Black Soils

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1. Definition and description

Black soils are inherently productive and fertile soils that are critical for food production globally. Given favorable climatic conditions, these soils allow high crop productivity. However, inappropriate management practices of black soils can lead significant losses of SOC, decline in soil quality, and resulti in emissions of carbon into the atmosphere. Sustainable use and management of black soils toward maintaining or increasing SOC stock is crucial for ensuring global food security and mitigation climate change.

Black soils are mineral soils which have a black surface horizon enriched with organic carbon that is at least 25 cm deep. Two categories of black soils (1st and 2nd categories) are recognized. The categories are distinguished to recognize the higher value, and thus greater need for protection, of some soils (Category 1), while still including a wider range of soils within the overall black soil definition (Category 2) (FAO, 2019).

The first category of black soils (which are the most vulnerable and endangered, and need the highest rate of protection at the global level) are those having all five properties given below:

- The presence of black or very dark surface horizons typically with a chroma of ≤3 moist, a value of ≤3 moist and ≤5 dry (by Munsell colours);
- The total thickness of black surface horizons ≥25 cm;
- Organic carbon content in the upper 25-cm of the black horizons between ≥1.2 percent (or ≥ 0.6 percent for tropical regions) and ≤20 percent;
- Cation exchange capacity (CEC) in the black surface horizons ≥25 cmol/kg; and
- A base saturation in the black surface horizons ≥50 percent.

Most, but not all 1st category Black soils have a well-developed granular or fine sub-angular structure and high aggregate stability in the black surface horizons that are in a non- or slightly degraded state, or in the humus-rich underlying horizon which has not been subjected to degradation.

The second category black soils (mostly endangered at the national level) are those having all three properties given below:

- The presence of black or very dark surface horizons typically with a chroma of ≤3 moist, a value of ≤3 moist and ≤5 dry (by Munsell colours);
- The total thickness of the black surface horizons of ≥ 25 cm; and
- Organic carbon content in the upper 25-cm of the black horizons between ≥1.2 percent (or ≥ 0.6 percent for tropical regions) and ≤20 percent.

This category does not include the CEC and base saturation criteria of the first class.

2. Global distribution of hotspot

On a world-wide basis, soil scientists generally include as types of black soils, the Chernozems, Kastanozems and Phaeozems (WRB), Isohumosols from Chinese soil classification, and Mollisols of Soil Taxonomy (Liu, 2012). Although these are the main classes, other classes are included in the concept of black soils, such as soils with Chernic, Mollic, Umbric, Hortic and Pretic horizons.

Among the main soil types, four locations can be highlighted globally. Chernozems (Mollisols) occurring extensively in the central region of North America, across the central plains of United States and southern region of Canada. Kastanozems and Phaeozems appear as discontinuous belts, which extend across southeastern Europe and central Asia. The western belt begins in the sub-humid steppes of southcentral Europe and extends across Russia and into the eastern belt, which is best represented in northeast China (Isohumosols). The fourth major location corresponds to the Pampas of South America, covering most of central-eastern Argentina, most of Uruguay´s territory, and part of the southern region of Brazil. Thus, the of the world's 916 million hectares of black soils occur in three regions of the northern hemisphere and one region south of the equator, the Parana-La Plata basin of South America. The understanding of this distribution as well as the genesis, uses and management, and threats to these soils, is crucial given that, when considering the natural fertility and land use of the black soils, these four regions collectively form the one of main world's natural granary (Liu *et al.*, 2010).

3. Global carbon stocks and additional carbon storage potential

In the WRB system of classification, the soils identified as Chernozems, Kastanozems and Phaeozems are included in the concept of black soils. Although in natural conditions they have high organic carbon content, in reality large areas of these soils are now degraded.

