3. Status and challenges of black soils

3.1 A global overview of black soils

Although black soils account for only 8.2 percent of the Global Land Area (FAO, 2022a), they are of paramount importance for food security, as highlighted by the UN Sustainable Development Goal 2 (i.e to end hunger, achieve food security and improve nutrition, and promote sustainable agriculture by 2030). The general category of black soils includes three main soil groups Chernozem, Kastanozem and Phaeozem, according to the World Reference Base for Soil Resources (WRB). Black soils are characterized by their thick, dark-coloured, and humus-rich topsoil. In general terms, black soils have granular and subangular blocky structure, optimal bulk density, and high amounts of plant nutrients. However all these favorable properties are only present in soils within virgin or quasi-pristine ecosystems, which are now rare (Montanarella *et al.*, 2021). There are other soil types also considered as black soils, as for example, swelling soils (Vertisols), volcanic soils (Andisols), anthropogenic soils, among others. Not all of them strictly comply with some of the conditions indicated for the Category 1 of black soil definition (such as having been formed under grassland vegetation) (FAO, 2019), but they all have some characteristics in their profiles that allow them to be classified as black soils, such as having a thick, dark-coloured, and humus-rich topsoil.

Apart from being highly productive lands, black soils are responsible for multiple ecosystem services such as water retention, maintenance of soil biodiversity from microorganism to megafauna, and soil fertility, and prevention of soil compaction and waterlogging. One of the most valuable services is accumulation of great amounts of SOC in a relatively stable form. Black soils are one of the most important pools of carbon accounting for 8.27 percent (56 PgC) of the total global SOC stock in the top 30 centimetres of the soil (FAO, 2022d).

These carbon stores are, however, endangered by the processes of organic carbon loss due to the accelerated humus oxidation under cultivation. In many places the loss of humus and nutrient mining are the most important threats to black soils because these soils are considered as highly fertile “by nature” and thus have not needed application of organic and mineral fertilizers. Black soils are under further threat from various physical, chemical, and biological degradation processes (FAO and ITPS, 2015).

Some of these processes are easily reversible through sustainable soil management practices, such as nutrient imbalance, compaction, and structural degradation. However, other processes are difficult to reverse. First, soil loss due to erosion (wind, water and meltwater), is the most widespread threat in all world’s soils. Wind erosion is a problem that tremendously affected the Midwestern of the United States of America (the infamous Dust Bowl in the 1930s) and west Siberia and north Kazakhstan in the ex-Union of Soviet Socialist Republics (USSR) during the development of virgin lands in 1950s. Currently, soil salinization is becoming a growing problem, especially in irrigated areas in the most arid parts of the distribution of black soils. Second, land use change for food production exacerbates unsustainable management practices such as aggressive tillage and overgrazing furthering losses due to erosion. Diffuse pollution processes affect black soils devoted to fibre agriculture. This happens for various reasons, including the use of inappropriate fertilization technologies with high doses of nitrogen and phosphorus fertilizers and manures, or the excessive or inadequate use of herbicides and pesticides whose decomposition products are potential contaminants in soils, streams and groundwater. Finally, many black soils are threatened by soil sealing, due to the advance of urban areas and infrastructure in overpopulated regions or countries. This advance makes thousands of hectares of previously black soils destined for food production disappear.

Photo 3.1 Black soil in Nenjiang county of Heilongjiang province, China

3.2 Multiple benefits of black soils

3.2.1 Ecosystem services (ES)

Soils are involved in most of the ecosystem services (ES) that enable life on Earth, such as the provision of food, fibre, bioenergy, and water; the regulation of climate, gas, floods, droughts, land degradation, water quality, and pests and diseases; the support of nutrient cycles, and habitat for organisms; and the cultural non-material benefits such as recreational, spiritual, and religious values (See Figure 3.2.1a). Black soils have distinctive soil properties that are key for providing essential ES, for example, high soil organic matter contents and cation exchange capacities, better soil physical properties (soil structure, porosity, hydraulic conductivity, and infiltration) and habitats for soil organisms, which ensure the provision of food, fuel and fibre and freshwater, the regulation of climate, erosion control and water purification, and the support of nutrient cycling (Adhikari and Hartemink, 2016).

Although all soils are responsible for and intervene in the provision of ES, black soils have a preponderant role in the provision of healthy food, nutrient and water reserves, habitat for organisms, among other functions. That is why the loss of organic matter due to unsustainable management practices is likely causes a greater impact than in other less fertile soils.

The linkages between soil and ecosystem services were represented by Adhikari and Hartemink (2016) through a diagram (See Figure 3.2.1a) that conceptualizes soils as a complex system which provides multiple benefits for the environment and society, and the need to study it in a holistic approach to understand the multiple interactions between soil functions, ecosystem services and human well-being.

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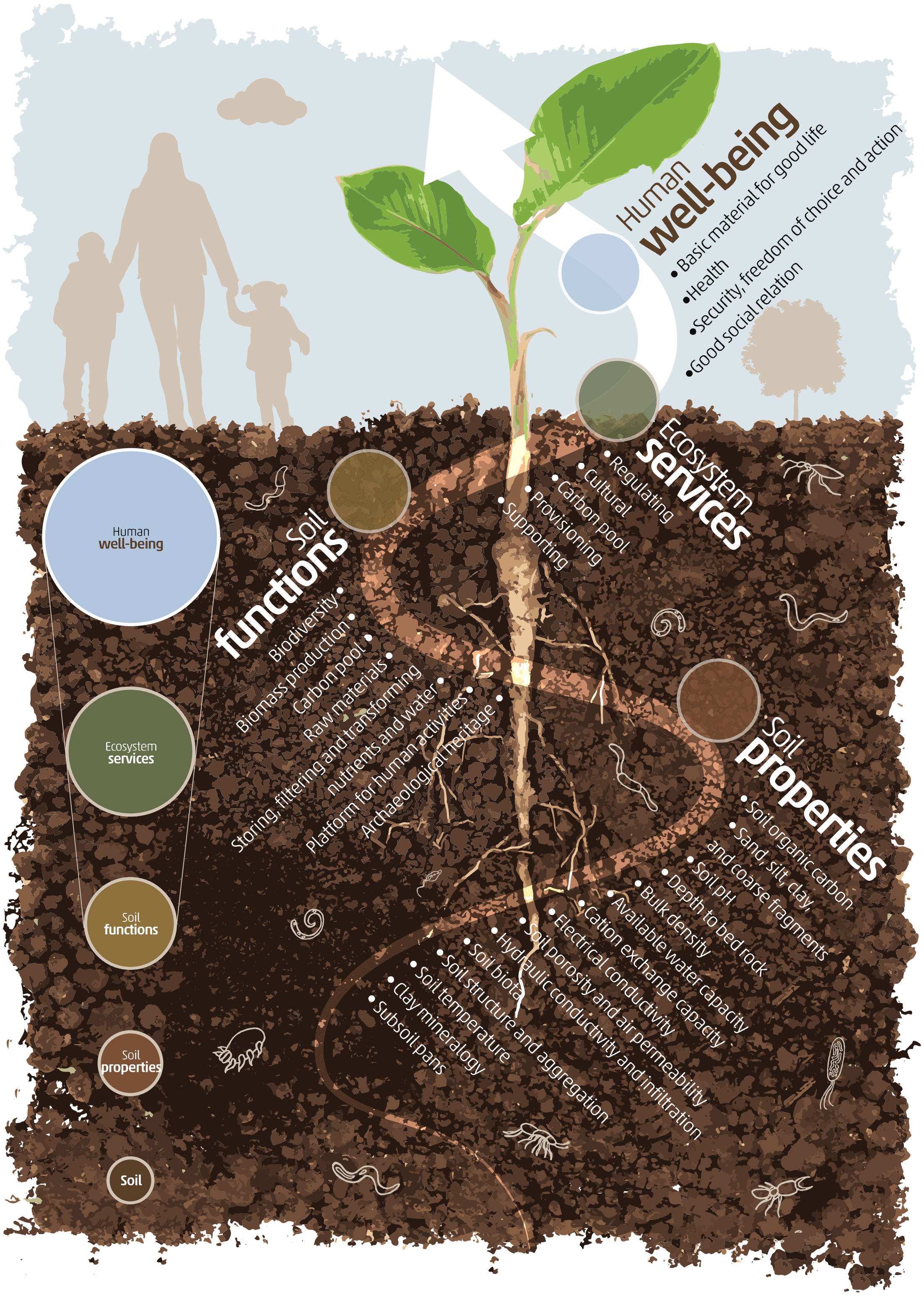

Figure 3.2.1a A conceptual diagram linking key soil properties to ecosystem services through soil functions for the well being of humans

Source: Adhikari, K. & Hartemink, A.E. 2016. *Linking soils to ecosystem services–A global review.* Geoderma, 262: 101–111. https://doi.org/10.1016/j.geoderma.2015.08.009

Anthropic soil erosion driven by conversion of natural ecosystems to agroecosystems and mechanical tillage, has numerous adverse impacts on ecosystem services. There are: 1) on-site impacts like the degradation of soil quality, reduction of agronomic productivity, and the decrease in use-efficiency of inputs; and 2) off-site impacts like accelerated soil erosion that promotes eutrophication and contamination, and sedimentation of reservoirs and waterways, and emissions of CO_2, CH_4, and N_2O (Lal, 2014) (Figure 3.2.1b).

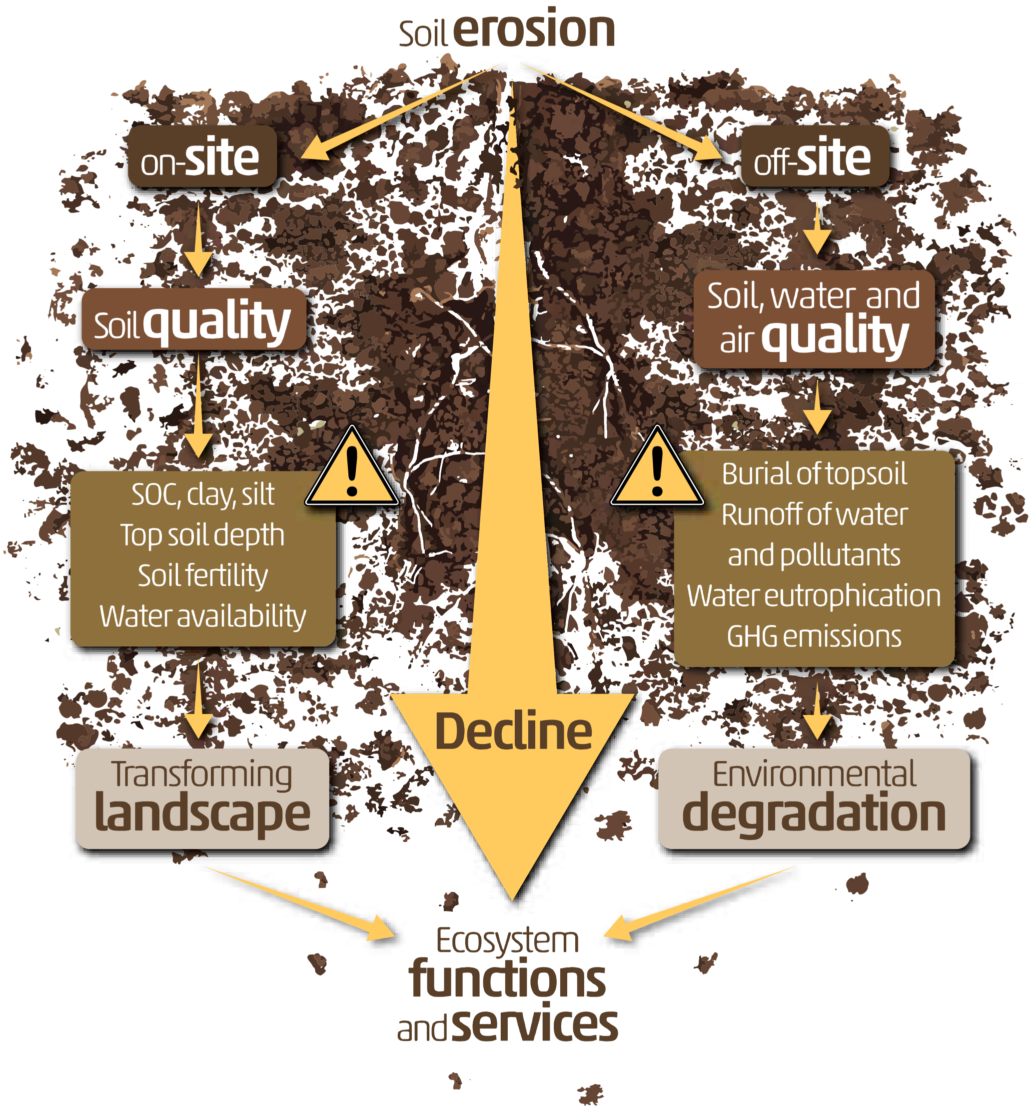

Figure 3.2.1b Adverse effects of accelerated erosion on ecosystem functions and services

