4. Sustainable management of black soils: from practices to policies

4.1 Good practices to address sustainable management of black soils

In the coming decades, a crucial challenge for humanity will be meeting future food demands without further undermining the integrity of the Earth's environmental systems. As the food basket of the world, black soils are already degraded significantly after land use change from natural ecosystem to farmland, but main soil threats such as erosion by water and wind, loss of soil organic carbon (SOC) and soil organic matter (SOM), and nutrient imbalance will further endanger its ecosystem service functions. For example, during the past several decades, black soils have lost about 50 percent of their initial SOC stock due to soil erosion, degradation, and other unsustainable human activities (Gollany *et al.,* 2011). Responding to these threats, there is increasing focus on 'Sustainable Soil Management' as a means to maintain or increase productivity on underperforming black soils while simultaneously decreasing the environmental impacts of management practices. However, it is unclear what such efforts might entail for the future of intergraded management practices and policy strategies for black soil conservation. Here we present a global scale assessment of sustainable management practices of black soils that may be necessary to achieve increased yields and decreased environmental impact.

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Black soil project implementation, Harbin China, May 2022.

The Sinograin II project, a collaborative project between Norway and China, aims to exploit smart agricultural technologies to improve the sustainability of agriculture in China. Black soils in the north-eastern region of China are very fertile and are mainly used for grain production (Dybdal 2019, 2020), and have been described as a "giant panda in cultivated land". However, the intensive agricultural production, the lack of sustainable soil management practices and the excessive use of fertilizers have led to a decline in their fertility. With the aim of restoring these soils and implementing climate-smart agrotechnologies such as precision fertilization and APP-based tools for sustainable production systems, scientists from the Norwegian Institute of Bioeconomy Research (NIBIO), the Chinese Academy of Agricultural Sciences (CAAS), Heilongjiang Academy of Agricultural Sciences (HAAS), Nanjing Agricultural University and other Chinese partners are collaborating on the Sinograin II project. This project, which is financed by the Norwegian Ministry of Foreign Affairs, and a total budget of NOK 18.8 million, seeks to apply innovative technologies that contribute to food security and the environment in China. Sinograin II is mainly based on precision nitrogen management technologies, automatic pest prediction to improve pesticide use efficiency, influence of innovative farming technologies, management of nutrient inputs for sustainable food production, and research on the agro-tech extension and household adoption of precision agricultural technology and its economic, social and environmental effects. One technology being developed for black soils in the Heilongjiang region is the validation of a digital soil health card (SHC). This card is easy for farmers to use and makes use of soil health information such as soil structure and number of earthworms in the soil, among other parameters. Using this card allows farmers to make decisions on nutrient and fertilizer requirements for individual farms in order to improve the productivity of their crops while maintaining healthy soils. An APP-based SHC is under development and shall be tested in the near future. The development and exploitation of these climate-smart tools promotes and contributes to the protection, restoration and sustainable management of black soils.

4.1.1 Tillage

To reduce the impact of tillage and seeding systems on soil health, the frequency (number of passes across the field that results in a soil disturbance) and intensity (mass of soil disturbed in a single pass) must be reduced. Conventional tillage (CT) usually involves a complete inversion of the soil with a moldboard or disc-plough followed by several tillage operations before seeding. For example, CT which includes moldboard plough (MP), has caused the loss of SOC and the severe soil degradation of soil structure in black soil region due to its very fine-grained feature (Sun *et al.*, 2016). Much of the tillage research has focused on physical and chemical processes under contrasting tillage systems, and found that conservation tillage increased the soil water content, soil macroporosity and soil organic carbon content and decreased soil bulk density. A range of tillage and seeding systems have been developed to reduce the intensity and frequency with the objective of maintaining and improving soil health and crop yield. Tillage and seeding systems for conservation management tend to fall into three categories, non-inversion tillage, strip tillage and no-till, with tillage intensity and frequency decreasing as you move from non-inversion tillage to strip tillage and finally to no-till (Morris *et al.,* 2010). It is also important to recognize that complementary agronomic practices need to be used in an integrated system with tillage and seeding management practices to protect and conserve black soils (Freitas and Landers, 2014; Veum *et al.,* 2015; Nunes *et al.,* 2018).

Non-inversion tillage

Description of the practice

Non-inversion tillage includes crop production systems which mix crop residues with the top 8 to 10 cm of soil in the entire row and inter row area (Hayes, 1985; Morris *et al.,* 2010). A protective quantity of residue is left on the soil surface during the year. The cultivator system, chisel system, disk system, stubble mulch system, rotary tillage system, and similar systems are all considered to be non-inversion tillage (Photo 4.1.1a).

Photo 4.1.1a Non-inversion tillage, Shirokiv of Ukraine

Range of applicability

The technique is applied under a wide variety of climate conditions and crops such as soybean and maize in black soil areas. It can be potentially applied to all climatic areas and crops, in climatic zones such as warm temperate dry, warm temperate humid, cool temperate moist, and tropical wet.

Benefits of the practice

Non-inversion tillage was found to improve many physical, chemical and biological soil properties compared to CT (Holland *et al.*, 2004). For instance, with monoculture maize in a black soil area in temperate zone of northeast China, non-inversion tillage reduced soil erosion compared to conventional tillage (Sun *et al.*, 2016). In addition, non-inversion tillage combined with maize-soybean rotation enhanced the soil microbial metabolic activity and increased the fungi-to-bacteria (F/B) ratio in the plough layer, and improved microbial biomass and abundance in the surface layer (Sun *et al.*, 2016). Amino sugar is also an essential tool for investigating the presence of microbial residues in soil, higher amino sugar content in CT improves long-term SOC stabilization in black soils more than traditionally believed (Sun *et al.*, 2016). These practices are especially important in addressing soil erosion, SOC and biodiversity loss, and compaction.

Recommendations and potential barriers for adoption

Non-inversion tillage can reduce soil erosion compared to convention tillage, but if several tillage operations occur between cropping seasons with very little residue left on the soil surface, there is very little protection of the black soils that may lead to soil degradation.

No-till

Description of the practice

No-till is a system where a crop is planted directly into a seedbed that has not been tilled since harvest of the previous crop. It is a common practice used in black soil regions of the world. It is also called zero tillage, under the umbrella of conservation agriculture. The no-till operation consists of a one-pass planting and fertilizer operation in which the soil and the surface residues are minimally disturbed. No-till systems eliminate all mechanical seedbed preparation before seeding and fertilizer placement except for the opening of a narrow (2 to 3 cm wide) strip or small hole in the ground for seed placement to ensure adequate seed to soil contact. The entire soil surface is covered by crop residue, mulch or sod. The surface residues of such a system are of critical importance for soil and water conservation. Weed control is generally achieved with herbicides or in some cases with cover crops and crop rotation (Derpsch, 2003) (Photo 4.1.1b).

Photo 4.1.1b No-till maize crop, Pampas of Argentina

Range of applicability

On black soils, particularly in grasslands of dry regions in the northern hemisphere, no-till is widely practiced for soil moisture conservation and soil erosion control (Derpsch *et al.,* 2010). Similar practices are adopted for grain production in the "pampas" region of South America, where soil erosion control is an additional objective (Díaz-Zorita, Duerte and Grove *et al.,* 2002; Alvarez *et al.*, 2009). It has also been shown that conservation tillage promotes the formation of stable macro-aggregates and contributes to black soil structure improvements in northeast China (Fan *et al.*, 2010). On the other hand, a recent study assessing conservation agriculture and control of soil erosion in Brazil forecasts a continuous increase in the area with adoption of conservation agriculture by the year 2030, including no-till (Polidoro *et al.*, 2021). The exponential growth of no-till occurred on black soils with annual crops in the south region of Brazil, and crops in rotation or integrated systems with pasture and forest in the cerrado's biome.

Benefits of the practice

CT system, including continuous mouldboard and disc-ploughing and the removal of post-harvest residues, has caused a significant loss of SOM and serious soil degradation in several black soil regions (Follett, 2001; Alvarez *et al.,* 2009). The ongoing land degradation has threatened sustainable crop production and even national food security (Liu *et al.,* 2010). To effectively reverse the degradation of black soils, no-till has been proposed to farmers as partial replacements for CT. Positive effects of no-till on soil health parameters have been widely documented and include major reductions in soil erosion and fuel consumption, reduced CO_2 emissions, and enhanced water quality, biological activity, soil fertility and production stability (Pretty, 2008; Derpsch *et al.,* 2010; Lafond *et al.,* 2011a). In black soil areas, studies have also reported better soil aggregation, higher SOC, and increased potentially mineralizable nitrogen (N) in no-till soils (McConkey *et al.,* 2003; Pikul *et al.,* 2009; Malhi *et al.,* 2009; Lafond *et al.,* 2011b). Lafond *et al.*, (2011b) observed that N uptake and yields in long-term (31 years) no-till exceeded those in short-term (nine years) no-till, suggesting that even after nine years, and possibly even after 31 years, no-till soils may still be in a soil-building phase. Higher SOC retention in no-till was observed due to fungal mediated aggregate stabilization in no-till practice in a black soil region of northeast China (Ding *et al.*, 2011). Merante *et al.*, (2017) reported annual SOC increases by zero tillage and direct drilling (also known as no-till seeding) of 0.04 to 0.45 tonnes C/ha in different countries and regions. Meanwhile, microbial biomass and nematode abundance and the alteration in their community composition at the micro-niche within aggregates could contribute to the higher SOC sequestration under no tillage (Zhang *et al.*, 2013).

The effect on no-till on crop yields vary, depending on crop species and weather conditions (Malhi and Lemke, 2007). No-till often increases crop yields and water use efficiency under dry conditions, but can result in reduced yield under wet conditions (Azooz and Arshad, 1998; Arshad, Soon and Arooz, 2002). However, in the tropical mid-latitude black soils of Brazil, no-till has been successfully implemented into a cropping system that has intense, erosive rains that occur normally at the start of the planting season (Freitas and Landers, 2014). Furthermore, studies have also showed the potential to mitigate greenhouse gas (GHS) emissions in areas converted to agriculture by using systems with legume-based crop rotations combined with no-till (Pillar, Tornquist and Bayer, 2012). No-till systems based on the use of herbicides can favor the development of glyphosate-resistant weeds, mainly in low intensity rotations (Johnson *et al.,* 2009). Sustainable management of black soils through no tillage can address main soil threats such as SOC and biological loss, erosion, compaction and nutrient imbalance.