The SOC stock evaluation by using GSOCmap and WRB classification provided a general C stock in the Black Soils, presented in a global level and including only the soil types: Chernozems, Kastanozems and Phaeozems (FAO, 2019; FAO, 2009). The results showed that total SOC stock of Black Soils is 54.8 Pg, with an average value of SOC stock of 66.4 t/ha (Table 14).

Table 14. Total SOC stock and mean SOC stock of black soils within 30 cm soil layer for the Chernozems, Kastanozems and Phaeozems classes in the WRB system

Soil Reference Group WRB	SOC stock (Pg)	Mean SOC (t/ha)
Chernozems	19.7	89.6
Phaeozems	18.2	62.2
Kastanozems	16.9	47.5
Total of Black soils	54.8	66.4

4. Importance of black soil conservation for the provision of specific ecosystem services

Black soils are the most productive carbon-rich soils and provide multiple benefits including ecosystem services, food production and security, human well-being, and climate change mitigation and adaptation (Figure 15).

4.1. Minimization of threats to soil functions

Black soils include those with abundant nutrients for crops´ growth and organic carbon as well as good physical properties. The distinctive characteristics of the first category of black soils are their dark-colored, humus-rich surface horizon, and the high base saturation (Eckmeier *et al.*, 2007). In addition, characteristics such as appropriate pH, adequate available nitrogen, potassium, and suitable levels of most micro-nutrients, allow Black soils to maintain or improve soil nutrient balance and cycling, when practices of sustainable management are used (Balashov and Buchkina, 2011; Zhang *et al.*, 2013). Black soils have good soil physical properties in terms of soil bulk density, soil aggregation, wet-aggregate stability, and water infiltration rate. Those characteristics allow these soils to regulate water supply in the field in terms of the mitigation of floods and droughts and of water quality (Balashov and Buchkina, 2011; Chen *et al.*, 2014). As carbon-rich soils they are a reserve of components such as sugar, amino acids and carboxylic acids, which are natural resources for growth of soil microbial community (Zhang and Han, 2015). Nutrients in black soils, such as nitrogen and phosphorus, also contribute to abundant soil biodiversity (Galloway, 2004).

4.2. Increases in production and food security

The high soil organic matter content, good soil fertility and physical structure of black soils makes them the most fertile and productive soils in natural conditions, and they are therefore intensively and extensively cultivated. Global analysis showed that out of the total land dedicated to growing crops, 19 percent of the farmland is currently comprised of black soils, and out of the total area covered by black soils, 62 percent is used as croplands (USGS, 2015; HWSD, 2009).

In Russia, among the 221 million hectares of agricultural lands, 60-70 percent is of soils with Chernozemic horizons (Avetov *et al.*, 2011). In Slovakia, black soils are covering an area of 474 885 hectares (Kobza and Pálka, 2017), which is approximately 20 percent of total area of agricultural soils in the country. In China, the total area of black soils is 35 million hectares (Liu *et al.*, 2012), black soils have been important food basket since 1950s, producing 15.9 percent, 33.6 percent, and 33.9 percent of rice, corn, and soybeans of whole China in 2014 (Bureau of statistics of China, 2015). In the United States, black soils (Mollisols) cover about 196 million hectares, 36.9 percent of which are used for livestock and crop production (Wickham *et al.*, 2014). Most of the Mollisols in South America are used for grain and oilseed crops, orchards, forage, and crops for fiber production. They are also used for cattle raising and dairy farming, feeding the cattle with grains, forage crops or natural pastures (Durán *et al.*, 2011).

4.3. Improvement of human well-being

Black soils contribute to human wellbeing by providing nutritious food, enriching folks culture and offering alternative livelihoods. Multiple nutritious foods are produced in black soils region globally including cereals, beans, meat, etc. In Brazil, the contribution of pre-Colombian indigenous communities, which for hundred years cultivated the low lands in the Amazon region, adding materials such as charcoal, fish bones, with organic matter, formed fertile soils now called Amazonian Dark Earths (Schmidt *et al.*, 2014; Anne, 2015; Kern *et al.*, 2019). In northeast China, people associate the black soils with a symbol of healthy and positive characters to enhance the value of their personality, products and culture (Cui *et al.*, 2017). The aesthetic and recreation values of black soils also offer opportunities for increasing income of farmers.