Source: Lal, R. 2014. *Soil conservation and ecosystem services.* International Soil and Water Conservation Research, 2(3): 36-47. https://doi.org/10.1016/S2095- 6339(15)30021-6

3.2.2 Climate change mitigation and adaptation

Black soils can contribute to both the mitigation of and adaptation to climate change. On the one hand, black soils have a high potential to mitigate climate change due to their high SOC sequestration potential (See Figure 3.2.2). According to FAO's Global Soil Organic Carbon map (GSOCmap), in the top 30 centimetres SOC stock of black soils is on average 56 PgC (or 77.24 tonnes C/ha), which is higher than the average of SOC stock in all mineral soils (FAO, 2022b). On the other hand, black soils have been cultivated since many centuries in Europe and Asia, and in the last 150 to 200 years in America and Oceania. After extensive and intensive cultivation (for cereals, pastures, ranges, and forage systems), black soils have significant losses of SOC (See Figure 3.2.2). According to various estimates, SOC loss of up to 50 percent of initial SOC occurred after conversion from a natural system to intensive farming, as happened in intensively cropped soils of the United States of America (Gollany *et al.,* 2011). This SOC loss results from of inappropriate land use and unsustainable management practices, leading to declining soil quality. The decline in soil quality is generally characterized by poor topsoil structure, increased soil erosion, resulting in emissions of carbon into the atmosphere exacerbating climate change (Lal, 2019).

Much of the carbon loss was caused using aggressive tillage systems, but also by the replacement of perennial vegetation (grasslands, forests) by annual crops, which in general generate lower carbon returns to the soil and hydrological imbalances (Fan *et al.*, 2017). When grasslands are converted to croplands, they lose on average 36 percent of their SOC stocks after 20 years (Poeplau *et al.,* 2011).

Soil organic carbon sequestration represents 25 percent of the total potential of climate change mitigation solutions (23.8 Gt of CO_2e per year) (Bossio *et al.*, 2020). Forty percent of potential solutions for climate change mitigation through soil carbon is to maintain the existing SOC stocks, and the remaining 60 percent is rebuilding the depleted SOC stocks. The historical loss of substantial amounts of SOC confers black soils a low enough baseline to achieve significant SOC gains on the path to recovery. Nature-based solutions based on SOC-centered sustainable management practices have multiples benefits, and no tradeoffs have been identified (Smith *et al.,* 2020). The major potential for SOC sequestration is in black soils devoted to annual crops. This potential is mainly due to the large yield gaps and/or large historic SOC losses (Amelung *et al.,* 2020). After an appropriate land use and soil management, these black soils can increase their SOC and improve their quality. As a result, the rise of atmospheric CO_2 can be mitigated in black soil regions (Liu *et al.,* 2012). In conclusion, sustainable use and management of black soils toward maintaining or increasing their SOC stocks could be key for climate change mitigation and adaptation.

Black soils will contribute to mitigation through increases in carbon by sequestration in their profiles resulting from the adoption of nature-based practices such as those reviewed by Smith *et al.*, (2020). Many of these practices, such as improved cropland management, improved forest management, and increased SOC content, are based on more intensification and do not create demand for more land conversion. This land productivity increase for food production can avoid emissions that would occur through expansion of the agricultural land area (Mueller *et al.,* 2012), or by reducing the greenhouse gas intensity of products (Bennetzen, Smith and Porter, 2016). Improved cropland, grazing, and livestock management have moderate carbon mitigation potential, although their impact can be high because of the high number of hectares that they occupy.

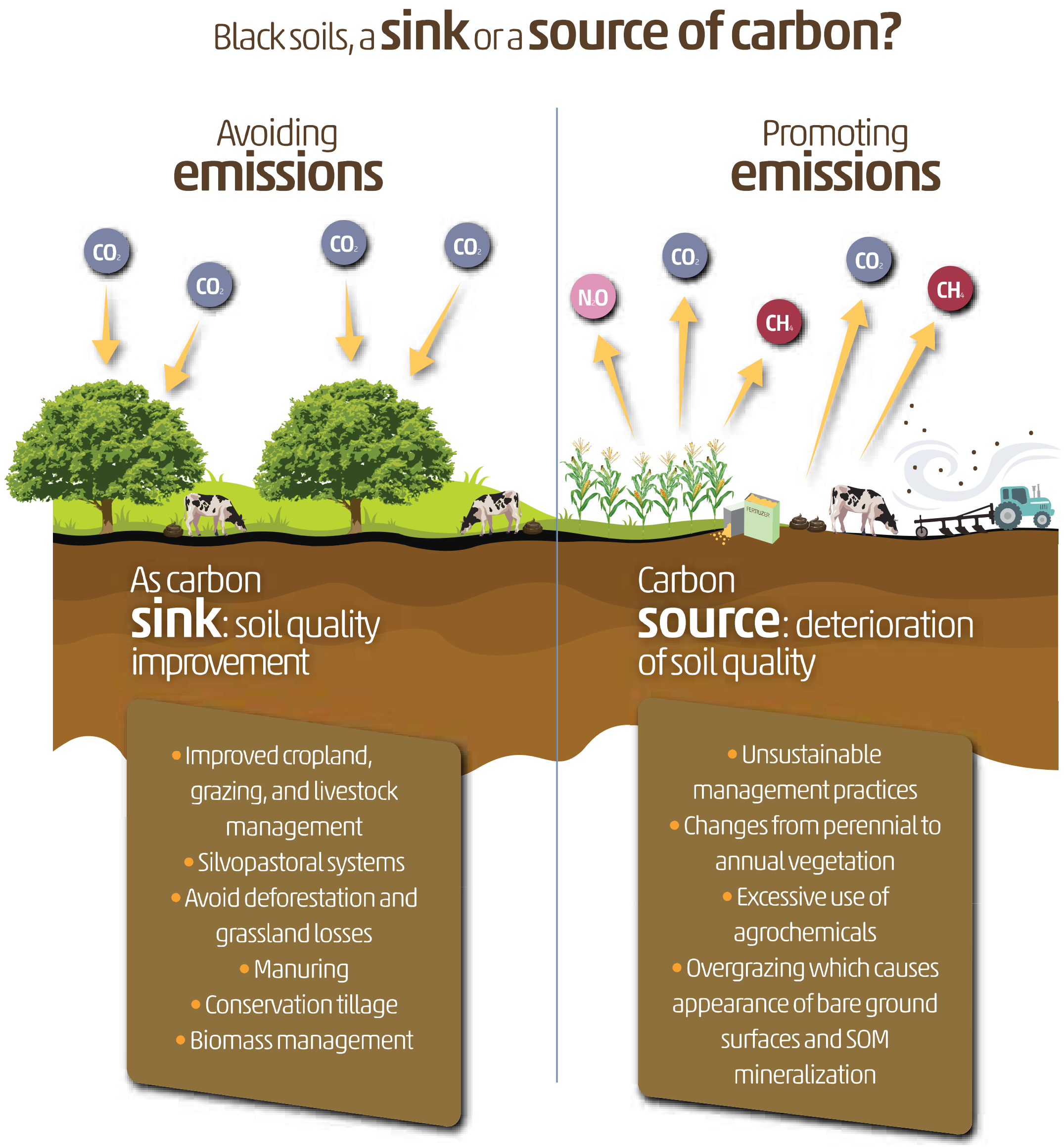

Figure 3.2.2 Duality of black soils as carbon sinks or emitters as a function of management practices

Source: Author's elaboration

3.2.3 Human well-being

Black soils contribute to human well-being by providing food security, filtering water, protection against chemicals and pathogens, and cultural ecosystem services (Brevik and Sauer, 2015) (See Figure 3.2.3). After hundreds of years of farming, black soils continue to be a symbol of healthy and nutritional food in many local cultures (Liu *et al.*, 2012). Black soils contain sufficient nutrients and provide nutritious food to people living there and in other regions, thus avoiding negative effects on human health (Steffan *et al.,* 2018).

There is evidence of the contribution of black soils made by ancient civilizations, as found in the Amazon region where pre-Columbian indigenous communities cultivated lowlands hundred years ago, left a legacy of charcoal, fish bones, and organic matter. The highly fertile soils, now called Amazonian Dark Earths evolved through these materials (Kern *et al.*, 2019; Anne, 2015; Schmidt *et al.*, 2014). Cultural values associated with black soils are observed in northeast China, where people associate them with healthy and positive characters to enhance the value of their personality, products, and culture (Cui *et al.,* 2017).


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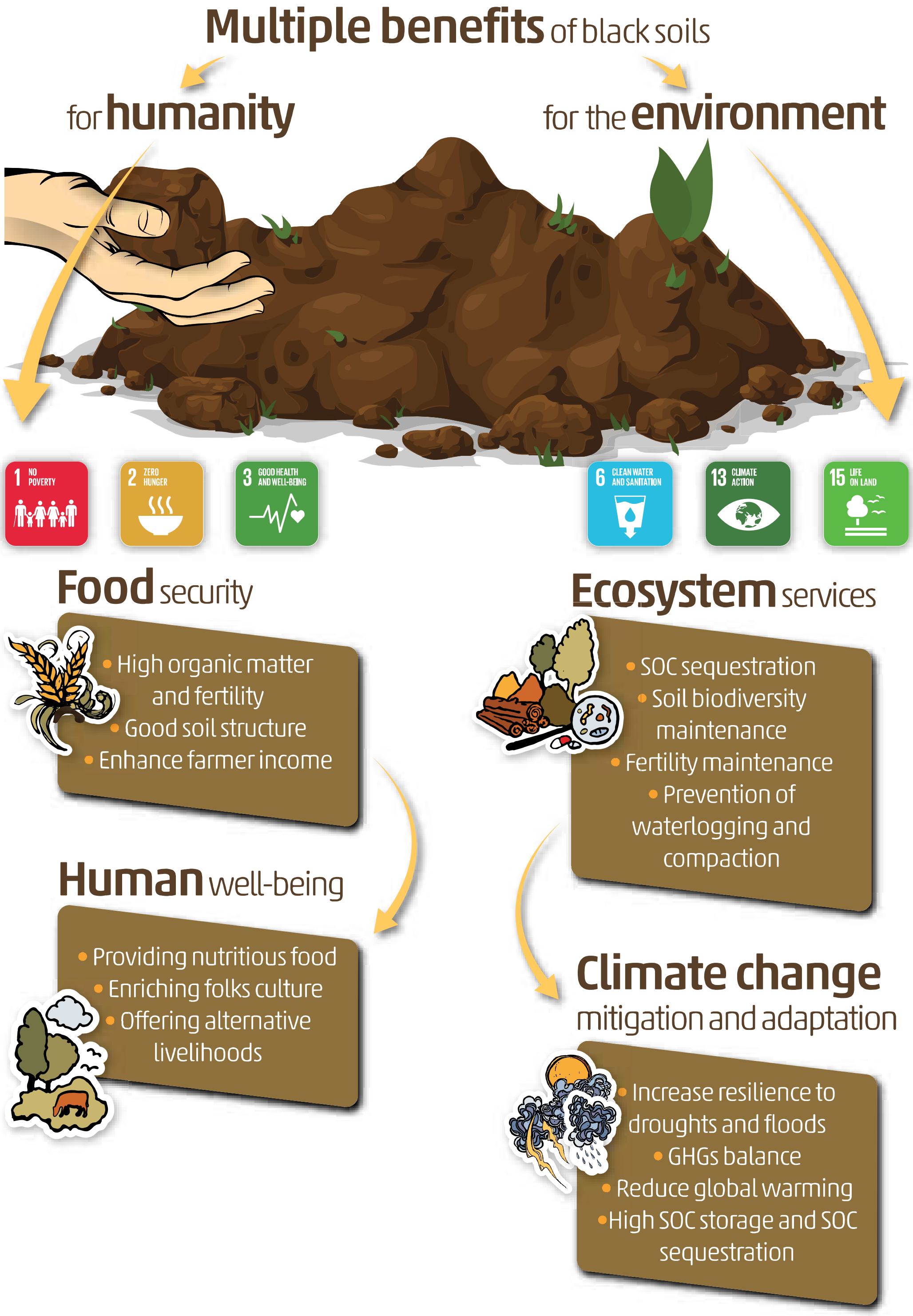

Multiple benefits of black soils

for **humanity**

Food security

- High organic matter and fertility
- Good soil structure
- Enhance farmer income

Human well-being

- Providing nutritious food
- Enriching folks culture
- Offering alternative livelihoods

for the **environment**

Ecosystem services

- SOC sequestration
- Soil biodiversity maintenance
- Fertility maintenance
- Prevention of waterlogging and compaction

Climate change mitigation and adaptation

- Increase resilience to droughts and floods
- GHGs balance
- Reduce global warming
- High SOC storage and SOC sequestration

Figure 3.2.3 Multiple benefits of black soils

Source: Author's elaboration

3.2.4 Food production and food security

Global analysis shows that out of the total land dedicated to growing crops, 17 percent of the farmland is currently occupied by black soils (Chernozems, Kastanozems and Phaeozems) (IUSS Working Group WRB, 2006), and out of the total area covered by black soils, one third of the black soil area is used as croplands (FAO, 2022a), due, in part, to its inherent fertility. This high fertility often leads to underestimation of the risks of degradation, although these soils are strongly affected by irreversible degradation processes such as erosion, nutrient imbalance, compaction and structural degradation (FAO and ITPS, 2015).

