially, a transition from natural vegetative cover to agricultural cover was observed due to the expansion of intensive agriculture. Subsequently, with the arrival of globalization and industrial and urban development, another trend was revealed in Europe: agricultural soils began to be converted into building and urban soils.

Particularly, as shown in Figure 8, during the period 2000-2018 it was observed that:

- The artificial surface has changed the most (+ 7.1%);
- The areas of arable land and permanent crops became smaller by 0.5%. Czechia, Hungary, Spain and southern Portugal have recorded the largest losses [23];
- The areas destined for pastures and mosaic farmland have undergone reductions, especially in Ireland, France, Germany and Spain;
- Wetlands have shrunk by 1% over the last two decades, especially due to the conversion to agricultural land, industrial sites and afforestation;
- Forests, transitional woodlands and natural grassland have experienced the least reductions.

Figure 8. *Changes in land cover types. EEA-39*[4]*. 2000-2018. Retrieved from* [23]*, p. 118.*



Finally, the 2018 mapping of Europe's land cover by Copernicus Land Monitoring Service indicates a relatively stable proportion of Europe's main land cover types in the EEA's member countries and cooperating countries [23].

2.3.2 Urban sprawl, land take and abandonment of agricultural land

Pressures on land use are particularly associated with urban sprawl and infrastructures expansion. In fact, in Europe, as evidenced by changes in land cover, cities and infrastructure are continuing to expand at the expense of agricultural and fertile territories [2].

The factors that simultaneously and irreversibly contribute to the long-term reduction of the availability of territorial resources, compromising their capacity to provide the main ecosystem functions, are:

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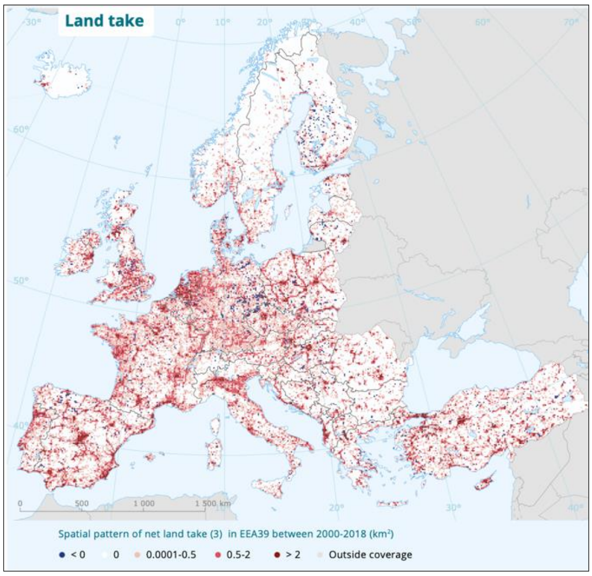
[4] It includes: Albania, Austria, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kosovo, Latvia, Liechtenstein, Lithuania, Luxemburg, Malta, Montenegro, Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzeland, Turkey, United Kingdom [53].

- Intensification of land take [2], [23], namely of the process by which agricultural areas, forests and other natural and semi-natural areas are removed from their habitat and converted into building and urban land. For the period 2000-2018 (see Figure 9), 80% of the productive soils were converted into urban agglomerations, at the expense of arable land, pastures and mosaic farmlands [23].

  Recently, land reconversion for agricultural purposes occurs in some European countries, but, unfortunately, the subtraction of productive land continues to take place with rates 11 times higher than those of reconversion.

  Fortunately, the rate of increase in artificial surface areas has slowed down in recent years.

Figure 9. Land take in Europe. 2000-2018. Retrieved from [2], *p. 19.*



- Fragmentation of the landscape [2], [23]. Human activities have modified an increasing share of the landscapes of our planet through the expansion of urban areas and their supporting infrastructure. Those irreversible changes often constitute real barriers for wildlife and plant dispersal, fragmenting habitats into smaller and more isolated patches and jeopardizing both the ecosystem services supply and survival of the natural biodiversity of an area.

  In Europe approx. 28% of the area was strongly fragmentated in 2015 with an increase of 0.7% compared with 2009 [31]. Luxemburg, Belgium and Malta had the largest proportions of strongly fragmented landscape compared with their country area, while the Baltic countries, Finland and Sweden were, on average, the least fragmented countries [31][5].
- Land abandonment, especially in remote regions where the local economy relies heavily on the agricultural activities of often small-scale farms with low agricultural productivity.

  In the next 20 to 30 years, significant areas of agricultural land are expected to be abandoned in many parts of Europe. It is an issue because in uncultivated land natural revegetation often results in ecosystems with fewer species [2];
- Waterproofing of surfaces [2];

[5] Data referred to 2015.

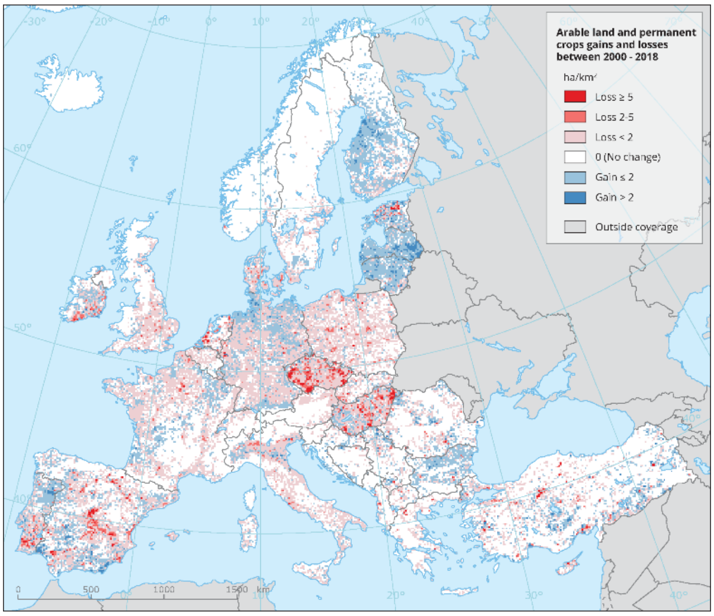
- Erosion generated by the removal and destruction of the natural vegetative layer of the soil for the construction of buildings and infrastructures.