4.4. Mitigation of and adaptation to climate change

Black soils have a high potential to mitigate climate change due to their inherently high SOC content. For example, according to the results of Global Soil Organic Carbon map (GSOCmap), average SOC stock of Black soils is 66.4 t/ha in top 30 cm, which is higher than the average of SOC stock in all soil types (57.34 t/ha) (FAO and ITPS, 2019). Although at the global level there is to date little information on potential GHG emissions from black soils, it is known that black soils are both extensively and intensively farmed (cereal, pasture, range and forage system) resulting in significant losses of organic carbon. According to various estimates, black soils lost 20 to 50 percent of SOC in 50 to 100 years after conversion from natural system to intensive farming system. For example, in the United States of America, in intensive continuous corn cropping system, SOC decreased by more than 50 percent in 100 years (Gollany *et al.*, 2011). The significant losses of SOC in black soils are typically the result of inappropriate land use and poor management practices, leading to a decline in soil quality and soil structure as well as increased soil erosion, resulting in emissions of carbon into the atmosphere. On the other hand, appropriate land use and soil management can lead to an increase of SOC and improved soil quality and multiple benefits (Figure 15) that can partially mitigate the rise of atmospheric CO_2 in black soil regions (Liu *et al.*, 2012). In conclusion, sustainable use and management of black soils toward maintaining or increasing SOC stock could be crucial for climate change mitigation and adaptation.