In cold regions of east Europe and Eurasia, there are black soils with high inherent fertility (Chernozems). If the annual weather such as precipitation and temperature is supportive, these soils can ensure food security for the countries (Avetov *et al.,* 2011; Kogan, Adamenko and Kulbida, 2011; Kobza and Pálka, 2017). Food security is a national priority in China, a country where black soils are considered the food basket since the 1950s. They have been responsible for the production of 15.9 percent of rice, 33.6 percent of maize, and 33.9 percent of soybeans in 2014 (Bureau of Statistics of China, 2015). In the United States of America, black soils cover 31.2 million hectares, and 42 percent of them are used for crop production (Soil Survey Staff, 2014; FAO, 2022a). In the southern cone of South America, most of the black soils sustain the production of grain and oilseed crops, orchards, forage, and crops for fibre production. They are also used for cattle raising and dairy farming, feeding the cattle with grains, forage crops or natural pastures (Durán, 2010; Durán *et al.*, 2011; Rubio, Pereyra and Taboada, 2019).

A set of international initiatives, such as the International Network on black soils, the 4 x 1 000 Initiative (Soussana *et al.,* 2019), and the framework of the Global Soil Partnership (Rojas *et al.,* 2016) have highlighted the need to maintain healthy soils and address threats to more fertile soils in order to cope with a 60 percent increase in food demand by 2050. Black soils are very fertile, and they are considered “the world crop basket” or “giant pandas in cultivated farmland” (Zhang and Liu, 2020) (See Figure 3.2.4). They are expected to receive increased use pressure in future decades that require better management practices and governance.

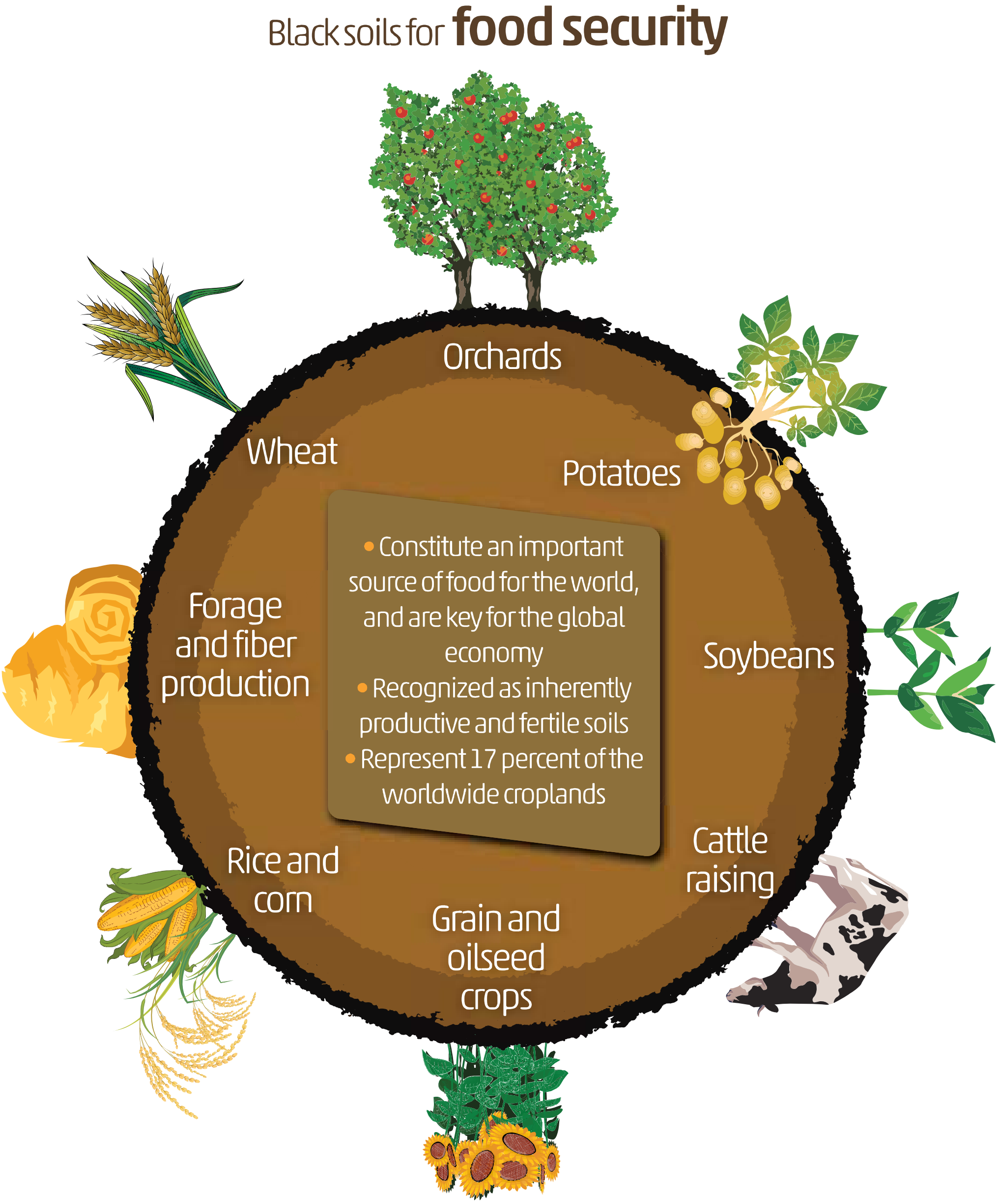

Figure 3.2.4 Black soils as a key player for global food security

Source: Author's elaboration

3.3 Main threats to black soils

The Status of the World's Soil Resources report (FAO and ITPS, 2015) highlighted the most significant threats to soil functions at the global scale, specifically soil erosion, loss of SOC and nutrient imbalance, and the current outlook is that this situation will worsen unless concerted actions are taken by all, the private sector, governments, international organizations and academia.

Black soils are not the exception and are affected by all global threats. As already mentioned, most of the cultivated black soils have already lost at least half of their carbon stocks and suffer from moderate to severe erosion processes, among other degradation processes. Other ongoing soil threats are soil nutrient unbalances, soil sealing and soil biodiversity loss (See Figure 3.3a).

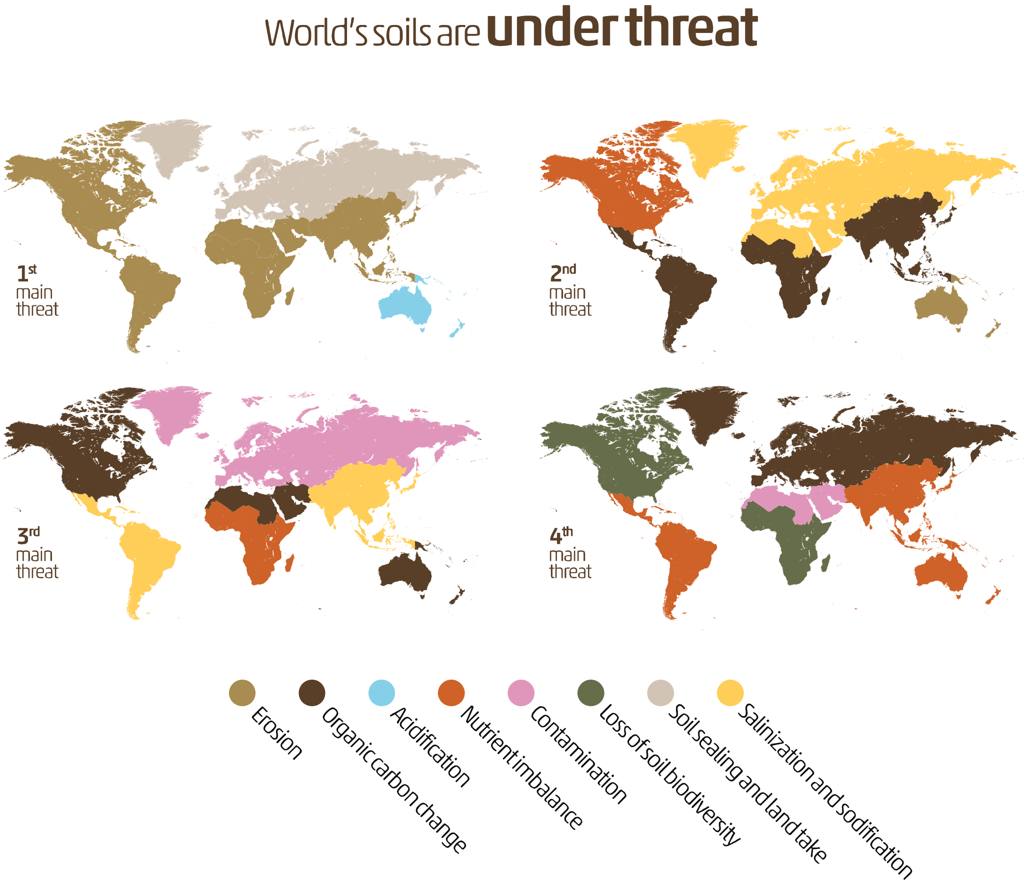

Figure 3.3a Global assessment of the four main threats to soil by FAO regions

Source: Montanarella, L., Pennock, D.J., McKenzie, N., Badraoui, M., Chude, V., Baptista, I., Mamo, T., Yemefack, M., Aulakh, m.s., Yagi, K., Hong, Suk Young., Vijarnsorn, P., Zhang, G., Arrouays, D., Black, H., Krasilnikov, P., JSobocká, A., Alegre, J., Henriquez, C.R., Mendonça-Santos, M.L., Taboada, M., Espinosa-Victoria, D., AlShankiti, A., AlaviPanah, S.K., Elsheikh, E.A.E.M., Hempel, J., Arbestain, M.C., Nachtergaele, F. & Ronald V. 2016. World's soils are under threat. SOIL, 2(1): 79–82. https://doi. org/10.5194/soil-2-79-2016

3.3.1 Soil organic carbon loss

Land use changes and unsustainable management practices lead to generalized significant soil organic carbon (SOC) losses in black soils. SOC changes appear as the second main threat in South America due to deforestation, intensive cultivation of grasslands and monocultures, in northeast China due to land use change and degradation of grassland, and in Europe due to the replacement of the natural vegetation; all of these are regions where black soils are predominant or at least conspicuous (See Figure 3.3a).

The black soils of Ukraine provide a well-documented example of SOC loss. Since 1970 there have been significant changes in the reserves of organic matter in Ukraine. Average losses of SOC due to irrational land use over 140 years since the time of V. V. Dokuchae have reached 22 percent about 19 percent in the Steppe, and more than 20 percent in Polissya (Baliuk and Kucher, 2019).