Recommendations and potential barriers for adoption

There are environmental conditions that limit the effectiveness of the no-till seeding system. As mentioned previously, excess moisture that does not allow the seed bed and rooting zone to aerate can be problematical. Currently, the timing and length of this period of aeration is not well understood. Obviously, seeding is delayed and restricted when the seed bed is saturated during seeding. Soil temperature during germination and emergence can also be delayed in some crops such as maize (Licht and Al-Kaisi, 2005; Vyn and Raimbault, 1993), in black soil regions with temperate or cold climates.

In resource-limited cropping systems, it may take an extended period of time for the soil to reach an equilibrium before releasing a similar level of nutrients to the crop as is achieved through tillage. Reduced N mineralization under no-till may also reduce yields where N is limiting (Campbell *et al.,* 2001). Currently, organic cropping systems utilize tillage for weed control.

No-till strip tillage

Description of the practice

Strip till is a tillage system that combines no-till and full tillage to produce row crops (Nowatzki, Endres and DeJong-Hughes, 2017), and is commonly implemented in the black soil areas of the world. Narrow strips 15 to 30 cm wide are tilled in crop stubble, with the area between the rows left undisturbed. Often, fertilizer is injected into the tilled area during the strip-tilling operation. The tilled strips correspond to planter row widths of the next crop, and seeds are planted directly into the tilled strips. Strip tilling normally is done in the fall after harvest, but it also can be done in the spring before planting, where global position system (GPS) guidance is usually required to create the strips and seed the row crop into the strips (Photo 4.1.1c).

Photo 4.1.1c Strip till, Indian Head of Canada

Range of applicability
Strip till can be applied worldwide in arable crops, preferably on relatively flat land with poorly drained black soils. This type of tillage is performed with special equipment and can require the farmer to make multiple strips, depending on the strip-till implement used, and field conditions.

Benefits of the practice
Strip till warms the soil and allows aerobic conditions and a better seedbed than no-till. Strip till allows the soil's nutrients to be better match the plant's needs, while still giving residue cover to the soil between the rows. Strip tillage reduces bulk density and soil resistance to root growth while increasing the amount of biopores and soil water filtration rate (Laufer *et al.*, 2016). It also improves soil aggregate stability (Garcia-Franco *et al.*, 2018), which all together makes soils less prone to erosion (Dick and Gregorich, 2004). Strip tillage has several advantages in protecting and conserving black soils over CT and seeding systems while maintaining grain yield in row crops. The crop residue maintained on the soil surface between the cultivated strips also maintains SOM. In conclusion, soil erosion, nutrients imbalance, and compaction can be addressed by no-till strip tillage.

Recommendations and potential barriers for adoption
Strip tillage has an advantage over no-till in environments when early seeding results in reduced soil temperatures, and delayed and reduced plant emergence compared to traditional tillage operations. Under these environmental conditions strip till removes the negative impact on yield observed in a no-till seeding system (Licht and Al-Kaisi, 2005). The effect of these depressed yields with no-till are only observed in a few crops, the predominate one being maize. This has limited the development of no-till on black soils where maize is the predominant crop.

4.1.2 Soil organic cover

Cover crops

Description of the practice
Cover crops are defined as a "close-growing crop that provides soil protection, seeding protection, and soil improvement between periods of normal crop production, or between trees in orchards and vines in vineyards. When plowed under and incorporated into the soil, cover crops may be referred to as "green

manure crops" (SSSA, 2008). Cover crops are also called "living mulch" or "green manure". In some cases, cover crops can remain permanently on the soil, which constitutes a living soil cover. There are many cover crop practices implemented in black soil area around the world. Typically, cover crops are grasses, legumes, brassicas or mixtures of two or more species (Jian *et al.*, 2020). In Manitoba of Canada, alfalfa, red clover and winter pea were consistently established as spring-seeded relay crops in fall-seeded winter cereals (Thiessen Martins, Entz and Hoeppner, 2005; Cicek *et al.,* 2014; Blackshaw, Molnar and Moyer, 2010). In the Republic of Moldova, mixtures of grasses, alfalfa, steppe ryegrass and sainfoin are used as cover crop practices to improve soil quality and crop yield (Leah and Cerbari, 2015; Rusu, 2017) (Photo 4.1.1a).

Photo 4.1.2a Hairy vetch as cover crop, Salto, Argentina

Range of applicability

Cover crops can be a good practice for sustainable black soil management and needs to be adapted to the farming system, black soil types and climate. Double cropping, the production of a second crop after the first crop has been harvested, provides an opportunity to utilize late-season moisture and heat resources after the harvest of the cash crop. Early maturing crops, including annual forages or winter cereals can provide a window of opportunity for double cropping with cover crops (Thiessen Martens and Entz, 2001).

Benefits of the practice

Annually, no-till cover crops can sequester between 0.1 and 1 tonne SOC /ha relative to no-till depending on cover crop species, soil type, and precipitation input (Merante *et al.,* 2017; Poeplau and Don, 2015). Soil cultivated with perennial grass mixture (alfalfa + ryegrass and sainfoin + ryegrass) for 4 to 6 years, led to positive changes in SOM content and favorable modification in physical and chemical properties (Leah and Cerbari, 2015). In addition, the use of cover crop systems has allowed to moderate soil moisture and near-surface air temperature (Thiessen Martens, Hoeppner and Entz, 2001; Kahimba *et al.,* 2008). This effect has implications for snowmelt infiltration, depth of frost, and probably also for pest cycles and nutrient cycling. Cover crop management increased the soil water transport and water retention in black soils, as compared with bare soil rotations (Villarreal *et al.*, 2022). In this sense, a cover crop could be a suitable management in order to recover soils in terms of increasing of soil water transport compared with the soybean monocropping system in Mollisols in Argentina Pampas region (Villarreal *et al.*, 2022). Moreover, other studies reported that cover crops such as alfalfa, red clover and winter pea can reduce soil moisture in black soils in Canada in the case of an excessive moisture (Blackshaw, Molnar and Moyer, 2010; Kahimba *et al.,* 2008; Thiessen Martens, Hoeppner and Entz, 2001). As cover crops contribute to moisture regulation, their use can be a benefit in wet years as well as in dry years.

When legumes were used as cover crops, yield benefits to the subsequent crop were observed in all studies. In addition, weed suppression was observed by the alfalfa cover crop in the study conducted in Canada in winter cereals (Blackshaw, Molnar and Moyer, 2010). In organic farming, the use of fodder mixtures as cover crop is achieved with low consumption of fertilizer and without herbicides, which also has a positive economic impact (Leah and Cerbari, 2015). In summary, cover crops are a good practice to address SOC and biodiversity loss, compaction, and soil nutrients imbalance.

Recommendations and potential barriers for adoption

After the main crop has been harvested, the consistent establishment of a second crop can be difficult in many black soils regions due to extremely variable precipitation during this period (Thiessen and Entz, 2001). In southern Manitoba, researchers have successfully established a second crop after a winter cereal over several years of research; however, biomass production has been extremely variable, ranging from 95 to 2 357 kg/ha for double cropped black lentil, hairy vetch, and field pea; biomass production achieved at least 1 tonne /ha in only a few instances (Cicek *et al.,* 2014; Thiessen and Entz, 2001). Soil moisture and microclimate can be impacted by late-season cover crops. For example, if the subsequent season is drier, then the cover crop will compete with the main crop for the available water content, thereby creating soil moisture stress. This, in turn, will affect the crop performance and yield (Kahimba *et al.,* 2008).

There is evidence that an integrated long term strategy and plan which include all relevant sectors are key to achieve cover crop management and its benefit on soil quality and production. For example, in the Republic of Moldova, perennial cover crop of grasses, alfalfa, steppe ryegrass and sainfoin are used to improve soil quality and crop production of fodder. The practice can be implemented only when at least 15 percent of agricultural land used for restoring the livestock sector and perennial grasses (Leah and Cerbari, 2015).

Organic mulch

Description of the practice

Organic mulch involves the application of specific material on the soil surface in order to reduce water loss and soil erosion (which is the biggest challenge of black soils management) but also to suppress weeds, reduce splashing, modify soil temperatures and generally improve crop productivity. Organic mulches would entail any material such as straw, leaves or loose soil, etc. that is spread or formed upon the surface of the soil to protect the soil or plant roots from the effects of raindrops, soil crusting, freezing, evaporation, etc. (SSSA, 2020). In the Republic of Moldova, main mulch practice is shredding and spreading plant residue uniformly on the soil surface after harvest with N fertilizers (mineral or organic) at a depth of 6 to 10 cm. Meanwhile, plowing should be performed as late as possible, especially in October and November (Rusu, 2017). In Chinese black soils, a no-till management scheme with different quantities of maize straw mulching is being implemented in the field (Yang *et al.*, 2020) (Photo 4.1.2b).

Photo 4.1.2b Organic mulch, Lajitas, Argentina

Range of applicability

The use of mulches based on crop residues is applicable to any type of pedoclimatic context. Black soil areas with higher net primary productivity are less constrained in having enough crop residues such as maize, soybeans and wheat, to keep the soil completely covered with crop residues.

Benefits of the practice

The use of crop residues as mulches implies several benefits on soil properties. Straw mulching significantly increased the soil water content and SOC, soil total nutrients and soil microfauna (Deng *et al.*, 2021; Yang *et al.*, 2020). Furthermore, the effectiveness of mulching in reducing soil erosion was observed in Ukraine, where minimum tillage with 2.5 tonnes/ha of mulch in Mollisols increased available water, reduced runoff up to 3.8 m^3/ha and improved spring barley yield by 1.6 tonnes/ha (Hospodarenko, Trus and Prokopchuk, 2012). This trial also showed that straw mulching leads to a significant decrease of weeds, thereby decreasing the use of herbicides (Sun *et al.,* 2016).

In past decades, the C balance of Mollisols in croplands has been negative due to soil erosion, degradation, and other improper management (Xu *et al.*, 2020). An application of low quantity maize stover with a high frequency of mulching in major Mollisols areas of the world, compared to low frequency maize stover mulching, lead to significant increases in yield, SOC, total nitrogen, total phosphorus, and total potassium. This will contribute significantly to food production and climate change regulation (Yang *et al.*, 2020). Generally, organic mulch can address the soil challenges in terms of the SOC loss, soil erosion, and nutrient imbalance.