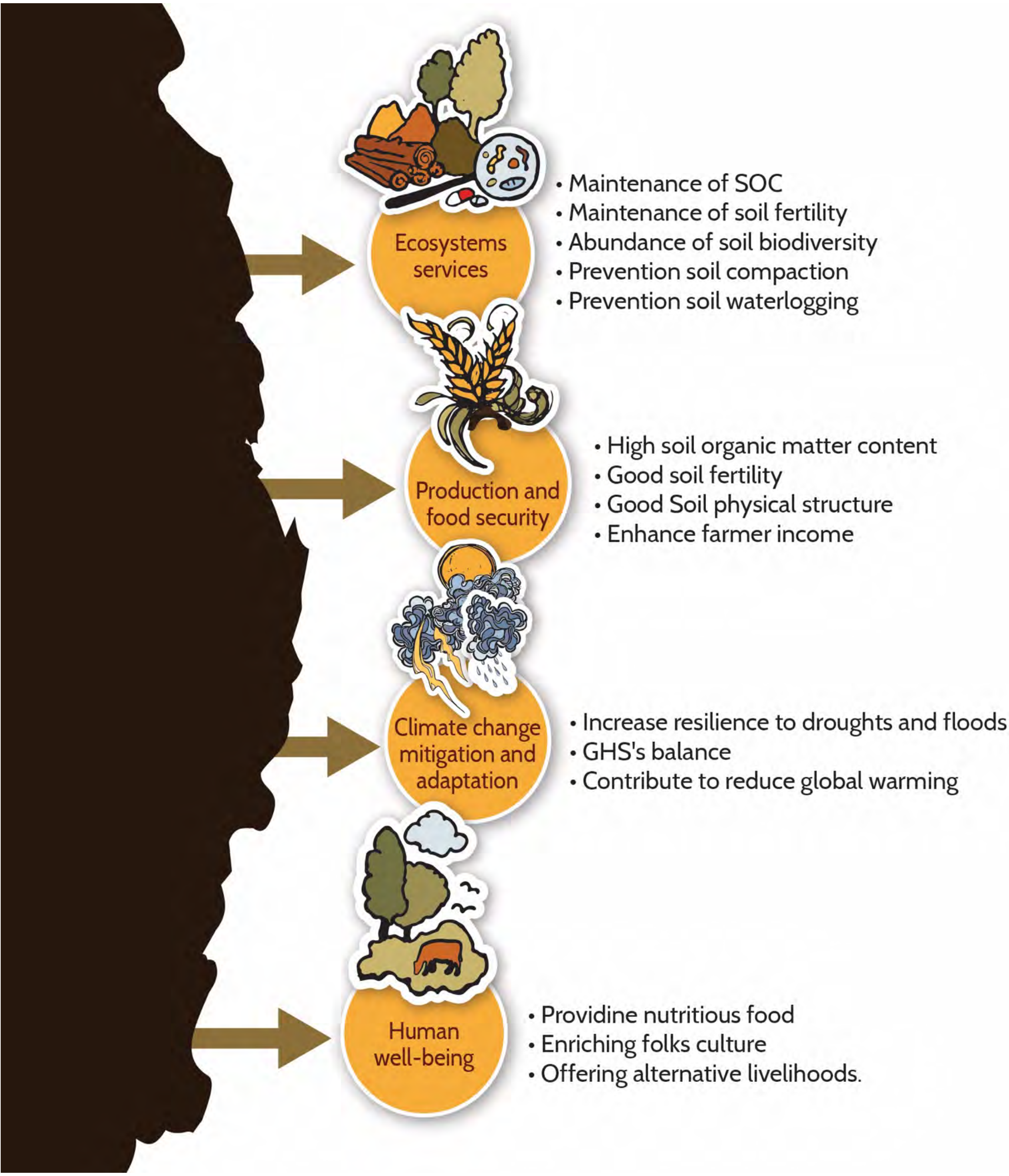

Figure 15. Mutiple benefits of black soils

5. General challenges and trends related to the black soils

5.1. Soil organic carbon loss

Land use change and inappropriate use and management soils lead to significantly decrease of soil organic carbon in Black Soils, in all regions of the world. The amount of soil organic matter content in weak, medium and severely eroded black soils has declined by 15, 25, and 40 percent, respectively in Russia (Iutynskaya and Patyka, 2010). Another study showed that 30 percent of organic matter has been lost in black soils of Ukraine (Balyuk and Medvedev, 2012). Black soils of the Republic of Moldova lost about 30 – 45 percent of carbon from the 0 – 25 cm layer over a period of 100 – 125 years (Krupenikov, 1992; Ciolacu, 2017). Chinese black soils have experienced an average annual rate of decline in soil carbon of 0.91, 0.97 and 0.48 percent, under monocropping systems of corn, soybean and wheat, respectively, in the 0 to 90 cm soil layers (Liu *et al.*, 2005). Excessive cultivation and summer fallowing have caused a 50 percent decline in soil organic matter in the Canadian prairie soils (Agriculture and Agri-Food Canada, 2003). Deforestation and subsequent cultivation have resulted in a pronounced depletion at the values of organic carbon (60–85 percent) in regions of black soils in Brazil (Rezapour and Alipour, 2017). Soil organic matter has decreased by 35.6 – 52.5 percent after a long cropping period in black soils in Argentina; all this demands the establishment of conservation practices to reduce losses of SOC and deterioration of soil quality (Durán, 2010). In Uruguay, SOC decreased more than 50 percent after only 50-year period (Baethgen and Morón, 2000).

5.2. Soil erosion

Erosion induced by rainfall and wind degrades the quality of black soils. A study showed that about a third of arable land is eroded from the black soils of Ukraine (Balyuk and Medvedev, 2012). From 1979 to 2014, cropping system conversion from forestry to dry lands aggravated erosion from 204.4 to 420.9 tons per km^2 per year in the black soil region of northeast China (Ouyang *et al.*, 2018). Changes in particle-size distribution and mainly organic matter of soils due to deforestation were responsible for a significant increase in the values of soil erodibility factor (a rise of 10–270 percent) on a study on these soils in Brazil (Rezapour and Alipour, 2017). Loss of soil by wind were observed in the lowlands with black soils in Eastern Austria, and new windbreaks are planted annually, thus increasing the protected areas by several thousand hectares per year (Strauss and Klaghofer, 2006).