According to Yatsuk (2015, 2018), the largest losses of humus occurred from the 1960s to 1980s, due to the intensification of agricultural production by increasing the area of row crops, especially sugar beets and corn. During this period, the annual losses of humus reached 0.55 to 0.60 tonnes/ha. These processes of soil dehumidification on agricultural lands continue. According to the results of agrochemical certification of agricultural lands during the last five rounds (1986 to 2010) the humus content in the soils of Ukraine decreased by 0.22 percent in absolute terms and is 3.14. In terms of soil and climatic zones, the largest decrease in humus content occurred in the soils of the steppe zone, dropping from 3.72 to 3.40 percent, (by 0.32 percent in absolute terms). In the Forest-Steppe these changes are slightly smaller but given the loss of humus are significant 0.19 percent. However, the dynamics of losses in the period up to 2015 is somewhat slowing down due to the introduction of new management practices (Yatsuk, 2018).

Studies from Canada also document the complex balance between organic matter additions and losses in black soils. In studies by Landi *et al.,* (2003 a, b, 2004), the net primary production of vegetation (NPP) of seeded forage grasses (based on dry matter) for the black Chernozems annual averaged about 490 g/m^2 for above ground and 206 g/m^2 below ground. The amount of organic C to a 1.2 m depth is nearly 150 MgC/ha. Annual average rates in the three soils studied 1.18 gC/M^2. Many researchers have suggested that prairie soils have lost about 30 percent of their organic matter under cultivation. The loss is estimated to be about 1.5 to 2 kg/m^2 by Mann (1986). Considering these losses over 80 years of agriculture practices, the annual rate of loss is about 19 to 25 gC/m^2. This is ten to thirty times greater than the accumulation rate in the Black Chernozems. This rate is likely to be higher at the early stage of C losses and before levelling off and reaching. Therefore, it may take only a few hundred years to lose the majority of the SOC. Organic C in subsoils is older than the SOC in A horizon and, therefore, can represent a vegetation composition different than that of today (Mermut and Acton, 1984).

Losses of SOC can also occur due to grazing. In soils of the Anaime moorland (Tolima, Colombia) (between 0 and 30 cm deep) pastures in use stored SOC of 34.4 tonnes/ha, while pastures without use for 20 years stored 22 tonnes/ha. One explanation is the possible increase of biomass in the fine roots that when decomposed provide greater carbon content to the soil (Maia *et al.*, 2010), while lack of pasture renewal probably decreases the contribution of senescent roots (Andrade, Espinosa and Moreno, 2014). However, this aspect requires further study (Castañeda-Martín and Montes-Pulido, 2017). Avellaneda-Torres, Leon-Sícard and Torres-Rojas, (2018) and Otero *et al.*, (2011) found the behaviour of organic C showed a trend of moorlands > potato farms > cattle farms. Similar results were found in Chingaza natural national park (NNP) and Nevados NNP, where the C was lower in the soil profiles of conserved highland ecosystems than in non-conserved ecosystems. The decrease in easily oxidised organic C in soils under potato and cattle farming might have been caused by the loss of native vegetation cover due to cattle farming relative to the Paramo, which exposed the soil to environmental factors such as water, air, and solar radiation and likely increased erosion (Otero *et al.*, 2011).

Restoring SOC stocks in black soils via reasonable management such as conservation tillage, manure and compost fertilization, and biomass management is crucial to sustainable development and is important for environmental stability (Xu *et al.,* 2020). Among the causes of the decline in SOC are land use change, aggressive tillage, inadequate cropping system management (such as monocultures), and limited replacement of nutrients (FAO and ITPS, 2015) (See Figure 3.3b). Studies in the Russian Federation and Ukraine show that the loss of soil vegetation cover favours erosion processes, and soil organic matter content (SOM) can decline by 15, 25, and 40 percent in weak, medium, and severely eroded black soils (Iutynskaya and Patyka, 2010).

Using a quantitative global SOM-crop yield potential model, Oldfield, Bradford and Wood (2019) found that wheat and maize yields are greater with higher concentrations of SOC and level off at approximately 2 percent SOC. Potential yield increases through higher SOC concentrations amount to 32 percent of the projected yield gap for maize and 60 percent of that for wheat.

The Status of the World's Soil Resources report (FAO and ITPS, 2015) concluded that a priority action should be to stabilize or increase the global SOM stocks (SOC and soil organisms). Locally appropriate SOC-improving management practices should be identified by each country and facilitate their implementation towards a national-level goal of achieving a stable or positive net SOC balance. Black soils should be prioritized to maintain and increase SOC stocks.

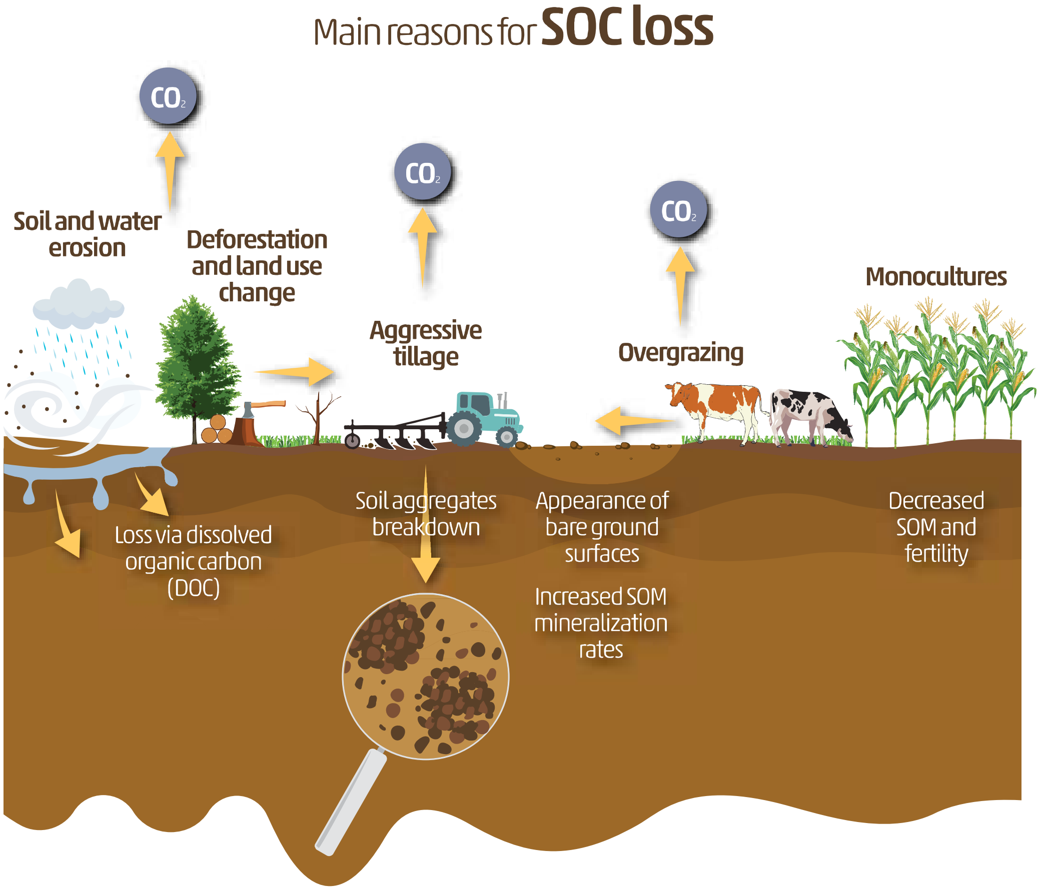

Figure 3.3b Mayor drivers of SOC loss

Source: Author's elaboration

15 | Recarbonization of global soils (RECSOIL)

RECSOIL is a FAO innovative initiative with the aim to boost soil health through the maintenance and enhancement of SOC stocks (FAO and ITPS, 2021). It unlocks the potential of SOC to provide multiple benefits through key ecosystem services. Healthy soils directly contribute to enhance food security and farm income, reducing poverty and malnutrition, providing essential ecosystem services, contribute to the achievement of the SDGs, fight climate change, and build soils' resilience to extreme climatic events and to pandemics. Black soils are the most productive carbon-rich soils and contain 8.2 percent of the world's SOC stocks. Their SOC sequestration potential is 10 percent of the global annual potential (FAO, 2022). However, this is not evenly distributed throughout the world. For example, in Europe and Eurasia, black soils account for 66 percent of the potential SOC sequestration, while only reaching 10 percent in Latin America and the Caribbean. Therefore, it is critical to prioritize those areas to restore and maintain SOC stock and avoid loses. That can be done through the implementation of initiatives such as RECSOIL at country level to unlock the potential of these precious soils for climate changes adaptation and mitigation, and halt greenhouse gases emissions.

Source: FAO & ITPS. 2021. *Recarbonizing global soils* –A technical manual of recommended management practices. Rome, FAO. https://doi.org/10.4060/cb6386en

3.3.2 Soil erosion

Globally soil erosion was identified as the most severe threat, leading to poorer water quality in developed regions and to lower crop yields in many developing regions (Montanarella *et al.,* 2016). Figure 3.3a shows that soil erosion is the first main threat in regions where black soils are predominant or co-dominant, for example, South and North America, eastern Europe and northeast China.

Erosion induced by rainfall and wind degrades the quality of all soils, including black soils (See Figure 3.3.2). Due to the degree of severity that has occurred (such as deep gullies, total soil loss), many studies have been carried out during the last decade in the black soil region. The dominant soil erosion processes are due to water, wind, and snow meltwater, with water erosion on hillside farmland being the major contributor to soil erosion (Xu *et al.,* 2010). Ouyang *et al.,* (2018) observed that from 1979 to 2014, cropping system conversion from forestry to dry lands increased erosion losses from 204 to 421 tonnes per km^2 per year (Ouyang *et al.,* 2018). These losses can be controlled by basin, contour, rat tunnel, and conservation tillage,


© Wei Wan

in combination with terraces and strip cultivation. Crop productivity can be increased by fertilizer or manure application (Liu *et al.,* 2011).

In Japan, Taniyama (1990) reported that there was about 40 to 50 cm of topsoil loss by water erosion during the 16 years after land use change from forest to vegetable plantation in the Andosols of the northern Kanto region, Japan. Counter measures for soil erosion adopted in Japan include contour farming, cover cropping to prevent bare land, greenbelt farming, terracing. The Ministry of Agriculture, Forestry and Fishery (MAFF) in Japan has announced basic principles of soil water erosion and sediment control, namely enhancement of rain water percolation to reduce surface flow water, minimization of surface flow velocity, construction of channel networks to drain rain water rain water safely and decreasing soil erodibility.

More than 90 percent of the agricultural area of the Pampas region in Argentina is currently cultivated under no-till, more recently combined with the cultivation of "cover crops" during the fallow period. This tends to reduce the loss of organic carbon and soil erosion due to the generalization of no-till practices.

Wind erosion is a phenomenon that mainly affects soils in semi-arid and arid areas, which often have low levels of plant cover and organic matter (Skidmore, 2017). In any case, climatic cycles with drought can generate predisposing causes of wind erosion, even in black soils, as happened with the dust bowl during the 1930s in the United States of America (Lee and Gill, 2015).

The combined effect of water and wind in Ukraine has been severe. The average annual soil loss from water and wind erosion is 15 tonnes/ha. This means that the country's soil cover loses about 740 million tonnes of the top, fertile soil layer every year (Baliuk *et al.*, 2010). The amount of land in Ukraine damaged by water erosion is up to 32 percent of the total area (13.3 million hectares). Of these hectares, 4.5 million hectares with medium and heavily washed soils, as well as 68 000 hectares that have completely lost the humus horizon. More than 6 million hectares are systematically affected by wind erosion, and up to 20 million hectares in years with dust storms. A particularly potentially dangerous zone in Ukraine is the southern Steppe (the main zone with Kastanozems and Calcic Glossic Chernozems). Thus, the number of days per year with dust storms in the southern steppe zone is 159, northern and central is 88, Forest-Steppe is about 33 days (Baliuk *et al.*, 2010).