Recommendations and potential barriers for adoption

Maintaining a low quantity but high frequency of mulch might efficiently boost soil health without compromising crop yields and as well optimize the use of stover. Applying a small quantity of stover mulching at high frequency might be sufficient for regenerative agriculture by efficiently improving soil health. When the stover quantity was limited, using small quantities for multiple additions can regenerate more stable and active bacterial communities, and result in greater soil fertility. Hence, applying a small quantity of stover mulching at high frequency might be sufficient for regenerative agriculture by efficiently improving soil health (Yang *et al.*, 2020).

An excessive amount of crop residues in specific pedoclimatic conditions can be counterproductive for grain yield. Mulches can lead to allelopathy, a common biological phenomenon by which one organism produces biochemicals that influence the growth, survival, development, and reproduction of other organisms, that reduces crop growth, lower soil temperatures that impede fast establishment of crops (Venterea, Maharjan and Dolan, 2011), as well as exacerbation of frost damage (Snyder and Melo-Abreu, 2005).

In general, to make progress when using mulch, it is not only necessary to adopt multidisciplinary thinking and effective integration of multiple viewpoints from scientific research and practical orientation from farmers, but it is also important to include effective cooperative actions to formulate policies for more regenerative agriculture and a more promising future (Sherwood and Uphoff, 2000).

4.1.3 Nutrient management

While black soils are inherently fertile, with a generally high SOM content (FAO, 2020), effective nutrient management is still critical for soil health, food security and environmental protection. The loss of SOM in black soils leads to the loss of related nutrients, such as N, P and K. However, many black soils also suffer acidification processes and loss of exchangeable bases and many essential micronutrients such as Zn. If these nutrients are not replenished, the ability of black soils to produce food may be affected. Nutrient management involves using nutrients as efficiently as possible to improve productivity while protecting the environment. Nutrient management depends on soil fertility, physical and biological as well as climate conditions, but one key principle behind nutrient management is balancing soil nutrient inputs with crop requirements. Achieving this balance, in essence, will lead to increased productivity and farm profitability, while at the same time, minimize nutrient losses to the environment. It is well-known that nutrient cycling in agroecosystems is a function of biotic (mineralization controlled by living organisms) and abiotic factors (physical or chemical including climate). Here, we describe some of the major issues and challenges related to nutrient management in black soils.

Manure additions

Description of the practice

Manure includes the excreta of animals raised for meat or other products whose chemical composition depends on the diet and the type of animal from which it originates (such as poultry, cows, sheep, horses and rabbits) and may also include the plant material (straw) used as bedding for animals. Manure can be found in liquid (liquid manure or slurry) or solid (solid manure) form. Manure can add essential plant nutrients (nitrogen, potassium, and phosphorus, collectively known as NPK) to the soil and improve soil quality. While partial substitutions of mineral fertilizers with manure can enhance crop yields, the complete replacement of mineral fertilization with manures can have detrimental effects on crop yields (Photo 4.1.3a).

Photo 4.1.3a Manure addition, Harbin city of China

Range of applicability

The use of manure is widely practiced among different climates, crop types, and in conjunction with other techniques such as the addition of synthetic fertilizers, type of tillage, and irrigation according to various black soil regions in our world. For instance, livestock manure and crop straw are the main components of organic fertilizer sources in China (Li, Liu and Ding, 2016). In North America, biosolids and slurries from municipal and industrial sources are also used.

Benefits of the practice

Manure application decreases soil bulk density, improves aggregate stability, and increases organic matter contents, phosphorus, bacterial and archaeal diversity, and infiltration in soils. Return of organic manure was a favorite measure to maintain or increase the content of SOC and its individual fractions, thus improving soil quality and crop production in black soil areas (Han *et al.,* 2006). In the long term, application of manure, whether as a stand-alone treatment, or combined with mineral fertilizers, results in increased levels of all forms of phosphorus (total, organic and mineral fraction) and soil fertility in general. This increase is most pronounced in the surface layer, which serves as a nutrient deposition zone, in black soils of Serbia (Milić *et al.,* 2019). Inorganic fertilizer and manure amendment alter the soil bacterial and archaeal community. In black soils of northeast China, the incorporation of inorganic fertilizer and manure increase soil bacterial and archaeal diversity (Ding *et al.,* 2016). Applications of manure were not enough to significantly increase the cumulative water infiltration into the black soils although a trend towards increased infiltration and exchange cations with manure application was observed (Assefa *et al.,* 2004).

The addition of fresh or composted manure promotes the growth and yield of vegetables, grains, and forage. In the northern part of black soil area in China, the management of manure is critical to improve crop production. The optimum management for maize and wheat production was to apply chemical fertilizer and manure without irrigation, but for soybean, it was to apply fertilizer and manure with irrigation (Liu *et al.,* 2004). In the Serbian black soil area, application of farmyard manure along with inorganic fertilizer had significant effect on grain yield in the investigated periods (Milić *et al.,* 2019).

The addition of manure improves the physical conditions and availability of organic carbon to support microbial processes that regulate nitrification and methanogenesis. For instance, increasing SOC, the greenhouse effect may be alleviated by sequestering more CO_2 in black soils of northeast China (Han *et al.,* 2006). Legumes and green manure are important for enhancing biological processes and increasing N availability in black soils, resulting in economic and environmental benefits in Ukraine (Baliuk and Miroshnychenko, 2016). The practice can successfully address threats such as SOC and biodiversity loss, nutrient imbalance and compaction if sustainable used.

Recommendations and potential barriers for adoption

Recycled organic manure along with appropriate chemical fertilizers is strongly recommended for the black soil area (Han *et al.*, 2006). The effect of manure application on soil chemical and physical properties in these soils is variable depending on soil and manure type. Salinity and sodicity assessment should be part of a monitoring programme on manured lands to ensure that soil quality and productivity are not adversely affected over the long-term by repeated manure applications (Assefa *et al.*, 2004). Addition of fresh manure should come with a caution because fast decomposition of fresh manure could produce soil warming and result in damage to plant roots. Manure adds N to soils and can lead to N_2O emissions, but by replacing chemical fertilizers, manure application can mitigate N_2O emissions to a certain extent (Guo *et al*. 2013). The use of manure requires adequate logistics in terms of storage sites, avoidance of contamination of water and requires the availability of machinery. A total replacement of synthetic fertilizer sources by manure should be considered carefully, at least for agriculture that is carried out over large areas.

Compost application

Description of the practice

"Composting is the biological decomposition of organic materials by microorganisms under controlled, aerobic conditions to a relatively stable humus-like material called compost". Thus, the application of compost on the soil can increase SOC and provide nutrients to soils. Well-prepared compost features a humus structure of stable aggregates and clay-humus complexes which improve the soil structure (Misra *et al.*, 2003). Through composting, biomass found on-farm can be reused, thus potentially avoid rotting and GHG emissions from crop residues, manure, leaves, etc. Compost can be made out of very different ingredients (such as manure, crop residues, biowaste and kitchen waste) and it is widely used among farmers, especially smallholder farmers. Different composting methods exist, mainly aerobic and anaerobic composting (Misra *et al.*, 2003) (Photo 4.1.3b).

Photo 4.1.3b Compost, Jinlin province of China

Range of applicability

The practice can be applied in any climatic region of black soils except in extreme cold or arid environments.

Benefits of the practice

Compost improves the soil structure through the formation of stable aggregates. Likewise, it regulates soil moisture and increases SOC, fertility, microbial and faunistic diversity of black soils. Consecutive applications of municipal sewage sludge composts improved the soil nutrient status, by adding slowly decomposing organic matter abundant in macronutrients (N, K and P) without causing excessive leaching of nitrate into the groundwater in black soils of Hungary (Farsang *et al.,* 2020). In Japan, the change of microbial biomass in Andosols and Chernozems was faster under the compost-compound fertilizer mixture (CCFM) than under the chemical fertilizer or control treatments. CCFM tended to enhance plant growth in both soils. Compost-compound has a soil carbon storage effect with less resultant GHG emissions, especially in Andosols (Sato *et al.*, 2022). In the Chernozem region of the Russian Federation, complex compost composed of the waste products of the agriculture (cattle manure and plant residues) and chemical fertilizer (phosphogypsum) improved aggregation in the phough layer and decreased soil bulk density. The water and air properties of the black soils can also be optimized, which was seen from an increase in the field and total water capacity, total porosity, and soil water storage (Belyuchenko and Antonenko, 2015). Regarding soil biodiversity, compost addition led to significant improvement in the soil fertility, while there is a positive effect on the abundance of ammonia oxidizers and denitrifies. Compost addition play crucial roles in shaping microbial community compositions and co-occurrence networks in black soils of northeast China (Yang *et al.*, 2017).

In the aspect of yield, compared to unfertilized controls, frequent compost application resulted in higher yields. The complete use and composting of available farm biomass (such as crop residues, green waste and manure) can also reduce the rotting and thus GHG emissions. Using a good quality compost regularly (annually or for each cropping season) can reduce the need for application of chemical fertilizers. In conclusion, the compost approach is a practice that addresses the black soil challenges such as nutrients imbalance, SOC loss, and soil biodiversity losses.

Recommendations and potential barriers for adoption

Using soil residual extractable P after ryegrass removal was high for fish-derived amendments and the commercial product, but the potential risk of P pollution needs to be considered when these are applied according to N requirements in black soils (Laos *et al.*, 2000).

An increase in the sorption potential of the organic mineral complex can decrease in the content of mobile forms of heavy metals in compost. Assissing the content of highly toxic metals in the upper layer of leached chernozem after harvesting is necessary to identify the concentration of heavy metals (Antonenko *et al.*, 2022). Composting animal manure, sewage sludge and wastes from the wine making industry and factories for soil fertilization. Application should be carried out according to the period and conditions of management (Rusu, 2017).

Chemical and mineral fertilization

Description of the practice

Even Black soils generally hold high soil fertility, but high intensive production pose a dangers in soil fertility reduction in those soils. Sufficient but not excessive use of fertilizers is necessary to maintain black soils. In addition, strategies that enhance SOM content and reduce overall soil degradation are vital to enhancing soil nutrient supply power in the black soil areas of the world (Campbell *et al.,* 1991, 2001; Malhi *et al.,* 2011a; 2011b; Castañeda-Martin and Montes-Pulido, 2017).