5.3. Soil nutrients imbalance

With the intensive use of black soils, without proper management of fertility, the levels of nutrients decrease significantly. Increasing deficiency of labile nutrients, especially nitrogen (declining from -41.4 kg/ha in 2001 to - 56.4 kg/ha in 2009) and potassium (declining from -32.9 to - 64.2 kg/ha between 2001 and 2009) has been observed in black soils of Russia (Grekov *et al.*, 2011; Medvedev, 2012). Stocks of nutrients have noticeably decreased in black soils of Ukraine (Balyuk and Medvedev, 2012), and excessive cultivation and summer fallowing have lowered soil nutrients in the Canadian prairie soils (Agriculture and Agri-Food Canada, 2003). A pronounced depletion was observed in values of total N (67–88 percent), cation exchange capacity (9–18 percent) and exchangeable cations (4–60 percent) after deforestation of black soils in Brazil (Rezapour and Alipour, 2017).

5.4. Soil compaction

Soil compaction is a common cause of black soil degradation. After 75 years of cultivation, the total amount of water-stable aggregates declined by 26.9±1.0 percent and the clay content by 26.9±1.0 percent in black soils from Russia (Balashov and Buchkina, 2011). A study in Ukraine showed that approximately 40 percent of the black soils have a compacted layer (Balyuk and Medvedev, 2012). Excessive cultivation and summer fallowing have degraded the Canadian prairie soils, resulting in poor surface structure (Agriculture and Agri-Food Canada, 2003). Without significant variation, 14–20 percent higher bulk density and 10–22 percent lower porosity values were observed in cultivated black soils compared to forest lands in Brazil (Rezapour and Alipour, 2017).

5.5. Salinization and acidification

Salinization and acidification are consequences of both natural (primary) and human-induced (secondary) processes. But human induced salinization and acidification by 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 Russia (Grekov *et al.*, 2011; Medvedev, 2012). Acidification of black soils, especially in the regions of Cherkassy and Sumy in Ukraine, was observed, where the value of pH dropped 0.3–0.5 units after 40–50 years cultivation (Grekov *et al.*, 2011; Medvedev, 2012). A decrease of soil pH by a factor of 0.27 was observed in Northeast China black soils region, from 2005 to 2014, showing a trend of acidification due to overuse of nitrogen fertilizers in intensive cropping systems (Tong, 2018).

In conclusion, Black soils are facing services threats in terms of soil organic carbon loss, soil nutrient imbalance, soil compaction and salinization and acidification. Actions are needed for sustainable management on black soils for insuring the productivity and ecological services of these carbonrich soils (Figure 16).