2.3.3 Agriculture and forestry

Over the past 70 years, land-use intensity and agricultural production have increasingly evolved from local to global industries aimed at feeding ever-growing populations, supporting changing tastes and responding to the growing demand for biofuels. More intensive agriculture has allowed Europe to produce food in greater quantities, but at the expense of the environment and traditional agriculture [2]. This has a range of negative impacts, such as [2], [15], [23]:

- Land abandonment and loss of arable land (Figure 10);

***Figure 10**. Arable land and permanent crops gains and losses. 2000-2018. Retrieved from* [32].



- Loss of soil fertility, caused by the intensification of harvest frequency;
- Loss and altering of biodiversity and European landscapes, also due to the use of high quantities of pesticides;
- Soil compaction by heavy machines;
- Increase in the susceptibility to wind and water erosion;
- Soil contamination due to the excessive use of synthetic fertilizers and plant protection products;
- Eutrophication and pollution of freshwater ecosystems due to the extra nutrients introduced by fertilizers and their consequent accumulation in the soil after the harvest [25], [33];
- Imbalances in global nitrogen and phosphorus flows [23], [25], [33];
- Air pollution and climate alteration, due to the unreasonable use of fertilizers;
- Loss of grasslands and consequent erosion due to overgrazing, land abandonment, conversion to cropland, increase of fertilization;

- Degradation of forest ecosystems caused by the acceleration in conversion to agricultural land for the growing demand for food and biofuels. Forest Europe states that 8% of the European forest area is intensively managed plantations and deforestation in Europe represents about 1% of the global deforestation entity. Deforestation causes loss of organic matter and carbon in the soil and an increase in CO_2 emissions into the atmosphere;
- Damages to local communities, economy, cultures and eating habits. More people have more limited space to live in and rely on; for example, for the period 1961-2015 the arable land use per person decreased by 36% for the Euro area [34].

These problems, initially focused on zones with fertile soil in Europe, are now widespread to regions with less fertile and more vulnerable soils, such as the Mediterranean area [2].

2.3.4 Land competition

As we have seen, the competition in land use is on a continuous rise; indeed in the coming years it will be necessary to increase the construction of buildings and the production of food, goods, services, biofuels and other plant-based products to satisfy the expected population increase [2], [23]. However, this is closely linked to the possibility of maintaining healthy soil and managing agricultural areas by adopting sustainable models [2].

2.3.5 Climate change and desertification

Climate change applies additional pressure to the land system, exacerbating the well-acknowledged ongoing land degradation processes of ecosystems and leading to the introduction of new degradation pathways in natural and semi-natural areas [20].

There is a dual relationship between climate change and land degradation, as one affects the other [2]. Climate change, through the increase of the global temperature and the variation and intensification of precipitation regimes, worsens soil and land resources, exacerbating most of their degradation processes both in terms of likelihood and consequences. In particular, they can involve in various combinations:

- Changes in vegetation cover and composition;
- Erosion;
- SOC decrease;
- Soil salinization and sodification;

- Reduction of soil moisture and intensification of the global water stress level. In particular, since the 1950s, the Mediterranean area has been largely affected by this problem, while Northern Europe has been recording an increasing trend [18];
- Melting of permafrost, resulting in the release of massive quantities of greenhouse gases into the atmosphere and the acceleration of global warming far beyond human's ability to control [2];
- Intensification of the vulnerability to desertification[6] for many of the European regions [35]. To date 13 EU Member States declare themselves affected by this problem [2]. Southern Portugal, some areas of Spain and southern Italy, south-east Greece, Malta, Cyprus and the areas bordering the Black Sea in Bulgaria and Romania present a particularly serious risk of desertification [36]. Between 2008-2017 the part of the territory with a high or very high sensitivity to desertification increased, equaling the extension of Greece and Slovakia together [36].
  Desertification, in turn, involves: the reduction of crops yields and productivity of agricultural areas; the intensification of erosion; the loss of portions of land, the alteration of coastal areas and the contamination by marine origin substances (e.g. salt) due to sea-level rise.
- Reduction in yields and significant effects on food production. The rapid increase in temperatures on the European land surface, starting from the second half of the 1980s, has caused hotter and drier summer conditions, triggering stress conditions for crops [18];

- Biological soil crust destruction;
- Reduction by up to 16% by 2050 of the income of the European agricultural sector [2];

All these effects are not only driven by climate change and do not spread uniformly across Europe but appear to be highly variable on a global and regional scale. It is difficult and challenging to exactly attribute and evaluate how climate changes contributes to the soil degradation processes due to several unclear factors. Unfortunately, climate change will continue driving changes in agricultural land management in the coming decades if land management will not be improved [20].

2.3.6 Transport development

Other pressures on land result from socio-economic factors [23]. For example, the expansion of transport infrastructures and the emissions generated by vehicular traffic impact the soil in terms of diffuse contamination, while road spills and facilities connected to the transport sector (e.g. petrol

[6] Desertification consists of "soil degradation in arid, semi-arid and dry sub-humid areas as a result of various factors, including climatic variations and human activities". Desertification does not refer to the conditions of areas normally designated as "deserts", but rather to arid areas [36].

station and car-repair facilities) contribute to local contamination [15]. Other negative impacts result from inadequate storage of hazardous chemicals, as these can easily penetrate into the soil and also contaminate groundwater [15]. In addition to contamination phenomena, the extension of roads and railways has also compromised soil biodiversity, helping to fragment natural habitats into ever-smaller spaces [2].
The consequences are more observable in all major European cities, such as London, Paris and the Ruhr area [15].

2.3.7 Development of the industrial sector and the tourism sector

Industrial, energetic, civil, urban, military and mining activities affect soil in terms of local and diffuse contamination [15], leading also to: soil compaction; surface sealing; soil and arable land loss; morphological changes; soil erosion; pollution of natural resources; dispersion of harmful substances in larger spaces and hydrological disruption.

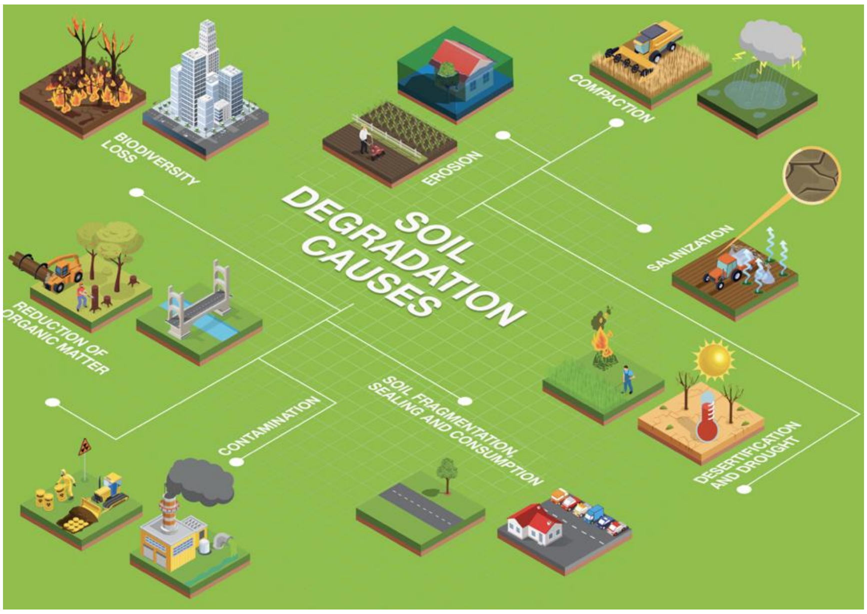
2.4 Soil degradation and threats

Soil threats (see Figure 11) are recognized as degradation processes and can occur in series or simultaneously, intensifying their consequences and negative impacts.
Below, the degradation phenomena will be analyzed individually with the dual objective of understanding:

- The pressures resulting from them;
- How the impacts of these threats negatively affect the functions of soil for humans and the environment.