There is a wide range of nutrient sources that are used in black soil regions. The most commonly used N fertilizer source is urea. Other chemical N fertilizer sources include calcium ammonium nitrate, ammonium sulphate, urea ammonium nitrate, anhydrous ammonia, and diammonium phosphate. Due to advances in fertilizer technology, coated fertilizer products that release nutrients slowly to the soil are also being used (such as environmentally smart nitrogen). While these coated products have shown great promise in reducing N_2O emissions and nitrate leaching during the growing season (Gao *et al.,* 2015; Gao *et al.,* 2018), N losses in the non-growing season may be elevated due to high residual soil mineral N content due to slow or delayed release of N (Clément *et al.*, 2020; Zvomuya *et al.,* 2003). Moreover, the associated cost and more or less inconsistent crop yield benefits have hindered widespread adoption of coated fertilizer products. In addition to this, products that utilize a urease or nitrification inhibitor are also used, but on a smaller scale (Amiro *et al.,* 2017).

Major chemical fertilizers used for P include monoammonium phosphate and superphosphate, while potassium chloride is the most widely used source of K. Sulphur (S) is applied in black soils as elemental S (the most commonly concentrated form of S), sulphate form (SO_4^{2-}) in sulphate-based fertilizers or a combination of both. S fertilizers used in black soils of Canada are ammonium sulphate, urea-ammonium sulphate, and sulphur bentonite. Other products that contain elemental S, as well as both elemental and sulphate-sulphur are also used in black soil areas such as Canada and China. In some regions, gypsum may also be used as an S source, particularly in organic production (Photo 4.1.3c).

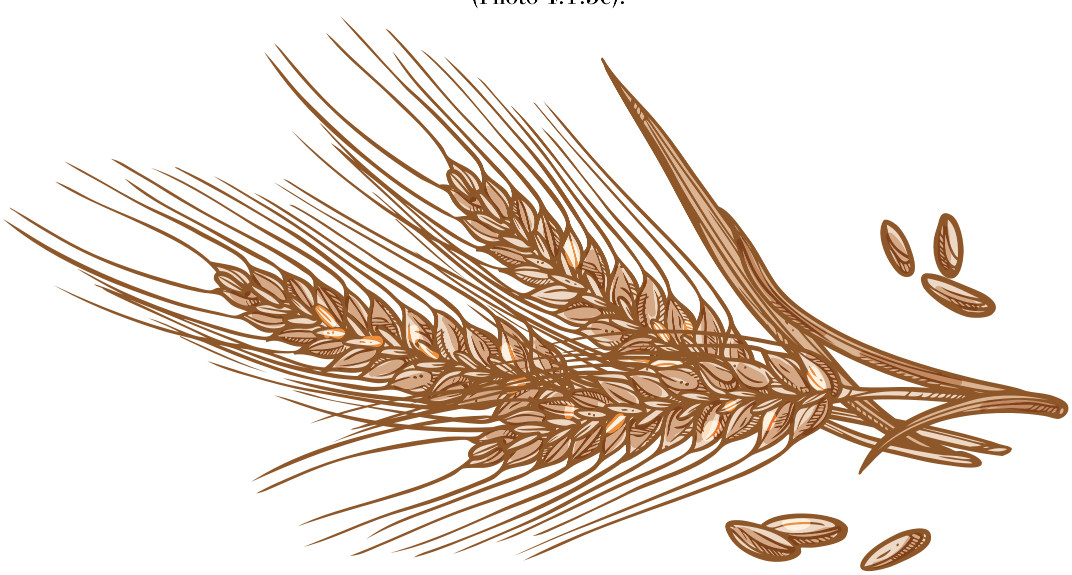

Photo 4.1.3c Nitrogen and phosphate fertilizers application, Indian Head of Canada

Range of applicability

The use of inorganic fertilizers has risen globally from 1960 to 2020. The growth of fertilizer use has been high in black soil regions of Asia. Fertilizer use increased across all the black soil regions including east Europe, northeast Asia, North America and South America. Over 80 percent of globally used fertilizers are made up of N, P and K whose 2020 cumulative demand was estimated at 115.3 million tonnes of N, 56 million tonnes of P and 36.7 million tonnes of K (FAO, 2020). For instance, chemical fertilizer is the main source of farmland nutrient input in China. In 2015, the consumption of chemical fertilizer in China reached 60.2 million tonnes, with the black soil area in the northeast accounting for 10.6 percent of the national fertilizer consumption (Li, Liu and He, 2017; Li, Liu and Ding, 2016).

Benefits of the practice

In comparison to a few studies where SOC was revealed to maintain or decrease after long term fertilizer application in black soils, other studies showed that additional manure application and optimized macro nutrition fertilization can increase SOC (Xie *et al.*, 2014; Ding *et al.*, 2012; Abrar *et al.*, 2020; Manojlović *et al.*, 2008; Russell *et al.*, 2005). Fertilizers also play a crucial role in improving the soil chemical properties and processes replacing deficient nutrients (macro and micronutrients). Among other functions, the basic cations (K^+, Ca^{2+}, Mg^{2+}) that are added with fertilizers are crucial for managing soil acidification. High ammoniacal nitrogen and sulfate fertilizers produce acidic reactions with a neutralizing effect on soil alkalinity.

Mineral fertilizer affects the physical properties of black soils. A combination of mineral fertilizers and organic manure and biochar can enhance the sequestration of SOC and improve soil physical environment such as aggregation and compared to the pure organic manure and mineral fertilizers in black soil regions (Chen *et al.,* 2010; Campbell *et al.*, 1986). It is important to note that in most cases inclusion of organic resources like manure resulted in better physical properties compared to mineral fertilizers.

Most of the biological benefits of fertilizer, including the micro, meso and macrofauna activities and processes are associated with SOM (Haynes and Naidu, 1998). Long-term studies have shown that application of NP and NPK fertilizers in addition to secondary and micronutrients reduce soil fungal, bacteria biodiversity and changed community composition in black soils of China (Zhou *et al.*, 2016; Wei *et al.*, 2008).

Globally, over 40 percent of crop yield is attributable to inorganic fertilizer nutrient inputs (Stewart *et al.,* 2005). The grain yield of most cereals could be doubled by applying the recommended rates of macronutrients as mineral fertilizers as well as in black soil regions (Pepo, Vad and Berényi, 2006; Kostić *et al.*, 2021; Campbell *et al.*, 2001; Liu *et al.*, 2001).

Sustainable use of mineral fertilization can address nutrient imbalance issues of black soils, but also can ease threats such as SOC loss and biodiversity losses if sustainably used.

Recommendations and potential barriers for adoption

Due to the dynamic nature of N, its content is highly variable in both space and time. For example, soil nitrate-N measured after harvest in fall autumn over a 12 year period in a semi-arid environment in the Canadian black soils varied from 21 to 44 kg N/ha, thereby significantly affecting N fertilizer application rates (St. Luce *et al.,* 2020). In black soils of northeast China, a study found that high levels of N fertilizer, 190 Kg N/ha and above, applied in the spring resulted in a large increase of soil nitrate-N at depth in the soil, demonstrating the need to manage N application rates to protect both ecological and soil health (Cai, Mi and Zhang, 2012). In addition, there is tremendous risk of acidification due to the widespread use of chemical N fertilizers. Application of nitrate-based rather than ammonium-based fertilizers can help to reduce fertilizer-induced acidity of black soils (Engel *et al.,* 2019).

An essential component of effective nutrient management is timely diagnosis of soil nutrient status. Soil testing is therefore a critical decision support tool for effective fertilizer management. It provides information on the nutrient balance and together with nutrient removal rates, will help guide fertilizer recommendations. Fertilizer application should take place at seeding or just prior to it. However, fertilizer application in late fall prior to soil freezing is quite common, especially with anhydrous ammonia (Tenuta *et al.,* 2016). Meanwhile, banding of N fertilizer has been shown to significantly reduce denitrification, ammonia volatilization, nitrate leaching, and increase N use efficiency (Gao *et al.*, 2015; Malhi *et al.,* 2001). Soil N supply is governed by N mineralization during the growing season and has proven difficult to accurately predict due to the complexity of this process, which is influenced by many biotic and abiotic factors. Nevertheless, in most countries, estimates of N requirements for various crops are available, which vary with soil type, local climatic conditions and other factors. These recommendations need to be periodically updated to account for varietal improvements through breeding, and changes in soil and crop management.

Technological advances in equipment, software and data processing including cost-effective sampling design and predictive soil mapping using machine learning, have provided more opportunities for measuring and monitoring plant nutrient and soil fertility, and overall health of black soils. Assessments as well as high-throughput laboratory techniques can rapidly and accurately assess several soil parameters that are integral for nutrient management in black soils. However, regional calibration data has to be collected in addition to existing global spectral libraries or soil libraries from countries and regions. The development of calibrations on black soils is a valuable line of research, with much to gain in terms of monitoring their degradation due to increasing pressures for food production and climate change.

Economic, social and physical limitations can hinder the adoption and implementation of sustainable fertilizer management and 4R principles. Interactions between producers and local agronomists, certified crop advisors, or researchers are instrumental in the adoption of the principles (Amiro *et al.,* 2017). Bruulsema, Peterson and Prochnow (2019) further suggested that the adoption and implementation of the principles "depend on engagement between science and industry not only at the farm level but along the full agricultural value chain".

In general, unlike other soils that require mineral fertilizers to be put into production, the black soils have a high fertility which means that they have high amounts of nutrients related to organic matter, such as N, P and K. In spite of this, the high production pressures that operate on black soils determines the need for nutrient replenishment, since many black soils already show signs of depleted fertility. Currently, black soils not only require adequate fertilization plans, but also the local adjustment of response models to the fertilization of the main crops produced, such as wheat and maize.

Biochar

Description of the practice

Biochar is a relatively recent term, used to name charred organic matter when it is applied to soil in a deliberate manner, with intent to improve soil properties and long-term carbon sequestration (Lehmann and Joseph, 2015). Pyrolysis is the most common technology employed to produce biochar. Biochar can and should be made from biomass waste materials. In black soil regions, biochar has been produced from maize and soybean straw or woodchip, but is normally added with manure or mineral fertilizers (Han *et al.*, 2019; Chathurika *et al.*, 2016; Yao *et al.*, 2017; Banik *et al.*, 2021) (Photo 4.1.3d).

Photo 4.1.3d Biochar application, Hulin city of China

Range of applicability

The addition of biochar to agricultural soils is receiving much attention due to the apparent benefits to soil quality and enhanced crop yields in black soil regions, as well as the potential to gain carbon credits by active carbon sequestration. The diverse physical and chemical characteristics of biochar make it a compelling and useful substance in a variety of applications, from smallholders to large-scale farming. It should be noted that biochars vary widely in properties depending on the feedstock and production conditions, so suitable biochar should be chosen to address the specific black soil constraints for each intended application. For instance, Charcoal, also known as black carbon or biochar, to refer to its soil quality enhancing properties and to deflect the link between charcoal, fire and forest loss, is considered a major contributor to the fertility of black soils in central Amazon (Glaser and Birk, 2012).