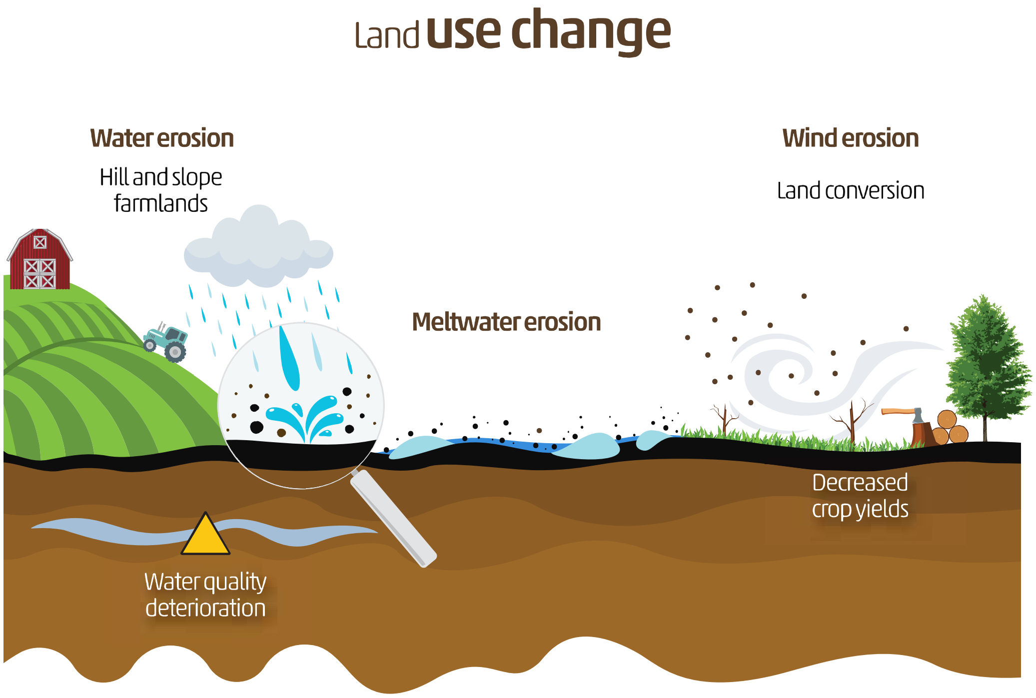

Figure 3.3.2 Main soil erosion processes of black soils
Source: Author's elaboration

Photo 3.3.2a Wind erosion in Liaoning province, China

Photo 3.3.2b Water erosion in Laetoli Gorge, the United Republic of Tanzania


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Photo 3.3.2c Wind erosion in Jiusan farm, China caused by land conversion and aggressive tillage


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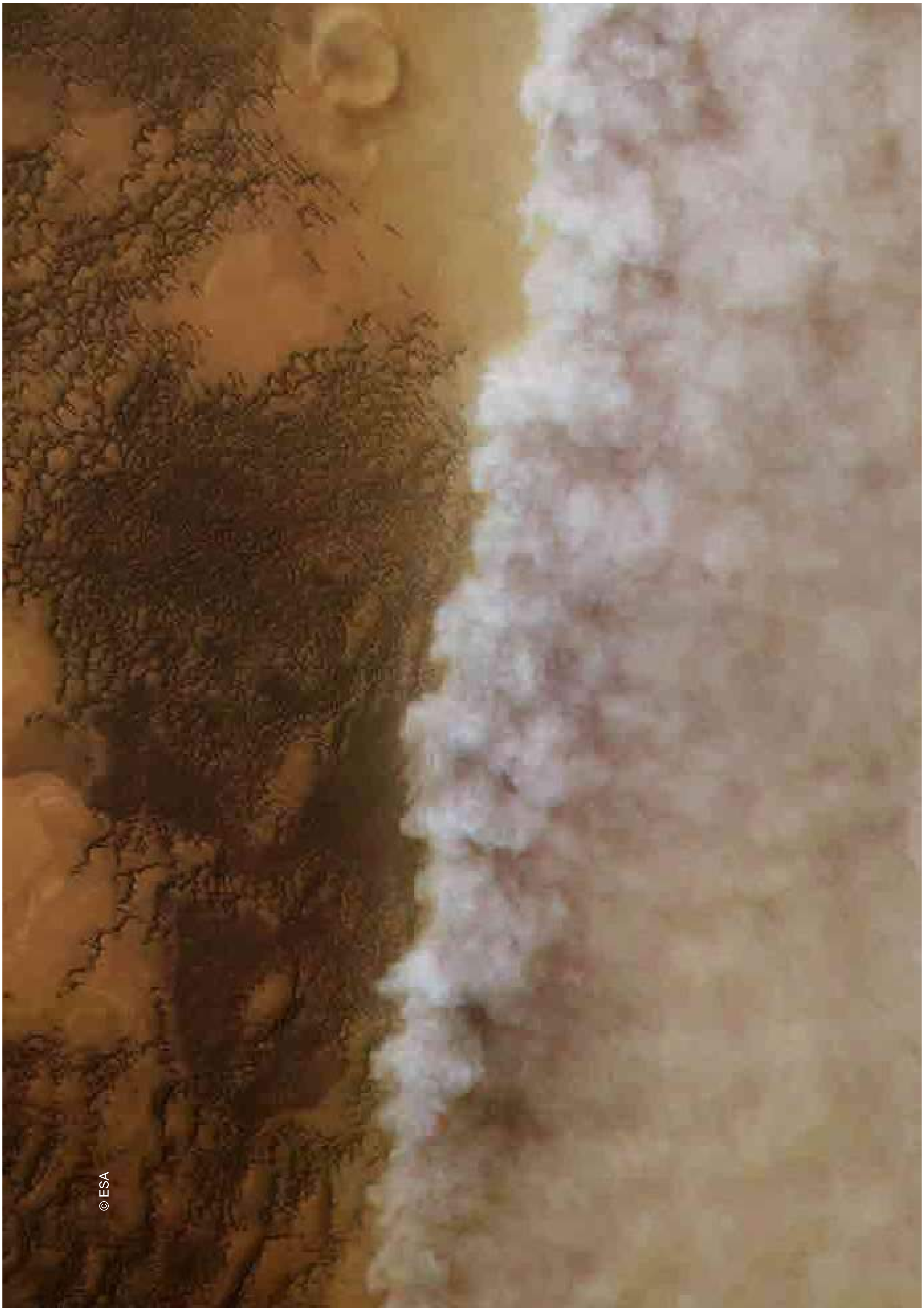
Photo 3.3.2d Water erosion in the Russian Federation



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16 | The infamous Dust Bowl!


© NOAA George E. Marsh Album

Dust storm approaching Stratford, Texas. Dust Bowl surveying in Texas.

The Dust Bowl was one of the largest sandstorms in the history of the United States of America that happened in the 1930s (History, 2020). This phenomenon began in the southern Great Plains and was caused by intensive farming, poor agricultural practices, and was associated with a period of severe droughts (History, 2020). Soil erosion and desertification on these lands caused massive dust storms affecting the states of Oklahoma, Kansas, Texas, New Mexico, and Colorado (Texas and Kansas have black soils) and reaching cities such as Washington, DC, and New York (Findmypast, 2015; SSSA, 2015). About 1.2 billion tonnes of soil were lost between 1934 and 1935 in the southern Great Plains (Britannica, 2022). These dust storms caused several adverse effects such as respiratory diseases causing the death of people and animals, with farmlands becoming unusable, and hunger and poverty spreading across several states (SSSA, 2015). Many people migrated to other places like California to escape the drought and the dust, and to find work (Findmypast, 2015). Following this huge catastrophe, the Soil Conservation Service (later the USDA Natural Resources Conservation Service) was founded to encourage farmers to adopt erosion mitigation strategies implementing sustainable management practices (reduced tillage, leaving crop residues in fields, strip cropping and crop rotation) to conserve soil and minimize erosion (SSSA, 2015). Desertification increasingly threatens significant land areas worldwide, affecting more than 100 countries, including the United States of America (SSSA, 2015).

Source: History. 2020. *Dust Bowl.* In: HISTORY. Cited 6 June 2022. https://www.history.com/topics/great-depression/ dust-bowl

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3.3.3 Soil nutrient imbalance

Nutrient imbalances include both deficits and excesses of soil nutrients. Imbalances were judged by Montanarella *et al.*, (2016) as the second main threat in North America, and the third greatest threat in most of Africa, in regions where black soils are conspicuous (See Figure 3.3.3).

Nitrogen (N) and phosphorus (P) fertilizer use need to be increased in infertile tropical and semi-tropical soils where the most food insecurity is found. Soil nutrient levels have decreased in the Argentine Pampas, because of the lack of resupply of nutrients, causing soil fertility to be exhausted in many places. Due to economic reasons, fertilizer use and soil testing was not historically widespread in Argentina and the level of nutrients such as N, P, calcium (Ca), magnesium (Mg) and zinc (Zn) has decreased (Rubio *et al.*, 2019; Lavado and Taboada, 2009). Nutrient stocks have also noticeably decreased in black soils of the Russian Federation (Grekov *et al.*, 2011; Medvedev, 2012), Ukraine (Balyuk and Medvedev, 2012), and Brazil (Rezapour and Alipour, 2017).

On the other hand, in other parts of the world with black soils, excessive N fertilization and decreasing N recovery rates by crops have caused dramatic increases in non-point source pollution from agriculture (Ju *et al.,* 2004). Nutrient excesses often originate in the use of high doses of synthetic fertilizers and organic manures containing N and P, with the consequent risks of pollution and therefore the eutrophication of groundwater and surface water (See Figure 3.3.3).

Soil phosphorus is strongly affected by interaction with soil minerals and organic matter. Due to this, P added as fertilizer (14.2 Tg P/year) and manure (9.6 Tg P/year) collectively exceeded P removal by harvested crops (12.3 Tg of P/year) at the global scale (Zang *et al.*, 2017). However, almost 30 percent of the global cropland area, particularly in Europe and South America, is deficient in soil P, either total or extractable by crops. Soil P deficits are common in areas producing forage crops used as livestock feed (MacDonald *et al.,* 2011). On the other hand, high P fertilizer application relative to crop P use resulted in a greater proportion of intense P surpluses (>13 kg of P/ha/year) in many areas with black soils. Together with N excesses, P surpluses represent a risk of eutrophication of freshwater and marine ecosystems (Dodds and Smith, 2016; Ngatia *et al.,* 2019). In Japan the overuse of chemical fertilizer causes nutrient imbalance in Andosols. Potassium is excessively accumulated in upland soils, and the ratio of magnesium to potassium is low (Japanese Soil Conservation Research Project Nationwide Council, 2021). The level of available phosphate in upland soils tends to be higher than the governmental recommendation (Japanese Soil Conservation Research Project Nationwide Council, 2021).


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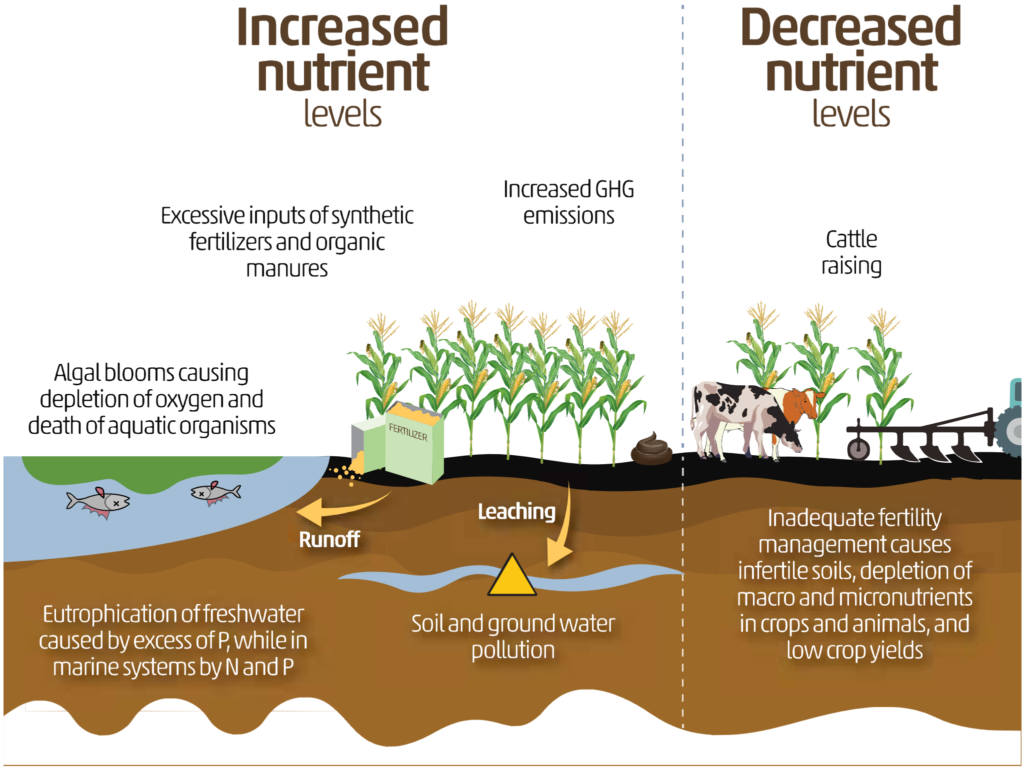


Figure 3.3.3 Effects of intensive use as a trigger on nutrient imbalance

Source: Author's elaboration

3.3.4 Soil compaction

Excessive soil compaction is a direct consequence of intense agricultural traffic of heavy machinery in the fields (See Figure 3.3.4), and a higher soil susceptibility because of organic matter content decreases and lower aggregate stability (Gupta and Allmaras, 1987; Montanarella *et al.,* 2016). Soil compaction is indicated by increases in soil bulk density and soil penetrometer resistance and decreases in soil macroporosity and water infiltration rates, among changes in other soil properties (Gupta and Allmaras, 1987; Liu *et al.,* 2010), with important consequences on crop yields (Liu *et al.,* 2010; Peralta, Alvarez and Taboada, 2021).