In addition, for each phenomenon, an attempt will be made to define its extent and severity within the European territory.

Figure 11. Soil threats. Retrieved from [3], *p. 9.*



2.4.1 Physical degradation of soils

Soil sealing

Soil sealing is defined as the phenomenon by which soil and land are lost and covered with impermeable material for the construction of roads, houses and other infrastructures [21], [23], [35]. The term is also used to indicate any change in the soil that makes it impervious [21].
The main causes of soil sealing are, therefore, urban sprawl and industrial and infrastructural development.

Usually, it involves the physical removal of the surface layer of the soil (topsoil) and is considered by most scientists and researchers an irreversible phenomenon, as it entails [2], [21], [23], [35]:

- Irreversible loss of most soil functions (e.g. food production, waste storage and temperature regulation);
- Alterations in biodiversity due to the reduction of gas, water and energy flows, the fragmentation of landscape habitats and the destruction of ecological corridors;
- Alteration of the natural water cycle, which, in turn, generates high flood risks;
- Reduction in the ability of the soil to absorb rain, with particularly severe alluvial peaks;

- Removal of fertile and good quality soil;
- Contamination of soil and groundwaters due to the high volumes of unfiltered runoff waters from households, roads and industrial sites;
- Intensification of climate change.

In 2015 (Figure 12), the area considered as sealed had an extension equal to about 12 football fields, while the average percentage annual increase in sealing for the period 2006-2015 across the EEA-39 reached about 1.6%. During the same period, on average 0.008% of the EEA-39 area was newly sealed every year [37]. The countries[7] with the largest sealed area in absolute terms in 2015 represented 76% of the total sealed area of the EEA-39, while they physically and territorially occupied only half of it [37].

Furthermore, the highest percentage of sealed area, concerning the extension of each country, was observed in Germany, Liechtenstein, Belgium, the Netherlands and Malta. Instead, Iceland, Norway, Lithuania and Sweden recorded the lowest percentages [37].

Overall, between 2006 and 2015 (Figure 13), there was an increase in imperviousness [37].

Figure 12*. Imperviousness density in 2015. Retrieved from* [37].

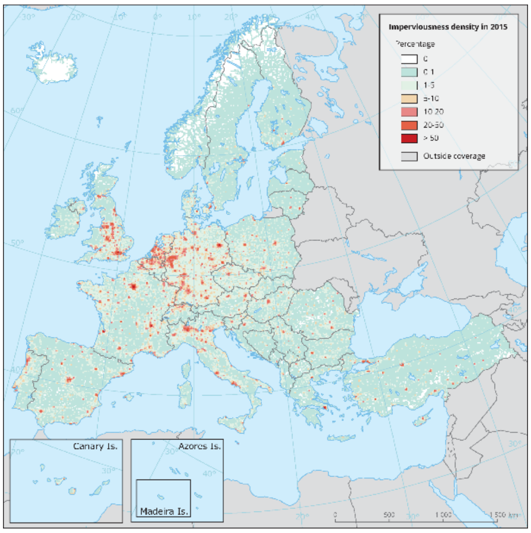
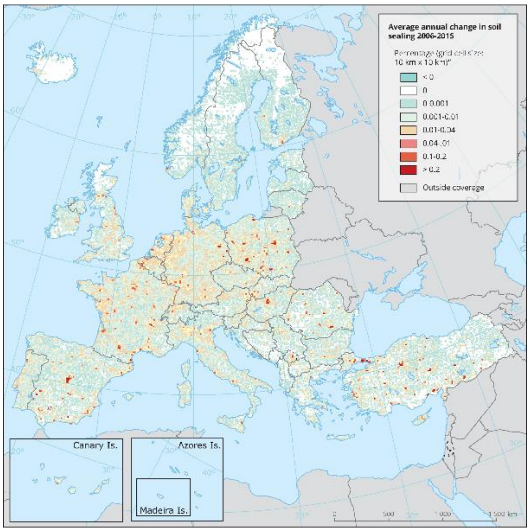


Figure 13*. Average annual change in soil sealing, 2006-2015. Retrieved from* [37].



To summarize, soil sealing has mainly affected intensely urbanized cities, especially in Western Europe, and areas where the expansion of tourism has dragged urban sprawl with it (e.g. coastal areas of the Mediterranean countries). The types of soil most affected by this degradation phenomenon are non-irrigated arable land and complex cultivated patterns.

[7] Germany, France, Italy, the United Kingdom, Spain, Turkey, Poland, the Netherlands, Romania and Portugal [37].

Soil erosion

Soil erosion is considered to be one of the most important soil degradation processes in the world, due to its unsustainable development rates and the severe limitations that it induces in the sustainable use of land, particularly in Europe [18], [21], [35].

It is a natural process that for millions of years has transformed the landscape that surrounds us [21], as it involves the removal of soil and rock particles due to the effect of physical and natural forces (e.g. rain, water flows, wind, ice, change in temperature, gravity) and other anthropogenic agents [21], [35]. Once removed, the soil particles are transported until they are deposited in an area different from their original one [35].

Of particular concern is the so-called accelerated erosion, which, due to anthropogenic phenomena and activities, has much higher development rates than soil formation rates [21].
Various types of erosion exist; among the most commonly known there are:

- Water erosion. It is the best known and most widespread form in the world and is caused by the action of water which, falling and flowing on the soil surface, causes the removal of its solid particles [21];
- Wind erosion. Originated by strong and persistent winds, it entails the removal and transport of soil particles via air (greater distances) or land (shorter distances) [35].

In general, any form of erosion involves on-site and off-site effects on the soil, the impacts of which are determined by local soil conditions (e.g. texture, organic matter content) and by environmental, economic and social characteristics of the area. On-site damage is more frequently measured, unlike off-site, which has long-term consequences [35].

Table 4 summarizes the main drivers that induce soil erosion and the main effects generated by it.

Table 4. *Causes and effects of soil erosion* [2], [21], [23], [35].