Benefits of the practice

Biochar contains organic matter and nutrients, and its addition can increase organic carbon, pH, total nitrogen, available phosphorus (P), available potassium (K) the cation-exchange capacity (CEC), readily available water (RAW) content, and decreased bulk density (BD).

In a Midwestern Mollisol of the United States of America, biochar application significantly increased soil pH, RAW content and SOC, availability of macro and micronutrients, and bulk density (Rogovska, 2014; Banik *et al.*, 2021). The manure-biochar incubation enabled biochar can stabilize the carbon and several nutrients from manure. The subsequent manure biochar mixture application to soil improved soil quality and plant nutrient availability compared to conventional manure application. In black soil region of northeast China, besides soil quality improvement by biochar amendment in terms of SOC, soil water, bulk density and available nutrition, soil bacterial community dynamics can also be shifted by biochar input and crop straw management, for example, soil fungal abundance increased with biochar addition (Qiao *et al.*, 2020; Yao *et al.*, 2017). In Canada, biochar application is not a practical management approach for improving soil fertility and nutrient cycling in surface Chernozems. Nevertheless, co-applying biochar with NP fertilizer appears to improve soil P availability in the short-term in Raymond and Lethbridge of Canada (Romero *et al.*, 2021).

Biochars could be used to solve both environmental and agronomic challenges and further improve the sustainability of animal and crop production agriculture. Biochar application can increase grain yield by 11 to 55 percent following very high stover application rates, presumably because biochar mitigated adverse effects of allelochemicals released from the decomposing maize residue. But during a severe drought, the effect of biochar on maize yield was limited (Rogovska, 2014). The result of a three-year project showed that the application of maize-straw biochar at a rate of 15.8 and 31.5 tonnes/ha had positive effects on crop yields in black soil areas (Jin *et al.*, 2020).

Inputting biochar benefits soil health through minimizing soil threats including SOC and biodiversity loss, compaction, nutrients imbalance.

Recommendations and potential barriers for adoption

Knowing the limiting factors of agricultural production in black soils of the country and understanding whether the desired results can be obtained with biochar is critical. Main characteristics of biochar must be considered when planning inputting biochar for its agronomic use, because once distributed, it cannot be removed from the soil. For example, research has indicated that application of corn straw biochar to soil at the rate of 400 g/kg can significantly increase soil pH, EC and resulted in decreases in CEC and exchangeable Ca^{2+} in comparison to untreated soil, then enhance soil salinization risk in black soils of northeast China (Meng *et al.*, 2021). To achieve the goals of biochar application discussed above, the choice of application methods depends on its physical and chemical properties as well as application amount.

The scale of production can be very different (medium, agricultural scale, kitchens) with very variable current costs. Optimal use of new technologies is only possible if they are rapidly adopted and widely disseminated. Although the increased yields of biochar production may be a boon to the new agricultural technology, the high costs can be a deterrent. As a result, before the widespread promotion of biochar systems, it is important to investigate the economic implications of biochar systems compared to conventional systems. The cost of using biochar in agriculture depends on the biochar application rate, the cost associated with transporting the biochar from the production plant to the experimental field and the value that can be derived from the energy produced.

4.1.4 Crop diversification

Many areas covered by black soils are managed under extensive agriculture, based on two or three annual crops (such as wheat, maize or soybeans). This trend to limited crop diversity resulted in a loss of biodiversity and soil physical deterioration (Peralta, Alvarez and Taboada, 2021). Crop diversification is a suitable tool to avoid overly simplified agricultural models, and to improve the quality of soil structure. Diversifying the cropping system is already being practiced by agricultural producers to overcome crop production challenges, such as high land values, increased input costs, varying weather factors, and increased demands for new products. Especially in black soil areas, long-term monocropping system such as maize and soybeans that damage soil health and food security. Thus, sustainability concerns have raised interest in crop diversification among agricultural producers, especially throughout the black soil areas.

Crop diversification means growing more than one crop in an area. Diversification can be accomplished by adding a new crop species or different varieties, or by changing the cropping system currently in use. Commonly it can mean adding more crops into an existing rotation. It can also include an integration of crops and livestock, defined as mixed farming. Crop diversity encompasses several aspects, such as crop species diversity, varietal diversity within crop species, and genetic diversity within crop species. It is recognized as one of the most feasible, cost-effective, and rational ways of developing a resilient agricultural cropping system.

Crop rotation

Description of the practice

In black soil regions, farmers using different species (mainly legumes) as precedents of the main crop (most often winter cereals) resulted in some increases in grain yields and improvement of soil quality. Nowadays, crop rotations are a common practice and, in some socioeconomic contexts are encouraged by agricultural policies in black soil areas. Scientific research has revealed that the benefits of this practice are due to improved resources use efficiency, increased N supply by legumes, and the breaking of pest cycles (Ryan *et al.*, 2008) (Photo 4.1.4a).

Photo 4.1.4a Crop rotation (soybeans and wheat), Russian Federation

Range of applicability

The use of crop rotations in permanent croplands can be ubiquitous, although a high degree of crop diversity is usually hindered by pedoclimate and socioeconomic limitations in black soil regions. Low temperatures and snowfall during autumn and winter months restricts crop cultivation until spring. In turn, different soil characteristics can limit the range of crops to be chosen for rotation. A clear example is the role played by soil pH on some crops. For instance, legumes are well adapted in slightly acidic to neutral soils whereas they grow poorly in alkaline black soils.

As stated, socioeconomic factors also play a major role in the use of diverse crop rotations in black soil areas. Since the advent of industrialized agriculture and the availability of synthetic fertilizers, cereal monocropping (i.e, wheat, maize, rice and barley) have been dominant in black soil regions. The specialization of industrial farms to only a few commodities and the lack of financial support to invest in different machinery also impede adoption by farmers in black soil regions.

Benefits of the practice

Crop rotation is closely linked to the diversification of production models. The design of a rotation is determined by the availability of water and the agroclimatic characteristics. The areas covered by black soils are under the threat of very simple rotations, with a tendency to monoculture, which favours not only the loss of fertility, but also the proliferation of resistant pests and weeds. It is necessary to design crop rotations with a greater presence of grasses (wheat, barley and corn), whose root system favours the development of stable aggregates in the soil. Specifically, soil physical properties are improved significantly when using diverse crops through a variety of mechanisms, which impact on soil structure. Some perennials such as alfalfa are used in in the rotation system of black soil areas, as they have a tap-root able to reach to very deep soil layers, enhancing the use of remnant soil water and nutrients, reducing drainage and N leaching. Moreover, legumes such as soybeans present higher activity in the rhizosphere (the environment close to the roots where most of soil biological activity occurs) and greater root exudation.

Regarding soil chemical properties benefits of rotation practice, soybean rotated with other crops that produce high amounts of residue improved soil fertility and thus had good potential to increase soybean yield and profitability in black soil regions of the Russian Federation and Canada (Zentner *et al.*, 1990; Stupakov *et al.*, 2019). And a long-term research of crop rotation leading to an increase of the ratio Cha: Cfa in (humic acids to fulvic acids) has been observed in Ukraine (Hospodarenko *et al.*, 2018).

Crop rotations also lead to improved soil biological properties of black soils. In the case of the northeast China black soil region, soil bacterial communities remarkably differed between maize monocropping and maize soybean rotation in both bulk and rhizosphere soils, and that bacterial abundance and community diversity were significantly higher in rotation than in monocropping. Compared with continuous cropping of soybeans, crop rotation increased bacterial abundance and diversity and altered the community composition both in the bulk and rhizosphere soils such as increased nematode abundance and their functional metabolic footprint (Zhang *et al.*, 2015; Liu *et al.,* 2017).

The benefits of crop rotations in terms of an increase in productivity for subsequent crops have been known in black soil regions. Crop rotations present different socioeconomic benefits. Inclusion of a grass legume forage crop or a legume green manure crop in the rotations with cereals produced consistent yield benefits. Yields of wheat grown on fallow after being cropped to legumes or grass legumes, and without the application of N or P fertilizer, were often higher than yields obtained in the well-fertilized monoculture wheat rotations. Furthermore, adopting diversified crop rotations, together with minimum and zero tillage management practices, will enhance non-renewable energy use efficiency of annual grain production in this sub-humid regions (Zentner *et al.*, 2004). For instance, the maize soybean rotation produced better yield and profitability, particularly in dry years, than monocropping system in the black soils of northeast China (Fan *et al.*, 2012). In the black soil region of Canada, soybeans that were rotated with other crops that produce high amounts of residue, improved soil fertility and thus showed good potential to increase soybean yield and profitability (Zentner *et al.*, 1990).
In summary, crop rotations provide multiple benefits that can address soil threats in terms of SOC and biodiversity loss, nutrients imbalance, compaction and pollution.

Recommendations and potential barriers for adoption

One of the most dramatic effects of crop rotation on soil C is how maize tends to increase soil C while soybean tends to lower soil C. This is one reason why crop rotations in the United States of America mid-west was dominated by maize, and not soybeans, in order to capture the highest soil C contents. The black soil zone of Canada includes crops with a range of C contents and C:N ratios. The two dominant grain crops, wheat and canola, tend to have high C:N ratios. Substituting oats for wheat reduces the C:N ratio of the rotation since oat has more N in straw than wheat. Adding pulses such as peas and lentils to the rotation further decreases the C:N ratio. Soybeans is unique among grain legumes in that its residue is very high in C, much higher than pea or lentil.
Before establishing any crop rotation, the pedoclimatic limitations to the different crops must be analyzed and taken into account. Potential markets must be explored and, if possible, secured before establishing alternative or neglected crops. These last should be implemented in small fractions of the available land.

Perennial crop

Description of the practice

Perennial crops are crops that, unlike annual crops such as cereals, don't need to be replanted each year. After harvest, they automatically grow back. Many fruit and nut crops are naturally perennial. The perennial crops provide an option to diverse cropping system and benefit properties of black soils, and is being used in the black soil zone of Canada and the United States of America (Entz *et al.*, 2002; Ryan *et al.*, 2018) (Photo 4.1.4b).

Photo 4.1.4b Perennial crops (Kernza), Canada

Range of applicability
The practice is applicable worldwide under a wide range of pedoclimatic conditions. The most suitable locations are those with degraded black soils on sloped land and ecologically sensitive areas that need to build soil health in terms of SOC, reducing erosion.