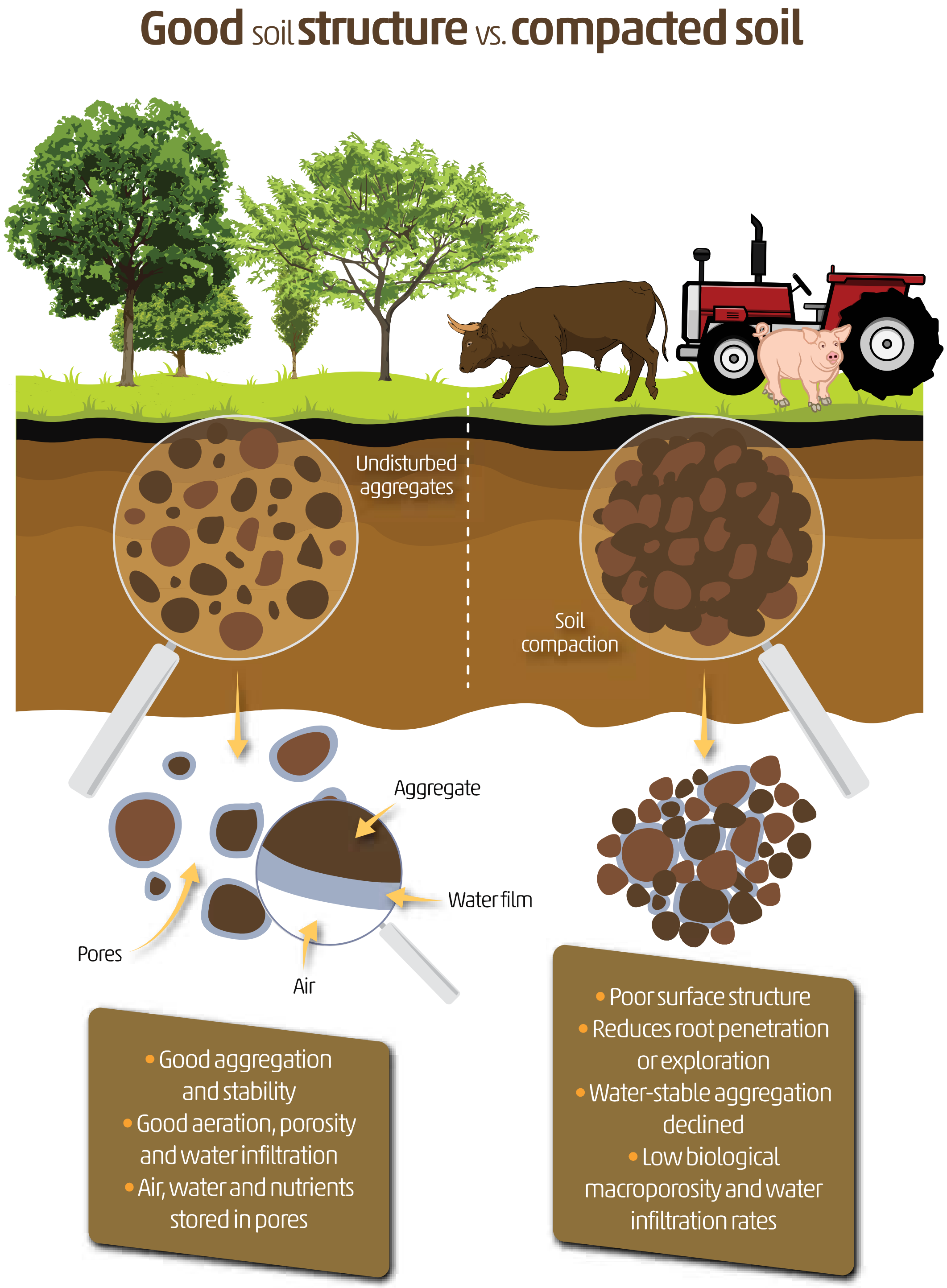
Evidence of soil compaction and physical deterioration of black soils is widely available. After 75 years of cultivation, water-stable aggregation declined by 27 percent and clay content by 27 percent in black soils of the Russian Federation (Balashov and Buchkina, 2011). This soil physical decline reached 40 percent in Ukraine, where many soils have a compacted layer (Balyuk and Medvedev, 2012). Likewise, intensive cultivation and summer fallowing have degraded the Canadian prairie soils, resulting in poor surface structure (Agriculture and Agri-Food Canada, 2003). Without significant variation, 14 to 20 percent higher bulk density and 10 to 22 percent lower porosity values were observed in cultivated black soils compared to forestlands in Brazil (Rezapour and Alipour, 2017).

Soil physical degradation has covered almost the entire area of distribution of black soils in Ukraine. This is due to a number of factors, including excessive ploughing of agricultural land (78 percent) (Medvedev, 2012; Yatsuk, 2015; Yatsuk, 2018; National report on the state of the environment in Ukraine in 2018, 2020), due to their suboptimal structure, intensive mechanical tillage led to widespread physical degradation. Physical degradation is manifested in the destructing of the upper layer, blocky (cloddy) after ploughing, swimming and crusting, the presence of a plough pan, and subsoil compaction. Physically degraded soils are prone to erosion, poor water retention properties, thus limiting the development of plant root systems (Baliuk *et al.*, 2010; Medvedev, 2012). In addition, with the current trends of climate change (aridization and warming) in Ukraine, there is already a de facto shift of natural-climatic zones from 100 to 150 km to the north, which brings new threats to desertification (Zatula and Zatula, 2020). These processes were already clearly traced 20 years ago (Pylypenko *et al.*, 2002).

Soil compaction is not only a consequence of tillage, as even under continuous conservation tillage farming it was repeatedly observed (Peralta, Alvarez and Taboada, 2021). In this case, the process affects the first layer of the soil, promotes planar aggregates and associated voids in crop rotations with long fallow periods (Alvarez *et al.*, 2014; Peralta, Alvarez and Taboada, 2021).

Additionally, burning, intensive grazing, tilling, and replacement of the natural grassland with more nutritive grass species in Colombia significantly affected water balance of the Colombian moorlands areas (Sarmiento and Frolich, 2002). Phenomena typically accompanying pasture farming and tillage, such as soil compaction and soil crusting, additionally alter the infiltration rates, water storage, and regulation capacity of moorlands.

The soils of the Pampas region in Argentine provide an example of the consequences of physical soil degradation. Continuous cultivation has generated soil physical degradation as sealing and compaction, increasing the processes of water erosion. Since the soils of the Pampas region, particularly in the Undulating Pampa, have been put into cultivation, they have lost an average of 50 percent of their original organic matter, while the total phosphorus of the surface horizon would have decreased by 80 percent (Sainz-Rozas, Echeverria and Angelini, 2011; Lavado, 2016).



- Good aggregation and stability
- Good aeration, porosity and water infiltration
- Air, water and nutrients stored in pores

- Poor surface structure
- Reduces root penetration or exploration
- Water-stable aggregation declined
- Low biological macroporosity and water infiltration rates

Figure 3.3.4 Effects of soil compaction

Source: Author's elaboration

Photo 3.3.4a Soil compaction caused by heavy machinery in Jilin province, China

Photo 3.3.4b Soil compaction caused by heavy machinery in Jilin province, China

3.3.5 Salinization

Salinization is a related processes that result from both natural (primary) and human-induced (secondary) processes (See Figure 3.3.5). In black soils the cases are due to: a) hydrological imbalances caused by changes in land use (such as the replacement of perennial vegetation such as forests, grasslands and pastures by annual crops), or associated with climate change, which causes the rise of saline groundwater to the surface (Taboada *et al.*, 2021); or b) the use of irrigation water with moderate to high salt content (Choudhary and Kharche, 2018; Bilanchyn *et al.*, 2021). In both cases, the increases in pH, electrical conductivity, and percentage of exchangeable sodium, decrease the quality of black soils. However, human-induced salinization owing to inappropriate soil and fertilizer management are the main challenges in regions of black soils. Secondary salinization of irrigated soils, accompanied by a reduction of the humus-rich layer depth was reported in the Russian Federation (Grekov *et al.*, 2011; Medvedev, 2012). In other cases, soil salinity in black soils is associated with swelling-shrinking processes and is not shown by saltpans on surface (Choudhary and Kharche, 2018).

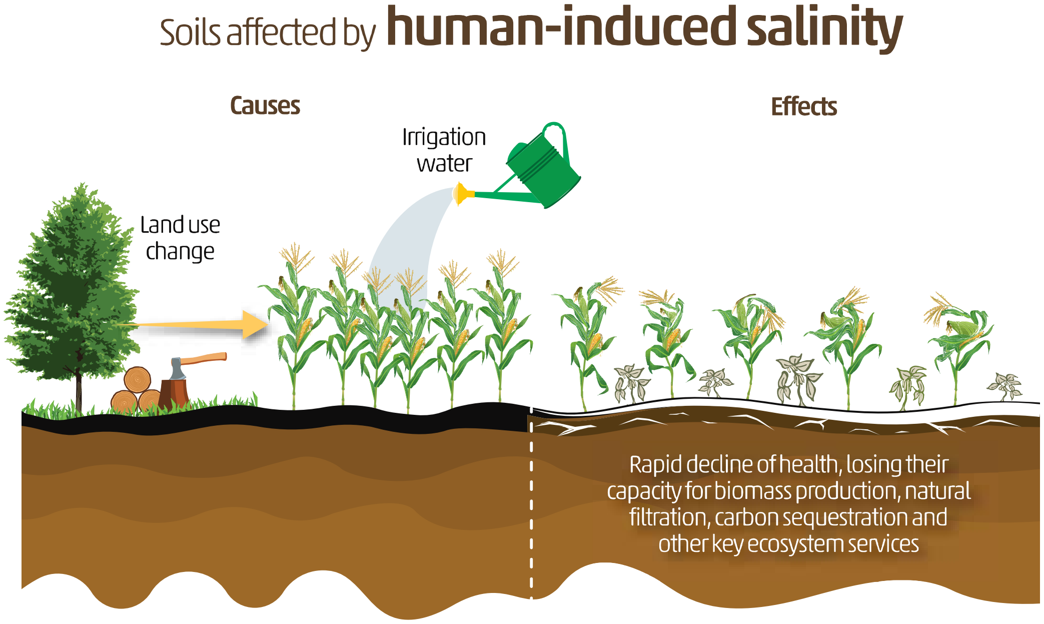
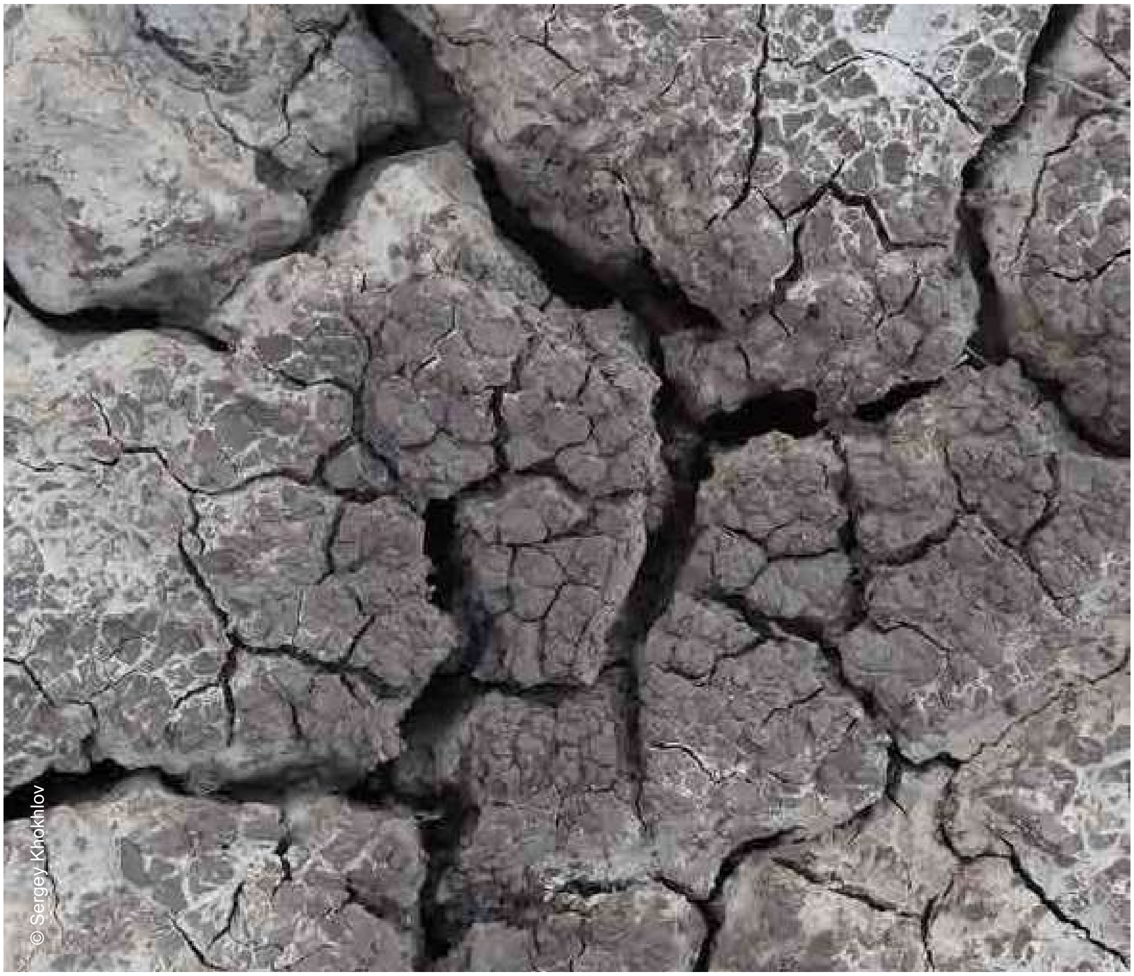