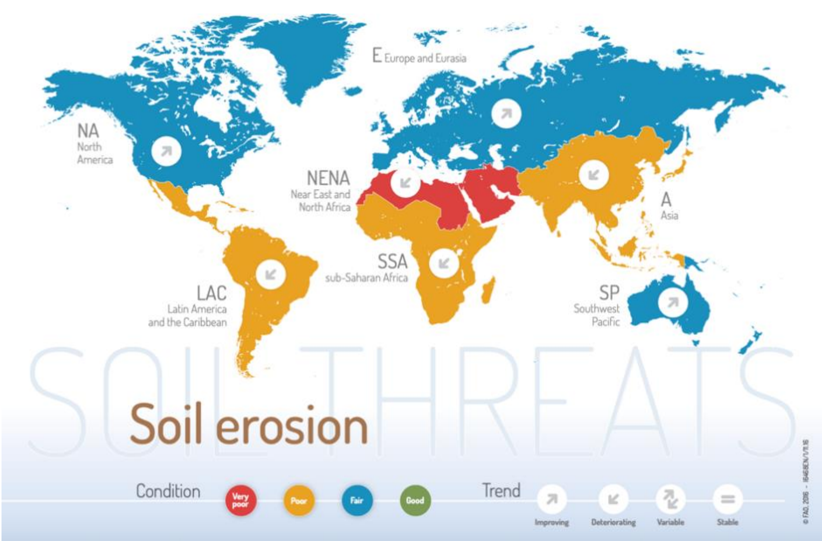
CAUSES	EFFECTS	
	On-site	***Off-site***
Development of agriculture Land cover change (e.g. clearing forests for cultivation) Cultivation and farming practices Overgrazing Controlled burning of wildfires Levelling of the land surface Harvesting of root crops Variation in the intensity of land management Excessive use of herbicides and fertilizers Removal of nutrients within the soil Alteration of hydrogeological and nitrogen cycles Precipitation and runoff Extreme atmospheric and climatic phenomena Land abandonment and marginalization Climate change	Formation of rills, gullies, and, in extreme cases, badlands	Buffering and filtration of pollutants also in water bodies, allowing them to travel large distances
	Irreversible loss of soil and topsoil	Floods and inundation
	Destruction of the surface cover[8]	Infrastructure burial
	Loss of organic matter	Obstruction of drainage networks
	Loss of fertility, productivity[9] and ecosystem functions of the soil (e.g. biomass provision, biodiversity protection, natural water and nutrient cycle)	Water eutrophication
	Social and economic disadvantages for the agricultural community	Reduction of channel capacity, block of culverts and increase of bank erosion
	Greater susceptibility to erosion	
	Net carbon release (e.g. CO_2)	

Figure 14 shows by a global point of view the conditions and trend of soil erosion[10].

For the European Union, erosion represents a relevant issue [38] and it is mainly caused by water, while wind affects it to a lesser extent [15].

[8] It has been estimated that 4.2 million hectares of crop roots contribute to the loss of 14.7 million tons of soil [23].
[9] In Russia, for example, long-term observations have shown that soil erosion has helped reduce the yield of leguminous crops by 15%, wheat by 32% and potatoes by 45% [25].
[10] The map was developed on the occasion of the World Soil Day on December 5,2015.

Figure 14. *Soil erosion world map: conditions and trends. Retrieved from* [39].

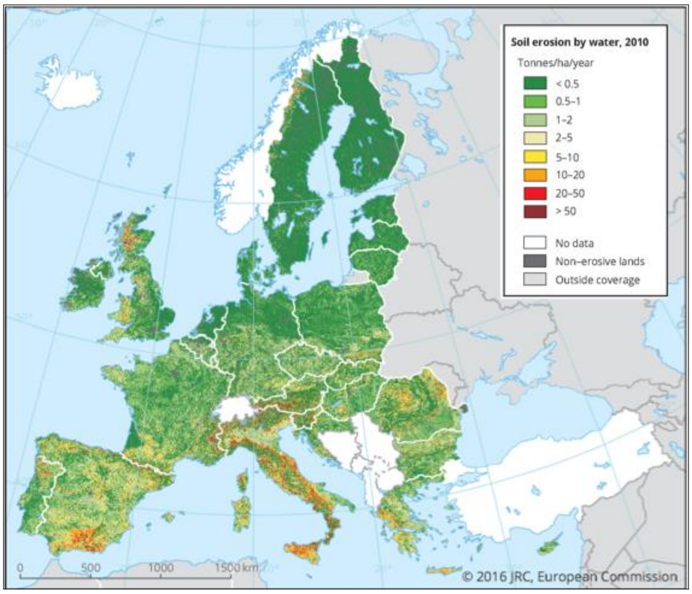


The EEA report "*European environment-state and outlook 2020*" shows that 12.7% of European land is affected by high to moderate erosion with soil loss rates above 5 t/ha/year. In particular, in Europe, water erosion involves a total loss of soil estimated at 970 million tons per year [23].

The Mediterranean regions, mainly due to its climatic and geographical conditions and the agricultural practices adopted, show a high risk of erosion.

In some places this phenomenon reached a stage of irreversibility [35]. Erosion risk affects also some areas of western and central Europe [35]. Furthermore, in particularly arid and semi-arid climates, erosion phenomena induce desertification.

Figure 15*. Estimated soil erosion by water. 2010. Retrieved from* [40].



Panagos et al. states that "*the highest soil loss rates are found in the Mediterranean areas and in the Alpine regions of Slovenia and western Austria, mainly due to a combination of high rainfall erosivity and steep topography*" [38] (see Figure 15).

Soil erosion is principally induced by climate change, as we have seen in the Table 4; some studies affirm that erosion rates can be expected to increase in the future as a result of rain events, coupled with sectorial changes and increases in particles size and soil compaction [23].

It is clear that erosion is spreading like wildfire throughout the world, but it should be remembered that precise estimates of its extent are not possible due to the absence of comparable data [35].