Benefits of the practice
Growing perennial grains for several years can regenerate soil health before rotating to annual crops. While growing perennial grains on sloped land and ecologically sensitive areas can reduce soil erosion and nutrient losses, hence providing both provide ecosystem services and supporting multifunctionality. For example, perennial legumes in rotation also reduce energy requirements by adding significant amounts of N to the black soils.

One perennial crop innovation since 2002 is "Perennial wheat" or Kernza (Thinopyrum intermedium) (Dick, Cattani and Entz, 2018). Adapted Kernza lines have now been developed (Cattani, 2019), and are being grown on a limited acreage, sometimes as a dual purpose grain and forage crop. Kernza has a particularly large root system, which will add to subsoil C in black soil zone cropping systems (Pugliese, Culman and Sprunger, 2019). In conclusion, inclusion of perennial crops is a good practice to address soil erosion and SOC.

Recommendations and potential barriers for adoption

Strategies that enhance multifunctionality are expected to play a major role in addressing limitations associated with low grain yields. Some management strategies can be combined to achieve greater functionality, such as growing perennial cereals with legumes for grain and forage on land that is sloped.

Because perennial grains are fundamentally different from annual grain or perennial forage crops, farmers need new information about management practices to optimize their production. Functionally diverse perennial grain polycultures can also provide a high level of ecosystem services, but, research is needed to identify combinations of perennial grain crops that are compatible and production practices that minimize management complexity.

4.1.5 Water conservation techniques

Description of the practice

Agronomic practices that can be implemented to control water erosion on cropland include residue management, conservation tillage, contour farming, crop rotation and cover crops (Weesies, Schertz and Kuenstler, 2017). Under tropical black soils in Brazil, soil erosion from precipitation has been successfully reduced by combining crop rotation, no-till, and permanent soil covering (Freitas and Landers, 2014). Those agricultural practices were discussed in previous sections. There are also several different irrigation methods used by producers around the world including: intermittent irrigation in rice, which allows the water level in the paddy to drop to low levels before being replenished; traveling lateral sprinkler systems that irrigate large fields to reduce cost per unit area; this necessitates high instantaneous application rates to meet crop water requirements over the entire field (Sojka and Bjorneberg, 2017); sprinkler systems, particularly centre pivots that operate on variable slopes and topography. Slope direction relative to the lateral affects how runoff accumulates; and in drip irrigation, where water is directly applied to the crop roots using a pressurized pipe system (Photo 4.1.5).

Photo 4.1.5 Drip irrigation, Kherson of Ukraine

Range of applicability

Both agronomic practices and irrigation systems practices are applicable to all black soils including arable lands, croplands, permanent crops and pastures. The structure of the vegetation in those practices determine their efficacy at a given location. They can be typically designed to achieve multiple objectives depending upon the land slope, topographic and climatic conditions.

Benefits of the practice

One of significant factors in the transformation of black soils is soil water management. It changes the main factors of soil formation, connections with the environment, and determines the subsequent evolution of soil cover. The specific changes depend on the quality and volume of soil water supply to the fields, climatic and hydrogeological conditions of irrigation development regions, the original properties of soils, irrigation equipment and technology, and current production practices. The changes can improve moisture supply, a positive balance of humus, macro and micronutrients, increased fertility, and balance soil pH (Baliuk *et al.*, 2017).

Intermittent irrigation in rice, increased storage of rainwater by reducing runoff water by 56 percent and reduced irrigation water use by 22 to 76 percent resulting in a 15 to 346 percent increase in water use efficiency (Avila *et al.,* 2015). The grain yield of the rice was not impacted by the irrigation method used in this study.

In traveling lateral sprinkler systems, sprinkler type, nozzle pressure, and nozzle size influence runoff and soil erosion by affecting application rate, wetted area, and droplet size. Low-pressure sprinklers, which reduce energy costs, have smaller pattern widths and therefore greater application rates (Jat *et al.,* 2009; Tahat *et al.,* 2020).

In drip irrigation, water is conveyed under pressure through pipe and released as drops or drips directly to soil on the field through emitters or drippers. The spacing between emitters depends upon the plant spacing. Only the immediate root zone of each plant is wetted. Therefore, this can be a very efficient method of irrigation with a low risk for soil erosion. However, this is a very capital and labor intensive system.

To summarise, soil water management and irrigation approaches can provide good opportunities to address soil erosion, SOC loss, and nutrient imbalance.

Recommendations before implementing the practice

Managing the full range of water supply on black soils from drought to periodic flooding requires several different approaches. Excess moisture can reduce the timeliness of seeding, while no-till and residue can increase moisture retention and reduce soil temperatures. A crop such as maize is particularly sensitive to this problem but even other crops such as wheat and canola can also be affected. Even in regions that tend to have excess moisture at seeding, water management is important due to the high likelihood of the crop experiencing moisture stress at some point during the growing season. No-till often increases crop yields and water use efficiency under dry conditions but can result in reduced yield under wet conditions (Azooz and Arshad 1998; Arshad, Soon and Arooz*,* 2002).

In the regarding of traveling lateral sprinkler systems, application rates for centre pivot and lateral move irrigation systems often exceed the soil infiltration rate meaning that runoff is a potential problem. Besides the irrigation methods, the water resource quality should be also considered during the decision making procedure. For example research results showed that there has not been any major detrimental effect on soil due to irrigation, but constant control of the quality of water for irrigation was necessary, as well as constant monitoring of the chemical properties of the irrigated soil (Choudhary and Kharche, 2018; Bilanchyn *et al.*, 2021). In general, as the climate becomes more arid, there is increased effectiveness of no-till in maximizing water use efficiency and grain yield of crops grown on black soils. This trend does appear to hold true in the midlatitude black soils of South America.

4.1.6 Biomass management

Description of the practice

Generally, crop straw amendment (SAT) is considered as the most effective method to increase soil carbon storage and crop yield through biomass management, especially in flat fields (Photo 4.1.6).

Other beneficial practices for biomass management including crop rotation that providing biomass with a high C to N ratio and cover crops that providing good quality and quantity biomass to soils.

Photo 4.1.6 Biomass management, Zhaoguan county of China

Range of applicability

Biomass use based on crop residues is applicable to any type of pedoclimatic context. Agroecosystems with greater net primary productivity pose fewer limitations to the availability of sufficient crop residues. Climate conditions such as temperature and soil moisture can impact biomass decomposition and seeding resulting in adjustment of biomass management practices. Besides this, in these and other regions the competition for crop residues for other purposes such as fodder, fuel or construction material further limits the potential to biomass management. The percentage of biomass that can be removed and returned differs as you move to wetter or dryer regions or a region with a shorter or longer winter.

Benefits of the practice

Surface residues due to biomass return can control erosion, but the amounts vary depending on soil texture and field slope. In the black soil zone, the amount of residues required to control water erosion increases with field slope, with estimates of 0.8 to 1.15 tonnes/ha on 6 to 9 percent slopes and 1.15 to 1.7 tonnes/ha on 10 to 15 percent slopes. Having the harvesting residue results in soil loss, particularly on fields with steep slopes (Gregg and Izaurralde, 2010). Harvesting residues decreases crop yields, under both conventional and conservation management, although less so under conservation management. Biomass retained provide higher soil C, total P, soluble and labile forms of inorganic and organic soil P compared with the biomass removed (Hao *et al.*, 2022; Li *et al.*, 2022). For instance, straw return influenced the dynamics of available nitrogen and phosphorus, and increased yield of crops (Zhang, Wang and Sheng, 2018). Labile organic carbon fractions were also more sensitive to different forms of straw return in Mollisol black soils (Li *et al.*, 2022).

Biomass management practice through rotation can optimize C:N ratios. In the black soil zone of Canada, the two dominant grain crops, wheat and canola, tend to have high C:N ratios. Substituting oats for wheat reduces the C:N ratio of the rotation since oat has more N in straw than wheat. Adding pulses such as peas and lentils to the rotation further decreases the C:N ratio. Soybeans is unique among grain legumes in that its residue is very high in C, and much higher than pea or lentil.

Biomass management has also been shown to moderate the near-surface soil and air temperature (Thiessen Martens *et al.*, 2001; Kahimba *et al.*, 2008).

Biomass management is a very crucial practice that can address many soil threats such as SOC and biodiversity loss, erosion, nutrients imbalance, acidification, and compaction.

Recommendations before implementing the practice and Potential barriers for adoption

In black soils of cold regions, the returned straw in the soil cannot complete degrade. The rate of biomass return should be considered according to the ecological condition. Incompletely degraded straw in the soil could block the emergence of seeds in next crop season. Furthermore, biomass management can impact soil moisture and microclimate as well. Studies in Canada have reported that productive cover crops can reduce soil moisture (Blackshaw, Molnar and Moyer, 2010; Kahimba *et al.,* 2008; Thiessen *et al.,* 2001). Depletion of soil water by the biomass management can be a benefit in wet years.

4.1.7 Integrated systems

Organic cropping system

Description of the practice

Organic cropping can occur in any of the above cropping systems in black soil areas but two restrictions are added: no chemical pest control and no addition of mineral fertilizers to supply nutrients to the crop. These restrictions increase the skills needed to conserve black soils in an organic farming system. The traditional method to control weeds in an organic cropping system has been to add more cultivation for eradicating weeds to the cropping system, which can increase the risk of soil degradation. Currently, two approaches are being explored and implemented to mitigate this increased risk to the soil, reducing tillage and improving soil physical and biological parameters. Research on reduced tillage in organic cropping systems has been conducted in black soil regions (Vaisman *et al.,* 2011; Podolsky, Blackshaw and Entz, 2016). Tools, such as the blade roller, have allowed vegetation to be managed and organic crops to be no-till seeded for multiple years (Halde, Bamford and Entz, 2015) (Photo 4.1.7a).

Photo 4.1.7a Organic no-till farming system (barley and spring wheat), Manitoba of Canada

Range of applicability
There is a worldwide applicability as the pedoclimate limitations are identical to all forms of agriculture in black soil areas.

Benefits of the practice
Legume cover crops included in organic farming system of black soils are particularly useful at improving soil physical (e.g aggregation) (Stainsby *et al.,* 2020) and biological parameters (Lupwayi *et al.,* 2018), and can provide a slow-release form of N for following crops (Thiessen Martins, Entz and Hoeppner, 2005). Thorup-Kristensen *et al.,* (2012) found that the addition of green manure cover crops resulted in an almost doubling in the average soil exploration by active root systems. Greater soil exploration was linked to greater subsoil inorganic N content (Thorup-Kristensen *et al.,* 2012). To sum up, an organic cropping system benefits soil health and addresses soil biodiversity loss, nutrient imbalance, and compaction.