Figure 3.3.5 Soils affected by human-induced salinity

Source: Author's elaboration

3.3.6 Acidification

The acidification of black soils is most commonly due to an excessive extraction of exchangeable bases (Ca, Mg, K) by crops without adequate replenishment or a consequence of N fertilization (See Figure 3.3.6). Acidification only appears as the first main threat in Oceania (See Figure 3.3a). In the regions of Cherkassy and Sumy (Ukraine), soil pH dropped 0.3 to 0.5 units after 40 to 50 years cultivation (Grekov *et al.*, 2011; Medvedev, 2012). In black soils of northeast China, from 2005 to 2014, a trend of acidification due to overuse of N fertilizers was detected in intensive cropping systems (Tong, 2018). It is interesting to note that in Chinese croplands, N-induced acidification was also associated with an accrual of soil organic matter (Zhang and Liu, 2020), and a great decrease in soil inorganic carbon (Raza *et al.*, 2020). Andosols in Japan can experience nutrient issues associated with acidification. In general, allophanic Silandic Andosols are originally weakly acidic, and aluminum toxicity does not occur frequently in plants on these soils. However, Silandic Andosols can become strongly acidic following the heavy application of chemical fertilizer (Fujii, Mori and Matsumoto, 2021). Strongly acidic Andosols with an accumulation of acidic materials dissolves a part of the active Al fraction in the soils, which causes Al toxicity and thereby leads to the shallow rooting of Al-susceptible crops (Fujii, Mori and Matsumoto, 2021). Additionally, the soil productivity of strongly acidic Andosols is lower than that of the original weakly acidic soil; for example, the number of bacteria decreases (e.g, from 160 x 106 cfu /g for weakly acidic soil to 10 x 106 cfu /g for strongly acidic soil) as do the levels of readily mineralizable soil nitrogen (Matsuyama *et al.*, 2005). To improve these nutritional imbalances, the appropriate use of soil amendments based on soil diagnosis is desired (Japanese Soil Conservation Research Project Nationwide Council, 2021).



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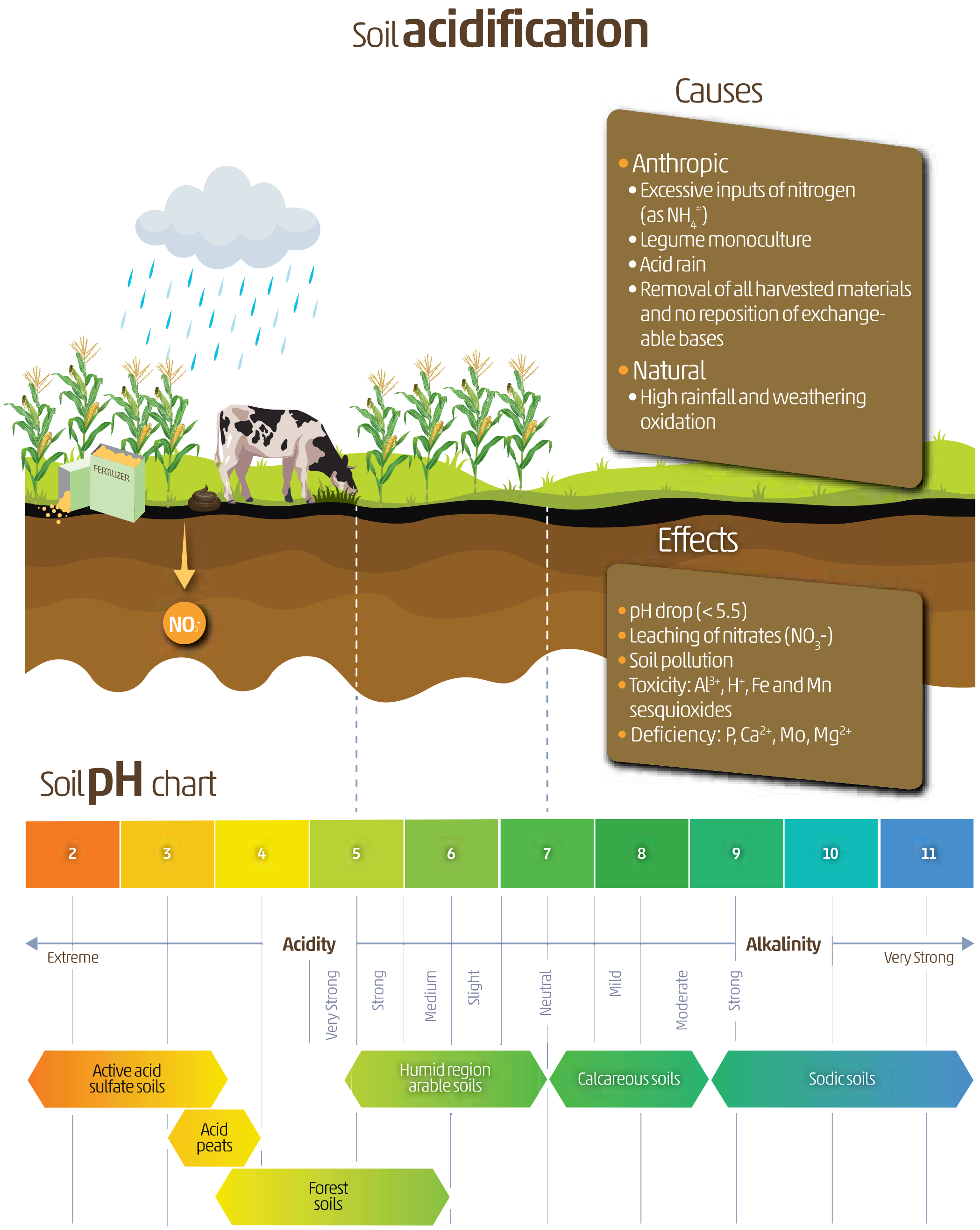

Soil **acidification**

Causes

- Anthropic
  - Excessive inputs of nitrogen (as NH$_4^+$)
  - Legume monoculture
  - Acid rain
  - Removal of all harvested materials and no reposition of exchangeable bases
- Natural
  - High rainfall and weathering oxidation

Effects

- pH drop (< 5.5)
- Leaching of nitrates (NO$_3^-$)
- Soil pollution
- Toxicity: Al^{3+}, H$^+$, Fe and Mn sesquioxides
- Deficiency: P, Ca^{2+}, Mo, Mg^{2+}

Figure 3.3.6 Causes and effects of soil acidification

Source: Author's elaboration

3.3.7 Soil biodiversity loss

Unlike other aspects of soil science, soil biodiversity remains poorly understood, in terms of anthropogenic impacts on the diversity of microbes and soil fauna that live unseen in soils. Only a small fraction of the immense morphological diversity of soil organisms is known, and this is especially true for microorganisms. Examples of this biological richness include bacteria (a), microscopic (b) and fruiting bodies of fungi (c), viruses (d), algae (e), protists (f), nematodes (g), mites (h), springtails (i), enchytraeids (j), earthworms (k), mealybugs (l), termites (m), ants (n), and mammals (o), among many others (Figure 3. 3.7a).

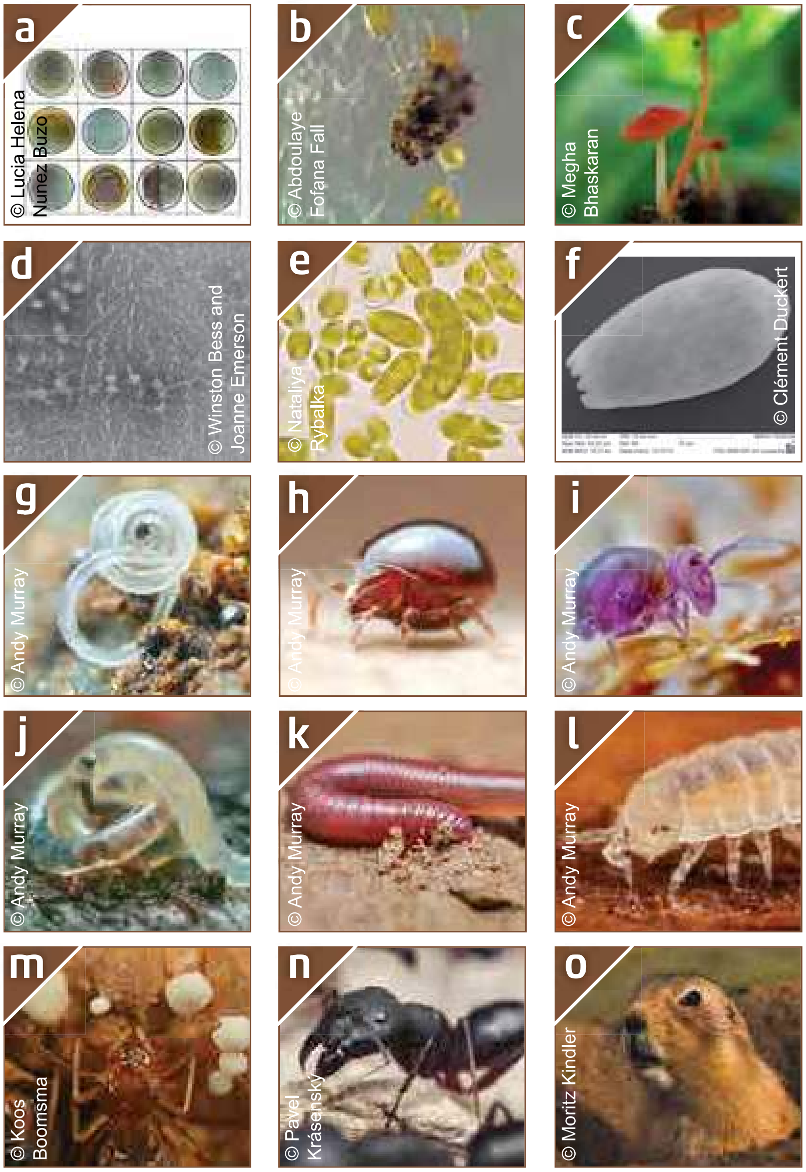

Figure 3.3.7a Overview of the most common soil biodiversity groups

Examples shown are bacteria (A), microscopic (B) and fruiting bodies of fungi (C), viruses (D), algae (E), protists (F), nematodes (G), mites (H), springtails (I), enchytraeids (J), earthworms (k), mealybugs (L), termites (M), ants (N), and mammals (O), among many others

Source: Author's elaboration

Most of black soils evolved supporting grassland vegetation with an active rhizosphere around the fibrous root system of the dominant grasses (Tisdall and Oades, 1982; Oades, 1993). These grasslands were characterized by floristic richness in plant communities, and an enormous soil biodiversity (from microbes to megafauna) which plays a key role in the provision of essential ecosystem services as carbon sequestration, nutrient cycling (carbon, nitrogen, phosphorus, and sulphur), water retention, provision of nutritious food, among others.