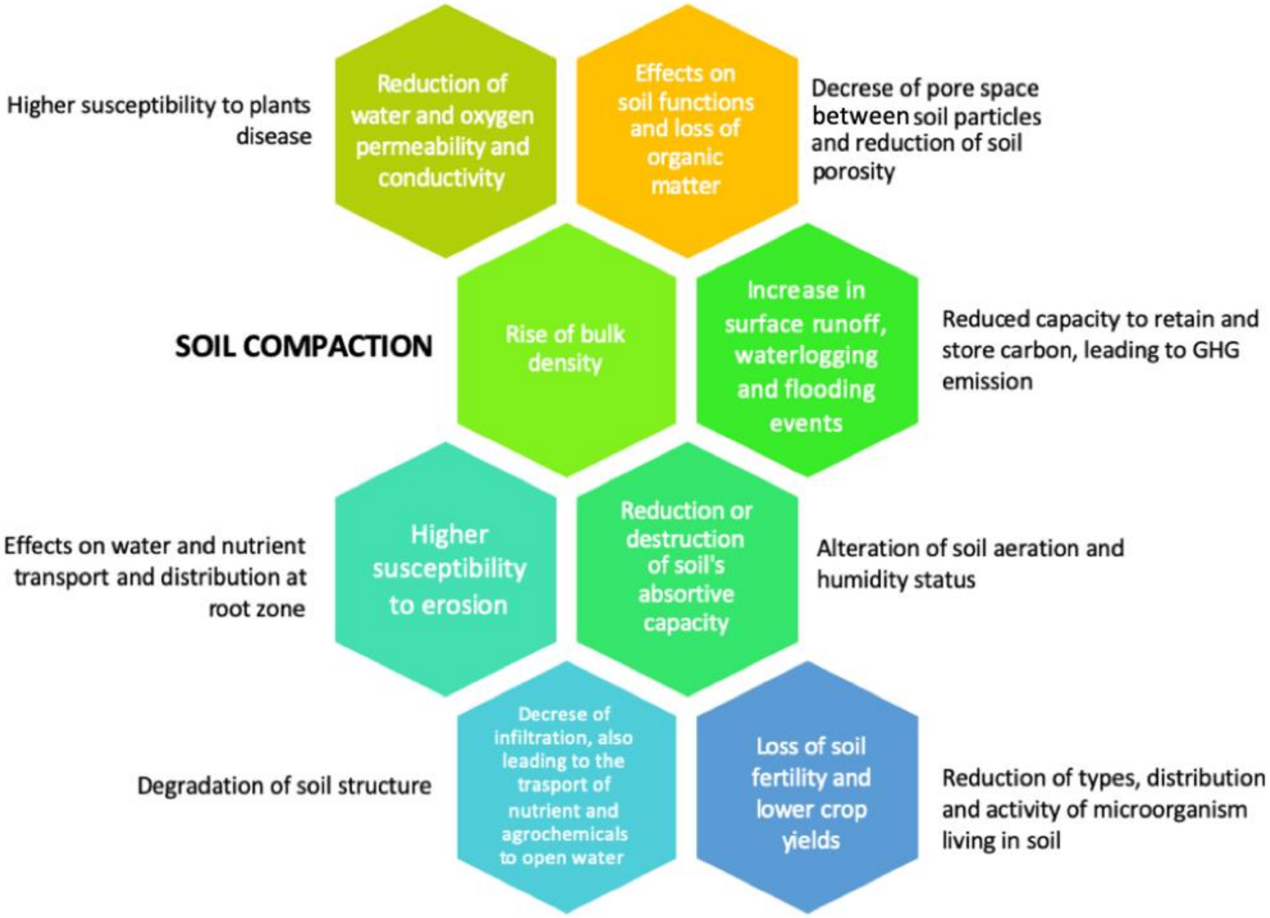
Soil compaction

Soil compaction is the densification and distortion of the aggregates that make up the soil due to applied mechanical stress [21], anthropogenic or natural causes [2], [3], [20], [22], [23], [25], [26], [33], [35], such as:

- Use of too heavy machinery for agricultural activities or for construction sites;
- Intensive grazing;
- Climate changes (e.g. increased rainfall during cold seasons);
- Increasingly shorter times for cultivation (e.g. intensive agriculture);
- Swellings or crevices of the ground itself;
- Land-use conversion.

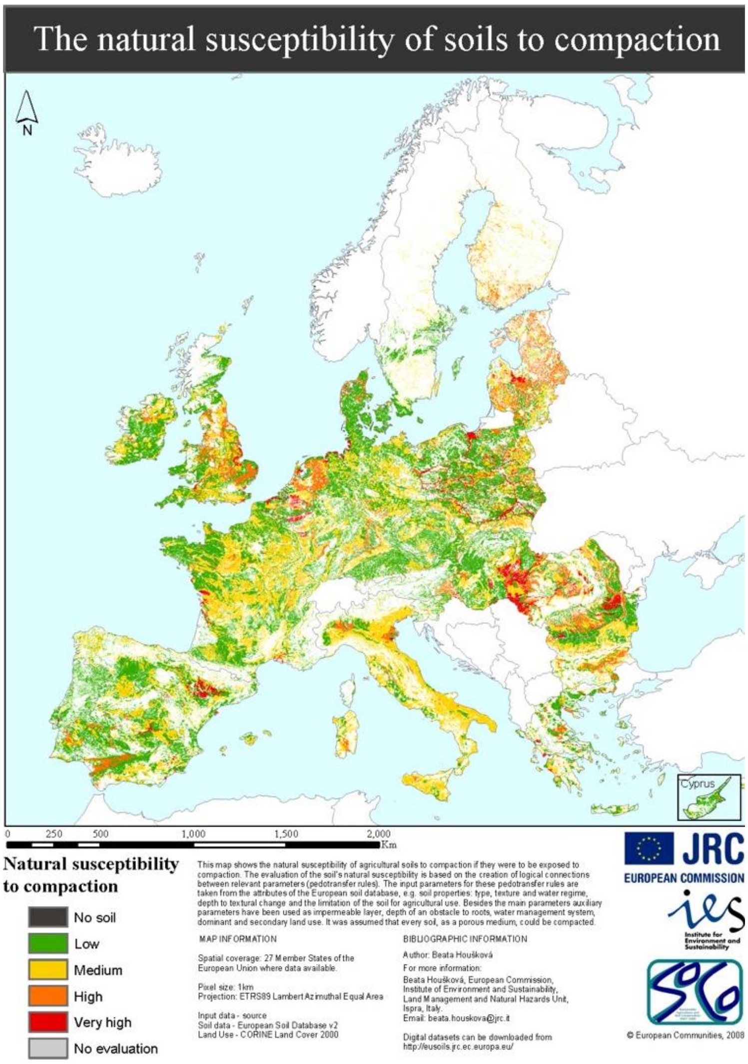
Figure 16 summarizes the principal negative impacts induced by soil compaction [2], [3], [20], [22], [23], [25], [26], [33], [35]. Compaction phenomena involve both topsoil and subsoil. The latter case is a hidden process with cumulative impacts over time. Therefore, subsoil compaction can be extremely difficult to individuate and remediate, also due to expensive restorative treatments [35]. Estimates regarding the extent of this phenomenon at a European level vary.

Figure 16. *Impacts and negative consequences caused by soil compaction.*



The "*European environment-state and outlook 2020*" report states that about 23% of the soils of the EU-28 are affected by highly critical compaction densities in the subsoil [23]. Figure 17 shows for the EU-27 countries the natural susceptibility of agricultural soils to compaction.

***Figure 17**. The natural susceptibility of soils to compaction. 2008. Retrieved from* [41].



2.4.2 Chemical degradation of soils

The concepts of soil contamination and pollution are often used to indicate the same phenomenon. In reality, soil contamination occurs when the concentration of chemical substances, nutrients or elements becomes, mainly due to anthropogenic activity, much higher than the natural background values that can be normally detected. A site, on the other hand, is defined as polluted when the concentration of chemical substances, being much higher than the maximum permissible levels, entails risks for humans, plants, animals, ecosystems and other natural resources (e.g. water) [21], [35].