Recommendations and potential barriers for adoption
The current level of practices implemented to protect black soils in organic cropping systems vary greatly from region to region and farm to farm within a region. The management required to implement cropping practices to protect soils in organic farming tend to be higher than in most conventional systems; however, producers utilizing an organic production system tend to be highly motivated to protect and improve their soil. In conclusion, organic agriculture is adequate for the management of soils, but requires fertility management based on organic and biological fertilizers, as well as biological pest control. These requirements make it difficult to adopt on a large scale, as is the case for the extensive production of annual crops such as soybeans, wheat, and maize.

Grassland conservation and restoration

Description of the practice

A good part of the world's black soils was formed under the influence of grassland vegetation (Photo 4.1.7b). Being replaced throughout time to produce annual crops. The periodic rotation of these annual systems with pasture periods favours the black soils to recover their original fertility, at least as regards organic matter and the quality of the structure. Grazing intensity and the regulation of stocking rates have been identified as one of the most important management practices to maintain or improve the quality of black soils (Sollenberger *et al.,* 2012). Some of the most common methods of measuring grazing intensity are stocking rate (animals/ha for a specified period of time), forage allowance (ratio of forage mass (kg/ha) to animal live weight (kg/ha), and grazing pressure (animal live weight kg/ha) to ratio of forage mass (kg/ha) (Allen *et al.,* 2011).

Stocking method is the manipulation of how, when, what and how much the animals graze. Rotational stocking and deferred stocking are two stocking methods discussed the most in conjunction with soil conservation (Allen *et al.,* 2011). Rotational stocking utilizes recurring periods of grazing and rest among three or more paddocks in a grazing management unit throughout the time when grazing is allowed. A key concept of deferred stocking is that the deferment is a conservation practice for restoring and maintaining the desired condition of the grazing land. It is not a practice to increase livestock production within a stocking season.

Other main grassland management practices include management of herbivore type, plant cover and plant species.

Photo 4.1.7b Grassland conservation and restoration, Municipally of Quaraí, Rio Grande do Sul state, Brazil

Range of applicability

The practices are applicable worldwide under a wide range of pedoclimate conditions where black soils dominated. Grassland a cold temperate zone is particularly suitable to those practices such as the east European plain, central Great Plains of North America, and pampas in South American.

Benefits of the practice

Modifying grazing intensity can reduce soil erosion, improve ground cover, C sequestration and plant vigor (Sollenberger *et al.,* 2012; Zhou *et al.,* 2017). It is also important in managing water quality (Van Poolen and Lacey, 1979) and species diversity (Herrero-Jáuregui and Oesterheld, 2018). Forage species, which affected the time of water use during the season, had more impact on soil water content than grazing intensity (Twerdoff *et al.,* 1999b). However, higher grazing intensities tended to have greater soil water content in the upper 7.5 cm of soil than lighter grazing intensities. This indicates that higher leaf areas observed in lighter grazing treatments utilized more soil water due to greater evaporative surfaces than heavier grazed treatments, which had lower leaf areas (Baron *et al.,* 2002).

The preference of different herbivores for grass, forbs and legumes can impact the species present in a pasture (Dumont *et al.,* 2011). Grazer effect on soil C storage exhibits substantial variability and depends on both herbivore assemblage and characteristics of grazed grassland (Chang *et al.,* 2018). This indicates that the interaction between herbivore type, plant species and grazing intensity may be region-specific and difficult to predict simple management practices over a wide range of environmental conditions.

Maintaining plant cover on a grazed landscape is important for protection of the soil, nutrient management, and a healthy microbial diversity. Research in Colorado, United States of America on a shortgrass steppe found that soils under plants had consistently higher C and N mineralization rates and, in some cases, higher total and microbial C and N levels than soils without plant cover (Vinton and Burke, 1995). They also found that soils under bunchgrasses tended to have higher C mineralization and microbial biomass C than soil under the rhizomatous grass, *Agropyron smithii*.

In a soil conservation context, stocking method can be used to ensure that soil cover is maintained and to protect soils when in a fragile state such as compaction of water saturated soils during a period of the year.

Overall, SOC and biodiversity loss and nutrient imbalance can be minimized by the practice of grassland conservation and restoration.

Recommendations and potential barriers for adoption

Overgrazing occurs when plants are exposed to intensive grazing for extended periods of time, or without sufficient recovery periods. It reduces the usefulness, productivity, nutritional value for livestock and biodiversity of the land, and can lead to the loss of ground cover, compaction, and soil erosion and reduced soil health. In addition, overgrazing can increase the occurrence of invasive species such as *Eragrostis plana*, which take the place of high quality native forage plants in the pampas of South America (Focht and Medeiros, 2012). Overgrazing is currently occurring in many regions. In Mongolia, the number of livestock increased by 265.3 percent between 1961 and 2019 and 11 percent of the total pastures were overgrazed (Unified Land Fund Classification Report, 2019; Research Conference material, 2015).

On the black soils studied by Twerdoff *et al.,* (1999a), as grazing intensity increased so did bulk density, but the maximum bulk densities attained did not reach levels considered limiting to productivity or sustainability in either perennial or annual pastures. Compaction in the pasture soil surface (0 to 2.5 cm) increased rapidly early in stand life, but levelled out with increasing stand age (Mapfumo *et al.,* 1999; Twerdoff *et al.,* 1999a). It appeared that annual pastures compacted (between 0 to 10 cm more) more rapidly than perennials, but generally bulk density for both annual and perennial pastures followed a quadratic relationship with cumulative cow-days and leveled off after about 40 to 60 cow-days over years and grazing cycles. Since the production of biomass is important to protect and improve the soil, sites that are more productive with higher rates of biomass tend to be more tolerant of the impacts of grazing intensity (Eldridge *et al.,* 2017; Schönbach *et al.,* 2011) and other management practices. Along with other management strategies, such as reseeding, weed control and prescribed burning, deferred stocking can furthermore improve the response of desired vegetation and, over time, increase animal production potential (Allen *et al.,* 2011). Other stocking methods can be utilized to address specific issues in specific environments (Bailey, McCartney and Schellenberg, 2010).

In this section, we presented a global-scale assessment of sustainable practices for promoting black soil health, ensuring food security, mitigating climate change and overcoming constrains. We find that SOC sequestration is significantly increased in black soil cropland through practices such as non-inversion tillage, no-till, manure additions, biochar, biomass management, and the management practices that are needed to maintain SOC considerably by organic mulch, perennial crops, no-till strip tillage, soil and water conservation techniques. Besides SOC, there are large opportunities to increase chemical, physical and biological properties by cover crops, organic mulch, no-till, no-till strip tillage, manure additions, while still allowing increase in production of major cereals. Meanwhile, practices such as over crops, a crop-livestock farming system, and no-till showed good performance in mitigating climate change with reduction of greenhouse gases from soil. Fertilization is another story. With sustainable management, chemical and mineral fertilizer inputs in terms of macro and micro nutrition can provide sufficient nutrients for crop growth with resulting in good yields and limited environmental damage. In addition to cropland, grassland management practices such as grazing intensity and plant cover can reduce soil erosion and improve C sequestration, while different herbivores can improve soil C storage. To this end, meeting the global food security and sustainability challenges of the coming decades through black soils is possible, but will require considerable changes in sustainable crop system, nutrient, tillage, and water management.

In theory, black soils are suitable for most cropping systems such as rotation, perennial and organic with any crops in both small and large scale farmlands. A diverse cropping system in black soils can provide better ecological services that maintain and increase productivity and mitigate negative impacts.

By targeting measures that minimize soil threats, sustainable management practices in black soil areas can address SOC loss, nutrient imbalance, biodiversity loss, compaction, and erosion. It is obviously those issues are fundamental to black soil protection especially in the aspect of crop production. However, it is difficult to find research and knowledge to address soil acidification, salinization and soil pollution. The reason could be that not all black soil areas are endangered by those soil threats. But, those three threats can damage black soil productivity and health in the longer term.

The future of black soil protection faces two great challenges: substantial increases in food demand must be met while mitigating soil threats. The sustainable use black soils with beneficial field practices and building suitable cropping systems are necessary strategies towards meeting these challenge, but they must be combined with efforts of awareness raising, education, extension and monitoring. Thereforeti is vital that independent policies and agricultural development programmes must address all black soil threats through good practices and cropping system.

4.2 Relevant policies for the protection, conservation and/or sustainable management of black soils

In order to achieve the goal of protecting black soils, legislation at both global and national levels need to be developed and implemented, supported by a monitoring framework to track the dynamics and status of black soils. There are a number of national soil policies that are relevant to the management, protection and conservation of soils (Table 4.1) but very few are specific to black soils.

Given the importance of black soils for food security and nutrition, climate change mitigation and adaptation, and their value as a limited natural resource, there is a need to consider the following:

- The definition of "black soils" coined by the International Network of black soils should be widely used when referring to black soil legislation.
- A global agreement towards the sustainable management, conservation and protection of black soils is much needed.
- The degradation of black soils should be halted, particularly addressing the main soil threats: soil erosion, loss of soil organic carbon and soil sealing.
- A global programme to restore black soils should be established with the understanding that this is a limited natural resource.
- Capacity development needs to become an important instrument of a global technical cooperation programme between countries that have black soils.