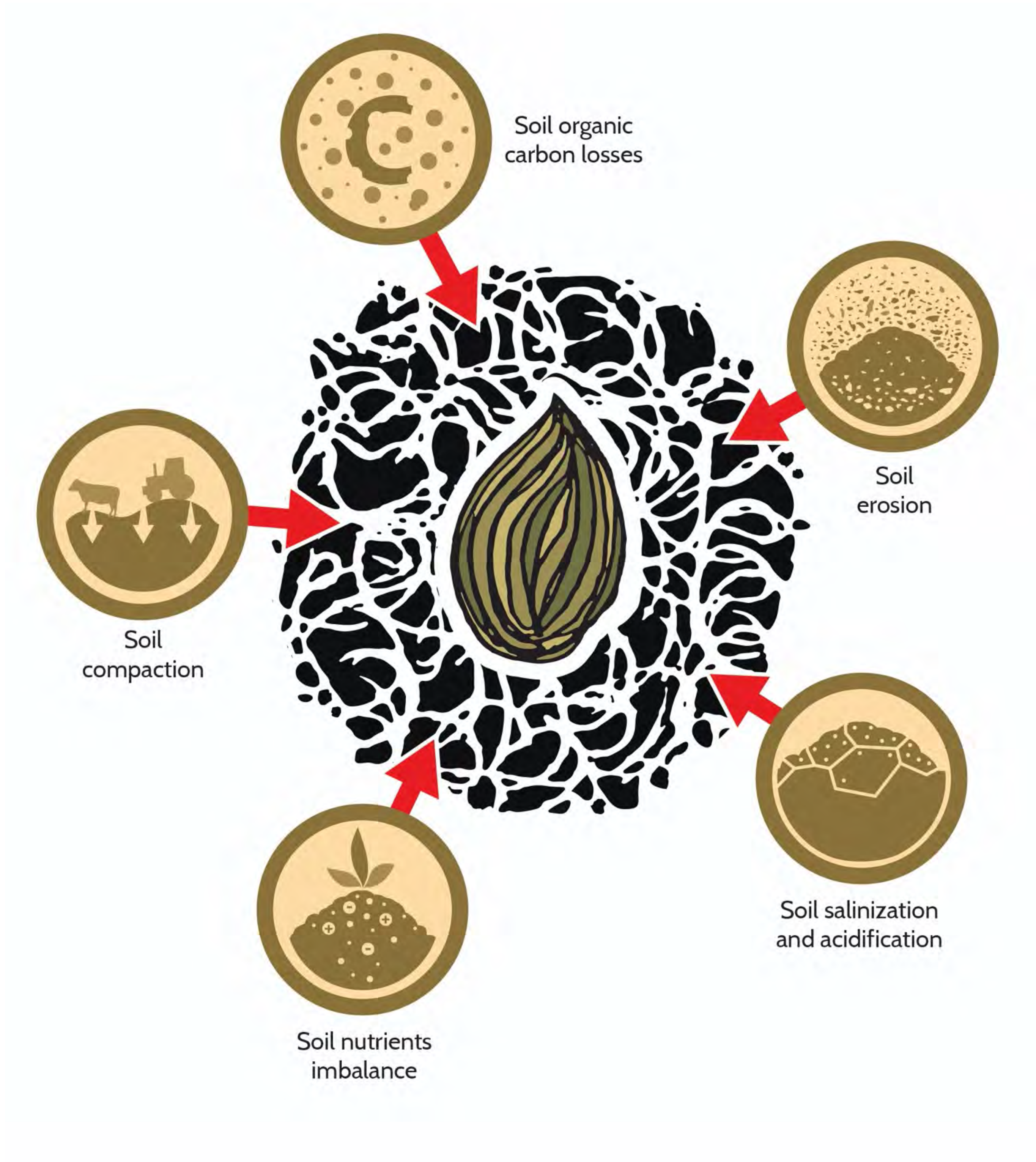

Figure 16. Main challenges to black soils

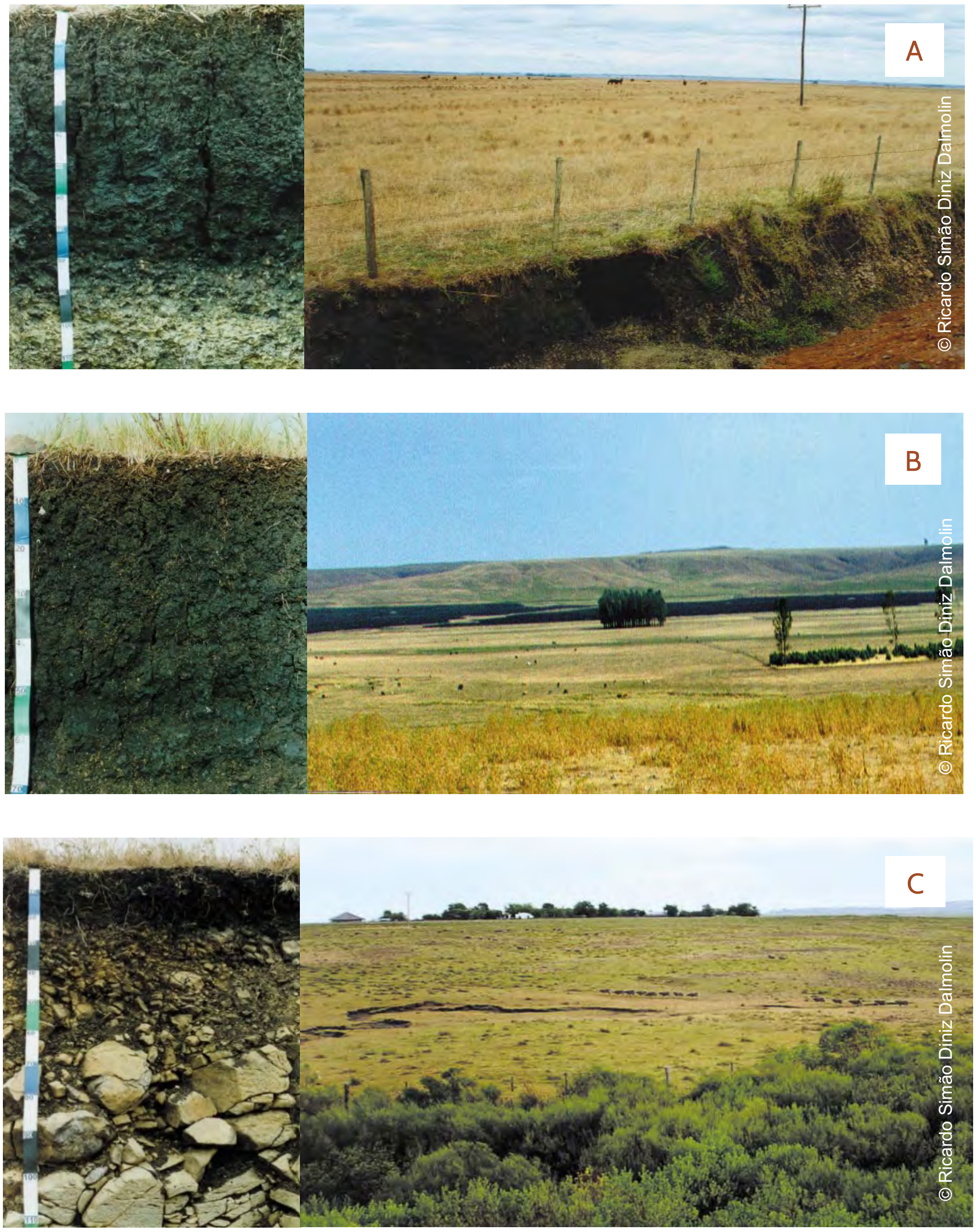

Photo 7. Profiles of Chernossolo (A), Vertissolo (B) and Neossolo (C) and landscape associated in the Pampas Biome, southern Brazil

Table 15. Related cases studies available in volumes 4 and 6

Title	Region	Duration of study (Years)	Volume	Case-study n°
16 years of no tillage and residue cover on continuous maize in a Black soil of China	Asia	16	4	10
Organo-mineral fertilization on a Ukrainian black soil	Europe	5	4	26
Application of swine and cattle manure through injection and broadcast systems in a black soil of the Pampas, Argentina	Latin America and the Caribbean	1	4	30
No tillage and cover crops in the Pampas, Argentina	Latin America and the Caribbean	2 to 8	4	31
Crop-pasture rotation on Black Soils of Uruguay and Argentine	Latin America and the Caribbean	10 to 48	4	39
Willow Riparian Buffer Systems for Biomass Production in the Black Soils of Elie, Manitoba, Canada	North America	6	4	42

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