Contaminated sites are the legacy of a long industrialization period that involved the uncontrolled release of hazardous substances into the environment [21] through [3] (see Figure 18):

1. Point and individual sources;
2. Diffused sources;
3. Phenomena of natural origin (e.g. atmospheric deposition, sedimentation of surface waters).

Figure 18. Key source of soil contamination in Europe. Retrieved from [2], *p. 18.*

Table 5 specifies the causes contributing to soil contamination and the main effects that derive from them.

Table 5. *Drivers leading soil contamination and its main threats* [3], [14], [21], [23], [33], [35].

SPECIFIC CAUSES OF SOIL CONTAMINATION	NEGATIVE EFFECTS AND CONSEQUENCES
○ Abandonment of waste and illegal burial of pollutants; ○ Illicit and illegal fires; ○ Addition of toxic substances through the use of polluted waters in agriculture; ○ Unsustainable agricultural practices; ○ Vehicular traffic; ○ Excessive use of fertilizers and pesticides; ○ Transport of contaminants through atmospheric phenomena (wind and rain); ○ Uncontrolled excesses and surpluses of nitrogen and phosphorus; ○ Industrial accidents; ○ Intensive land management.	○ Reduction of productivity and agricultural yield; ○ Transfer of pollutants through the soil and contamination of plants, animals and people through contamination of the food chain; ○ Loss and alteration of the ecosystem functions of the soil (e.g. buffering[11], filtration and transforming); ○ Loss of soil biodiversity; ○ Higher levels of radioactive and nuclear contamination; ○ Alteration of the nutritional cycle of plants due to excessive inputs of heavy metals, such as cadmium, mercury, arsenic and lead; ○ Pollution of groundwater and surface water bodies; ○ Reduced capacity of retention and transfer of nutrients to plants; ○ Saturation and eutrophication.

[11] When the buffering capacity for a specific element is exceeded, the substance is released into the environment, compromising groundwater and/or surface waters.

Soil characteristics play a fundamental role in the movement of chemicals within it; thanks to the specific buffering and filtration properties, soil acts as a reservoir for all the elements and substances released into the environment by human activities. Therefore, many pollutants tend to accumulate inside, even if some of them (e.g. heavy metals) are naturally present in the soil [21]. The most frequent contaminants within European soils are mineral oils (especially in Belgium and Lithuania) and heavy metals (mainly in Austria and the former Yugoslav Republic of Macedonia) [42][12].

In EU-28 potentially polluting activities involved about 2.8 million sites, of which only 24% were inventoried. Considering past and current estimates on the extent of contamination and the uncertainties relating to reliable analysis, progress has been made in the management and assessment of contaminated sites [23], [42]. However, there are several difficulties in estimating the extent of soil contamination across Europe due to substantial differences between European countries in the criteria for identifying contaminated sites.

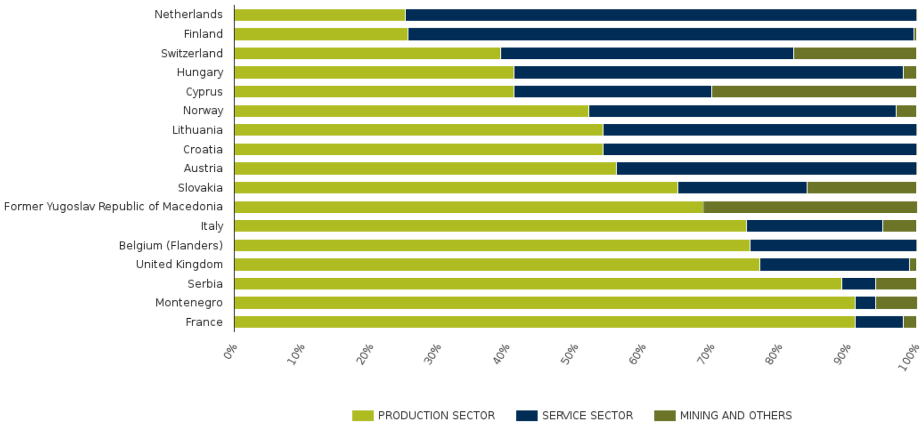
Local contamination

Local contamination is mainly caused by point sources due to the use of soil as a physical support (e.g. operating and/or decommissioned industrial plants, waste landfill).

In general, in Europe two-thirds of the local contamination has been caused by waste disposal and treatment, together with industrial and commercial activities [42].

The distribution of local sources (Figure 19) of contamination has not changed since 2006 and it is correlated to the specific industrial and commercial focuses for Countries [42].

Figure 19. Breakdown of sectors responsible of soil local contamination. Retrieved from [42].



[12] The estimates refer to the year 2011.

However, it is quite difficult to compare data due to the fluctuating and variable participation of European countries in monitoring and evaluation campaigns.

On average the production sector has contributed more local soil contamination (60 % of sites) than has the service sector (32 % of sites). To a lesser extent, mining activities are also important contributors to soil contamination in Cyprus, Slovakia, and the former Yugoslav Republic of Macedonia. Within the production sector the metallurgy industries have a higher frequency of incidence (13% of sites[13]), compared to the textile, leather, wood and paper industries; while in the service sector, petrol stations are the local contamination activities with the highest occurrence (15 % of sites[14]) [42][15].

Diffuse contamination

Diffuse contamination results from a variety of factors, such as atmospheric deposition of acidic compounds, toxic substances and contaminants, direct and excessive application of fertilizers and pesticides, as well as many other human activities.
In addition to the negative consequences already mentioned in Table 5, the most problematic phenomena attributable to diffuse contamination are soil acidification, heavy metal contamination and nutrient surplus (e.g. nitrogen and phosphorus) [15], [21].

Soil acidification

Soil acidification is mainly caused by the atmospheric deposition (dry or through precipitation) of acidic substances (principally compounds of nitrogen and sulfur) emitted by anthropogenic processes and activities (e.g. vehicular traffic, power plants and other industrial processes).
The soil acidification most worrying consequences are [14], [15], [21], [43], [44]:

- Limitation in the growth of plants roots;
- Reduction in agricultural yields;
- Increased accumulation of toxic or phytotoxic substances in the soil (e.g. aluminum);
- Reduction of soil pH.

[13] Mainly in Yugoslav Republic of Macedonia, France and Slovakia [42].
[14] Particularly in Netherlands, Finland, Hungary, Croatia, Italy and Belgium [42].
[15] The contaminated sites data showed in sub-paragraph "*Local contamination*" were collected and managed by the European Soil Data Centre (ESDAC). The data were collected in 2011-2012 through the EIONET network which consists of representative organizations from 38 European countries for a number of environmental themes.