One of the consequences of the transition to crops from grasslands on black soils is the loss of much of the original biodiversity, at levels that are not well known because these changes occurred a long time ago. It is difficult to think that these soils will recover their pristine or near pristine state, so one of the future challenges is how to recover at least part of this enormous lost biodiversity.

The effects of reducing soil biodiversity on soil functioning was studied in an experiment by Wagg *et al.*, (2014). A broad soil biodiversity gradient was reproduced in grassland microcosms (Figure 3.3.7b). Some groups of soil organisms (nematodes and mycorrhizal fungi) were eliminated within the gradient, while fungal and bacterial communities reduced in abundance and richness. Plant species diversity decreased strongly with the reduction of soil biodiversity and the simplification of soil communities. This supports previous findings that plant community composition is driven by the diversity and species composition of various groups of soil organisms. As is expected (and repeatedly seen in real examples), carbon sequestration also decreased along the gradient. Changes in soil biodiversity and soil community composition also influenced processes related to nutrient cycling.

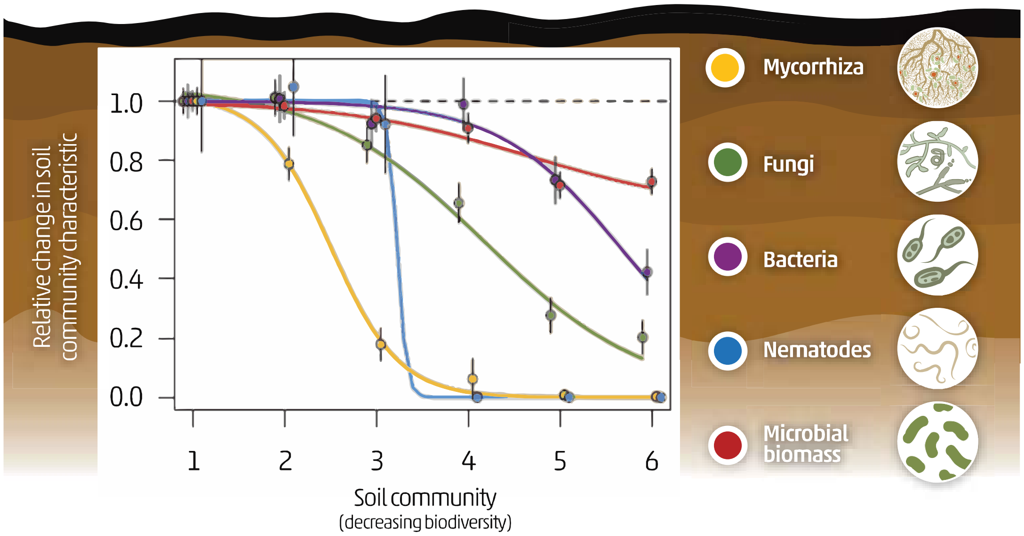

Figure 3.3.7b Change in soil community characteristics (abundance and richness) of various guilds of soil organisms in grassland communities

Means ± SEM are expressed as a ratio of the most complete soil treatment (dashed line), such that 0 represents no detection. The coloured lines highlight the general trend of changes in soil community characteristics along the gradient.

Source: Wagg, C., Bender, S.F., Widmer, F. & Van Der Heijden, M.G. 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proceedings of the National Academy of Sciences, 111(14): 5266–5270.https://doi.org/10.1073/pnas.1320054111

This simplification of soil communities due to cultivation has also been observed in the field. A valuable example of changes in arthropod communities (spiders, ants and carabids, among others) is provided by a study on black soils in northern China (Gao *et al.*, 2021). Due to intensive agricultural practices, a more simplified species richness and biodiversity was achieved at the local scale.

A well-documented effect of soil organisms is on the aggregation of the soil. The structure of the topsoil of black soils presents a hierarchical organization of aggregate sizes that depends on this enormous biodiversity. In fact, soil macroaggregates and soil clumps (units > 250 microns) depend for their stability on the binding and bonding mechanisms from cementing agents excreted in the soil rhizosphere and entanglement by fine roots and mycorrhizal hyphae. Soil mesopores (0.2 to 30 microns in diameter) and macropores (larger than 30 microns) are the habitat of many of the microorganisms and microfauna that make up soil biodiversity (Degens, 1997; Kay, 1990; Chantigny *et al.*, 1997). The protection of SOC within aggregates is a key element of increasing SOC levels to achieve carbon sequestration.

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17 | What is the relationship between wars and soil pollution?

The use of artillery possesses a severe risk to soil degradation and pollution especially with the use of mechanization and modern weapon technologies. The most common sources of pollution affected by armed conflicts are the following contaminants:

Sources of pollution	**Soil contaminants**
Conventional explosives	TNT, RDX, HMX
Fragmentation shells, bullets, cartridge cases and shotgun pellets	Copper, iron, lead and zinc
Armour-piercing projectiles	Depleted uranium
Incendiary weapons	White phosphorus and Napalm

Soil pollution can come from the use of nitro aromatic explosive compounds (FAO and UNEP, 2021). These compounds have a high persistence and once entered the soil, they tend to remain, harming the local biota and reducing the soil health and fertility. The negative effects from the use of incendiary weapons containing white phosphorus comes from their co-contaminants and residues of combustion. Such weapons may result in soil polluted with trace elements, hydrocarbons, organic solvents, surfactants, synthetic phenols, cyanide, dioxins, and radionuclides reducing soil fertility, crop yield and possessing risk to human health and the environment. The use of depleted uranium, one of the least studied forms of uranium, can penetrate the soil as deep as 50 cm. The dust that is emitted from the depleted uranium disperses and contaminates and polluting the soil over large area. Claims have been made that the depleted uranium dust can travel up to 40 km. After an attack with depleted uranium ammunition, this dust will be deposited on the ground and other surfaces as partially oxidized depleted uranium fragments of different sizes, and as uranium oxide dust.

The sources of soil pollution are very varied and range from the primary sector to the final stages of the life cycle of everyday products. For this reason, in order to prevent and reduce soil pollution by the armed conflicts, greater efforts must be made to reduce the use and production of toxic chemicals in the ammunition, to regulate and control industries and verify that their emissions do not introduce contaminants into the environment and that production and consumption systems move towards more sustainable schemes in which waste production is reduced.

Source: FAO & UNEP. 2021. *Global assessment of soil pollution – Summary for policy makers.* Rome, FAO. https://doi.org/10.4060/cb4827en

3.4 Challenges

The challenges faced by black soils arise from their preponderant role in food and fibre production under agricultural and livestock use. As mentioned before, the main threats that operate on them are erosion by water, tillage and wind, loss of SOC and organic matter, and nutrient imbalance. In addition, physical-structural deterioration should not be ruled out, and in some regions soil salinization, pollution with excess fertilizers and agrochemicals, and soil sealing due to urban advancement also occurs (FAO and ITPS 2015; Montanarella *et al.*, 2016). Main drivers of soil degradation are land use changes and unsuitable land management, unsustainable management practices and the lack of policies.

According to the FAO and ITPS, (2015) report, soil degradation should be minimized and degraded soils restored in those regions where people are most vulnerable, or where food production is critical, Global SOC and SOM stocks should be stabilized or increased, and that we should act to stabilize or reduce global N and P fertilizer use while simultaneously increasing fertilizer use in regions of nutrient deficiency.


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Photo 3.3.7 Black soils in Zhaoguang farm of Heilongjiang province, China

3.4.1 Land use change and land management

Due to projected increases in food demand crop production will need to increase by 70 to 110 percent by 2050 (Royal Society of London, 2009; Tilman *et al.*, 2011). As very fertile soils, black soils will be among the main actors in these increases in production and closing of gaps. To meet this objective, sustainable intensification of the current productive systems rather than agricultural expansion into forests and pastures is critical (Fischer and Connor, 2018; Guilpart *et al.*, 2017). Many black soils are also considered soils of high environmental value, where the protection of large carbon stocks and the restoration of these stocks should be included in overall soil resilience programmes to monitor, restore and maintain soil fertility and soil functions, and to enhance the key ecosystem services provided by these soils (Smith *et al.*, 2016).

As a successful example, in recent years, the Ministries of Agriculture, Science and Technology, Land and Resources, and the four provinces of black soil areas in northeast China have actively implemented a wide range of measures to protect and enhance black soils. These include high standard farmland construction, soil and water conservation, soil testing and formulated fertilization, soil organic matter increases, conservation tillage (reduced tillage and no-till), subsoiling for soil compaction alleviation and soil preparation, straw returning, and increasing the use of organic fertilizers (Li *et al.*, 2021). The comprehensive goal of black soil protection and utilization is to control the loss and degradation of black soils and keep water and fertility (Han *et al.*, 2018).

The adoption of restorative land use and recommended management practices are key to strengthen numerous ecosystem services provided by black soils, such as improving water quality and renewability, increasing below and above-ground biodiversity, enhancing soil resilience to climate change and extreme events, and mitigating climate change by sequestering carbon in soil and reducing CO_2, CH_4 and N_2O emissions (Lal, 2014).

3.4.2 Unsustainable management practices

The most cited unsustainable management practices for black soils are those that cause the main threats, that is, erosion, loss of SOC and SOM, nutrient imbalance, and salinization and sodification. Under agricultural management, these practices are usually aggressive tillage methods based on plowphshares and disc plows, harrows, and so on, monocultures, non-replenishment of nutrients with fertilizers, and the disappearance of pastures. Overgrazing and non-use of rational grazing systems is the most frequent cause on land destined for grazing. Soil pollution by pesticide residues is a major cause of degradation (Smith *et al.*, 2016).

3.4.3 Climate change and black soils

Climate change is very much related to the condition of black soils. From one side, climate change negatively impacts black soils. For instance, interactions between the increasing temperature and decreasing precipitation in black soil region led to reduced accumulation of soil organic matter, which results in poor soil fertility (Gong *et al.*, 2013). On the other side, the unsustainable management of black soils causes the loss of soil organic carbon and emits greenhouse gases to the atmosphere, exacerbating climate change. Evidence in black soils showed that organic matter amendments and tillage management can mitigate negative and exploit positive effects of climate change on crop production by enhancing soil quality (Song *et al.*, 2015; Menšík *et al.*, 2019; Farkas, *et al.*, 2018). Unfortunately, those practices are not often adopted by local governments and farmers due to multiple management and economic obstacles. The restoration of degraded black soils should be highlighted and inputted in the global climate change agenda in offsetting anthropogenic emissions and SOC sequestration (Lal, 2021).

3.4.4 Lack of policies

Many of the black soils appear in countries with low levels of soil governance, or where different laws and regulations relating to soil and water may exist, but with poor enforcement. Undoubtedly, the lack of effective policies in these sites is a major challenge to preserve the quality and health of black soils for agricultural use, and thus food security.

The implementation of practices for recovery or restoration of black soils mostly depends on good governance (in North America) and the availability of financial resources. This factor limits implementation of sustainable practices in all the affected countries, but mostly in developed countries. The problem lies in the fact that most of the food insecurity problems are not in the more developed countries but in the less developed parts of the world. This is the main challenge for sustainable management, not only for black soils, but also for all the productive soils in the world. Sustainable soil management should increase the supply of healthy food.