In Europe, the extent of the phenomenon is not homogeneous, so much so that it is easy to identify hotspots. In general, areas that have a high sensitivity to acidification are the Netherlands, Finland and Belgium [15]. In the EU-28 for the year 2010, the critical loads for acidification were exceeded in 7% of the ecosystem area and in some areas the interim goal of reducing acidification had not yet been met [45].

Heavy metal contamination

Trace metals are naturally present within the soil, as they too, like nutrients, are essential for the growth of animals and plants. Worrying are the cases in which these metals (mainly cadmium, lead, mercury, arsenic, chromium, copper, nickel, zinc and cobalt) occur in such high concentrations as to represent a threat to food security, human health and the environment, due to their toxic potential[16] and their high mobility of transfer.

Soil contamination by heavy metals strongly influences the nutritional content of food products, generating nutritional deficiencies and imbalances and favouring the transfer of these substances from food to humans [46], [47].

In Europe, while diffuse contamination through large-scale atmospheric deposition has been decreasing for lead and mercury since 1990, cadmium and copper are still accumulating in arable soils [23]. The presence of cadmium in the soil, mainly due to phosphate fertilizers, can cause severe health problems. In Europe, especially in southern countries, 45% of agricultural soils is characterized by cadmium accumulation, while the concentration of this element within the topsoil exceeds the limit set for groundwater used for drinking purposes [23].

Furthermore, a recent large-scale study showed that copper concentrations in vineyards were three times higher than the average level in European soils because of its extensive use as a fungicide in vineyards and orchards for decades [2]. The Mediterranean countries have recorded high accumulation rate values [48]. Copper is also added to animal feed (together with zinc) and is introduced into the environment when manure is spread over grasslands and other agricultural lands.

There is also a growing concern about the presence and accumulation of pesticide residues and their metabolites in the soil, due to their potential release via wind erosion and acidification. In the

[16] It depends not only on the concentration with which they are present within the soil but also on the climate, the type of soil and vegetation [15].

Netherlands, in one-third of the extractions from the aquifers, pesticide concentrations that exceeded pesticide standards were found. Two-thirds of the substances found were herbicides [23].

In a pilot study conducted using soil samples resulting from the LUCAS survey, more than 80% of the tested soils contained pesticide residues, while 58% of the samples contained mixtures of two or more residues for a total of 166 different combinations [23]. These results highlight the cumulative effects of pollutants and that pesticide mixtures in the soil are the rule and not the exception.
In conclusion, soil contamination is widely developed in Europe and various critical levels are still exceeded (e.g. cadmium) indicating that the soil filtration capacity has been surpassed in some areas.

Nutrient surplus

Nitrogen and phosphorus are essential elements for plant growth and are naturally present in the soil but can become dangerous if present in excessive quantities. Their excess is, in general, caused by the overuse of nitrogen-based and phosphate-based fertilizers and by natural deposition phenomena (dry or wet).

Surplus of nutrients (in particular nitrogen) can cause severe effects on the environment:

- Environmental pollution, substantial imbalances in global nitrogen and phosphorus flows [25], [33], soil acidification and eutrophication of groundwater;
- Reduction of the availability and prosperity of European forests [21];
- Reduction of biodiversity and alteration of the distribution of plant species in a wide range of European ecosystems [23];
- Alteration of ecosystem functions and soil properties (e.g. nutrient cycle, buffering and filtering capacity).

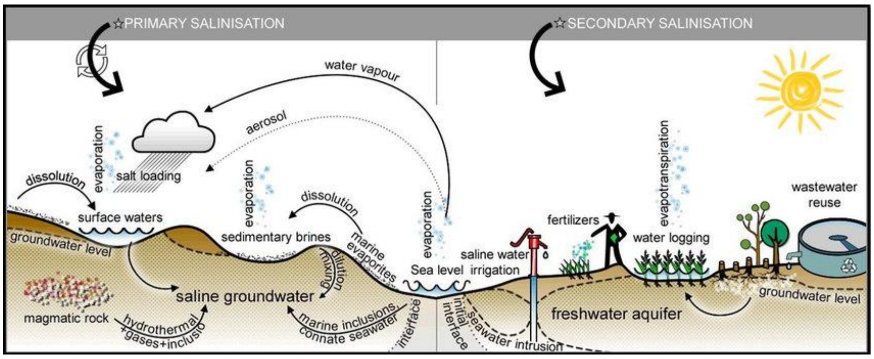
Europe is considered a global nitrogen hotspot due to the high export of nitrogen from rivers to coastal waters and the N_2O emissions produced, which represent 10% of the global ones [23].
In general, the distribution of nutrients in European soil is quite heterogeneous and, despite the constant or slightly decreased use of fertilizers, loads of nutrients from widespread agricultural sources remain high, especially in north-western Europe.
65-75% of agricultural soils in the EU-27 have nitrogen accumulations above the limit values and it has been estimated that to offset this excess it will be necessary to reduce nitrogen inputs by about 40% [23]. Furthermore, phosphorus surpluses are also relatively high in southern Europe due to low removal rates due to harvesting [23].

Salinization

Each soil has a natural given concentration of salts within it, necessary and essential for vegetative development [3].

Generally, soil salinization (see Figure 20) appears as a cumulative and irreversible phenomenon, the effects of which are clearly visible after a long time [3], [35].

Figure 20. Primary and secondary salinization. Retrieved from [49], *p. 72.*



This form of degradation involves the formation of a white or grey crust on the surface and in some areas, particularly in arid and semi-arid areas, the sterility of the soil itself, destroying all the vegetation and organisms that live in the soil [3], [50].

In Table 6 are listed the main causes and the most worrying damages concerning this degradation form.

Table 6. Causes and damages of soil salinization [35], [50], [51].

NATURAL CAUSES (Primary salinization)	ANTHROPIC CAUSES (secondary salinization)	EFFECTS AND DAMAGES
Physical or chemical weathering	Use of salt-rich irrigation water	Impaired vegetative activity
Transport from parent material, geological deposits or groundwater	Overexploitation of coastal groundwater aquifers causing seawater intrusion	Reduction of productivity and agricultural yields
Parent rock constituents (e.g. carbonate minerals and/or feldspars)	Inappropriate irrigation practices (e.g. poor quality waters, overpumping)	Greater sensitivity and less tolerability of crops to salinization
One-time submergence of soils under seawater	Poor drainage conditions	Induction of desertification
Sea level rise		Alteration of the water cycle and movement of salts in the soil
Evapotranspiration and lack of rainfall to flush the soils		Nutritional imbalances or toxicity

Wind action	Damage to soil biology
	Negative effect on farmers' income
	Negative effects on soil functions (e.g. provision of fresh water for livestock, wild animals and plants, regulation of groundwater quantity and quality, soil water and wind erosion, supporting habitats)

In Europe, soils affected by salt are located in the Caspian Basin, Ukraine, the Carpathian Basin, and the Iberian Peninsula. The salinity of the soil affects about 1 million hectares in the European Union (mainly in the Mediterranean countries) [3], [35]. Projected temperature increases and changes in precipitation characteristics are only likely to enhance the problem of salinization in many parts of Europe, especially in the Mediterranean region [50], [51].

Another study estimated that 3.8 million hectares in Europe are affected by this problem. However, while other studies show that salinization levels in Spain, Greece, Romans and Hungary are increasing, systemic data about the European extent are not available [35].

2.4.3 Biological degradation of soils

Loss of soil organic carbon

The organic matter content is a key element for the soil because:

- it affects the structure, stability, fertility, nutrient availability and ability to infiltrate and retain water and provide ecosystem services;
- it accelerates the decomposition of pollutants and it can attach them to soil particles, reducing the risk of release [16];
- it allows the soil to absorb carbon [16]. Remember that the soil, after the oceans, is the largest natural carbon reservoir and, as such, it plays an essential role in regulating climate change. It can conserve double the organic carbon retained by vegetation [16].

How the land is used and managed by humans hugely affects how the soil reacts to carbon, negatively impacting biodiversity and climate. For example, the conversion of grassland, land intended for forests or native ecosystems, into arable land results in the release of carbon dioxide into the atmosphere, contributing significantly to the imbalance of greenhouse gases in some European countries. It has been estimated that the current CO_2 emissions due to drying up, fires and exploitation of peat bogs are equal to over 10% of global emissions due to fossil fuels [16].
Human interventions also threaten and disturb European peatlands, the most efficient carbon sink of all terrestrial ecosystems [16], contributing to a further loss of carbon stock.

As matter of fact, in all European regions, the availability of living organisms (e.g. earthworms, bacteria and mites) has been severely and negatively affected by the intensive soil and land use by humans. The absence of these microorganisms leads to the alteration of the nutrient cycles essential for plant growth. Thus, organic matter losses are equal to biodiversity and soil ecosystem functions losses.

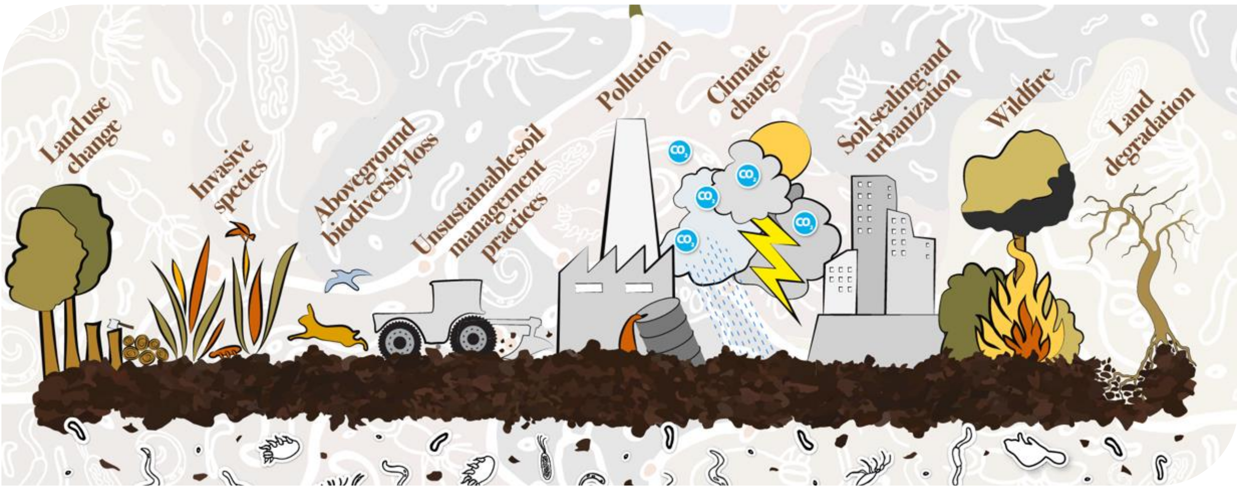
Loss of biodiversity

Soil biodiversity is the vast community of soil living organisms that determine the main biogeochemical processes that make life possible on Earth. Thus, biodiversity, as well as organic matter, is a fundamental element as:

- it contributes to the formation of the soil and improves its structure;
- a source of medicines and support to human health;
- it supports the nutrient cycle, plant growth and soil productivity;
- it contributes to soil remediation processes;
- it improves the soil's water retention and purification/filtration capabilities;
- it contributes to mitigation and adaptation to climate change;
- it improves the resilience of the soil to pests and plant diseases;
- it guarantees the maintenance and protection of ecosystems.

The main drivers behind biodiversity loss are summarized in Figure 21.

***Figure 21**. Main drivers of soil biodiversity loss. Retrieved and adapted from* [52].



Since we have previously had the opportunity to analyze most of the drivers reported above, let us focus on the invasive species, which can have major direct and indirect impacts on soil services and native biodiversity. In particular, invasive species alter nutrient dynamics and the abundance of microbial species in soil, affecting and reducing biological regulator populations, especially when they have species-specific relationships with plants.

3. CONCLUSION

Land and soil are essential for life on Earth. They provide the food we grow and eat, as well as other commodities such as animal feed, textiles or wood. Soil also provides a range of ecosystem services that allow for clean water, sustain biodiversity and regulate natural nutrient cycles and climate. Soil is a highly complex, dynamic and fragile system and is a limited and non-renewable resource; just think that it can take up to 1,000 years to produce 2-3 cm of soil! Unfortunately, it is often a largely underestimated resource, over-exploited and managed in an unsustainable way around the world.

Soil degradation is the sum of several processes (e.g. salinization, soil sealing, desertification, contamination, erosion): different factors that can occur simultaneously and can damage not only the ecosystems and the environment, but also the economic system.

Indeed, the intensive agriculture and the occupation of agricultural and semi-natural land by cities, commercial and industrial sites continue to exacerbate these phenomena. In addition, many anthropic activities continue to release pollutants into the environment, impacting food security, fertility and soil health. Today, traces of various contaminants can be found even in the most remote areas of our continent.

Another phenomenon that contributes to the alteration of the soil resource are the abandonment of agricultural land in rural communities with low economic fabric and productivity rates and a strong tendency towards urbanization. The soil is also heavily affected by climate change, which has repercussions both on food production and on environmental pollution.

In Europe, soil degradation is a serious and widespread problem [15]: it involves approx. 33% of the total European territory extent and approximately 37 million hectares of land are particularly vulnerable due to irreversible degradation processes [26]. Its extent across European countries is irregular and fragmented and really difficult to evaluate because of the adoption of different survey approaches and methodologies, the absence of continuous monitoring campaigns in some Member States and, consequently, the unavailability of data [15], [28].

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