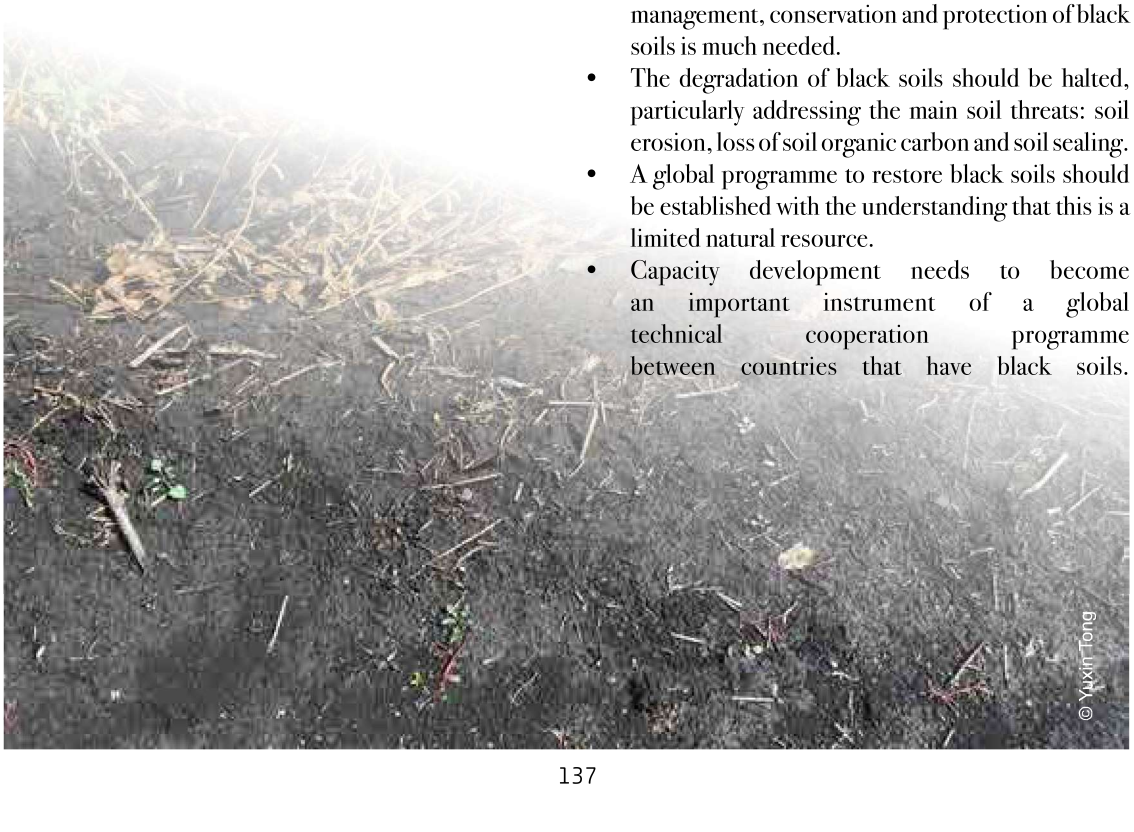
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Table 4.1 Legislation, programmes and institutional constraints of the countries for the protection, conservation and/or sustainable management of black soils

Source: Author's elaboration and legal instructions of black soil countries in Annex 1

Country	Availability of specific legislation on black soils	Legislation and regulation related to black soils	Research and programmes at national level on soil protection	Policy and institutional constraints for the conservation of black soils
Canada	No	At present, black soil conservation policies are created and initiated at various levels of government. More specifically, soil conservation related legislative acts such as Alberta Soil Conservation Act (Government of Alberta, 2011) and other provincial government incentive programmes (Government of Manitoba, 2008; Government of Saskatchewan, 2020) were initiated.	Every five years, the Programme reports on the health of the Canadian agriculture and agrifood system for the last 30 years (1981 to 2011) where it is used to compare Canada's agri-environmental performance. Among many agri-environmental performance indicators, soil cover as reported by the soil cover indicator has shown dramatic improvements.	In 1984, a report titled "Soil at Risk – Canada's Eroding Future" by the Standing Senate Committee on Agriculture, Fisheries and Forestry was published but a lot has changed since then. Climate, environment, agriculture management, new crops and increased production demand have posed new challenges in soil (including black) conservation.
Mongolia	No	At present, there are over 8 legal laws relevant black soil protection implemented in crop area of Mongolia (e.g Law on Land of Mongolia, 2002; Law on Agriculture of Mongolia, 2016).	"Sustainable development concept of Mongolia-2030" is fundamental for the sustainable development of soil for food production and agriculture including black soil management.	No long-term policy strategies specific focus on improving soil fertility and reducing erosion.
Uruguay	No	The soil conservation law was updated in 2008 and effectively applied from 2013. The Uruguayan law is based on the principle that soil conservation is of general interest, over any particular interest.	The Soil Use and Management Plan (SUMP): i) precise geographic location, ii) description of the rotation to be made, iii) projected yields of the different crops, and pastures in the rotation, iv) dominant soil type in the polygon, and v) topographic characteristics defining length and slope (LS) in USLE/RUSLE.	Despite using no-till (NT), the new cropping intensification was made by abandoning the rotation with pastures, going back to continuous cropping. These changes resulted again in soil erosion problems.

Country	Availability of specific legislation on black soils	Legislation and regulation related to black soils	Research and programmes at national level on soil protection	Policy and institutional constraints for the conservation of black soils
Brazil	No	National legislation of soil conservation apply to black soils. In July 1975, the law on mandatory soil conservation planning and erosion control was approved (Brazil Government, 1975). In August 1981, the National Environment Policy, highlights the rational use of soil, subsoil, water and air, and includes soil conservation in the national policies (Brazil Government, 1981).	Any action for the usage and management of rural soils, including black soils, must be carried out through planning, based on the concept of land use capacity or agricultural suitability, requiring the application of conservation practices validated by official research institutions.	Instruments proposed for the use, management, recovery and conservation of soil and water should consider the current conditions, changes in land occupation, and their limitations or potential.
Thailand	No	There are two types of regulatory documents that are related to soil conservation: Land Development Act and Land Use Plan.	The Land Use Plan of Thailand 2019 was formulated in response to the strategic framework of Thailand's 20-year National Strategy, which covered land suitability analysis and land potentials evaluation.	Legislation is being set forth the whole country on agricultural land preservation; such a policy should be implemented with awareness.

Country	Availability of specific legislation on black soils	Legislation and regulation related to black soils	Research and programmes at national level on soil protection	Policy and institutional constraints for the conservation of black soils
China	One national law, two provincial legislations targeting black soil protection	The 35th meeting of the Standing Committee of the 13th National People's Congress adopted the National Law of the Black Soil Protection on 24 June 2022. The law includes 34 regulations in terms of determining the scope of protection, assessment, monitoring, penalties, and ensure utilization as arable land; Jilin province has carried out the local legislation on the protection of black soils from 2016 including planning and evaluation, specific protection measures, supervision and management, legal liability, and bylaws, stipulation. Heilongjiang province enacted a local regulation on black soil protection in terms of use and planning, conservation and restoration, construction and utilization, monitoring and evaluation, supervision and management, legal liability.	The Ministry of Agriculture and Rural Affairs (MARA) has recently launched a plan of action for conservation tillage in the black soil area, and released the "National Black Soil Protection Project Implementation Plan (2021-2025)".	More efforts should be focused on the protection scope clarification, the development of protection mechanism, establishment of protection system, and construction of a legal liability system.

Country	Availability of specific legislation on black soils	Legislation and regulation related to black soils	Research and programmes at national level on soil protection	Policy and institutional constraints for the conservation of black soils
Bulgaria	No	Legal instrument in Bulgaria towards protection of soils is the hierarchy of norms, the principle of intelligibility and accessibility of the law in force. The elements of the legislation are contained in the following normative acts: The Law on Soils, the Act for Protection of Agricultural Land, and the Environmental Protection Act.	The Rural Development Programme (Bulgaria Government, 2014), especially now in the second programming period 2013–2020, supports and financially stimulates (subsidies / compensatory payments) activities in agriculture and rural areas related to environmental protection – soils and waters, and EU Natura 2000 protected areas network zones.	The analysis of the existing legislation in Bulgaria regarding the assessment of the impact on the soils including black soils shows the lack of uniform procedure according to the criteria; from these facts it can be inferred that fragmentation has been observed.
Poland	No	The Act on the Protection of Agricultural and Forest Land (Poland Government, 2017) is aimed to protect mineral soils of high quality and all organic soils located on the agricultural land in Poland.	The contamination status of arable soils is monitored every 5 years since 1995 within the countrywide national Programme "Monitoring of the chemistry of arable soils" (Poland Government, 1995).	The black soils have no special evaluation criteria but like other arable soils have to fulfill the strict criteria stated in the regulation (Poland Government, 2016).
Türkiye	No	The purpose of the Law 5403 is to determine the principles and procedures that will ensure the protection and development of the soil resources including black soils and ensure their planned use in accordance with the environmental priorities and sustainable development principles (Türkiye, 2005).	In order to protect soils, two main mechanisms were adopted (Article 5, 6 and 12) as 1) the establishment of the ''soil protection board (SPB)'' in each province 2) Preparation of Soil Conservation Projects (SCP).	Need to strengthen the coordination between different governmental bodies and distributed structure of soil information were the main challenges to implement the Voluntary Guidelines on Sustainable Soil Management (VGSSM)

Country	Availability of specific legislation on black soils	Legislation and regulation related to black soils	Research and programmes at national level on soil protection	Policy and institutional constraints for the conservation of black soils
Russian Federation	No	The regulatory documents on black soil conservation can be grouped into three categories.1) Related to the sustainable management of black soils, there is one document, namely: The code of a conscientious land user and it is adopted in the Belgorod administrative region; 2) related to the SSM of agricultural lands; 3) related to the protection of fertile topsoil in the areas subjected to construction, mining, geologic survey and other types of activity that pollutes or destroys the topsoil.	The federal target Programme "Preservation and restoration of soil fertility of agricultural lands and agrolandscapes as a national treasure of Russian Federation started in February 20 2006.	Additional research is required for a clearer categorization of the excess of the content of heavy metals and toxic elements; Comparison of the indicators of the contaminated upper fertile layer with the background values is also used, but the selection of the background territory is an obstacle, since the indicators can be varied much from it.
Slovakia	No	Laws relevant to black soil protection in Slovakia include the Protection and Use of Agricultural Soil (Soil Protection Act), Water Act, the Act for the Application of Sewage Sludge, Land Consolidation Act, The Act on Environmental Impacts Assessment.	Soil Service within the Soil Science and Conservation Research Institute (SSCRI) is responsible for collecting data on the soil quality in Slovakia and ensures that the owners/tenants comply with the provisions of the Soil Protection Act.	Prescribe measures and activities should be easy to be understand that the owners or tenants of the land can undertake in order to rectify the situation.
Ukraine	No	The Land Code of Ukraine is the basic national regulatory document in the field of owning, use, and disposal of land (Ukraine, 2002). Article 150 of Land Code of Ukraine has established the special legal status of black soils. All kinds of black soils are considered "especially valuable land" (EVL).	According to of the Ukrainian Law "On land protection", agrochemical surveys are systematically carried out in agricultural land in order to control the dynamics of soil fertility. Initial and current levels of key soil indicators are recorded in the special agrochemical passport (Ukraine Government, 2003b).	Currently the large areas of black soils in Ukraine are heavily affected by war events leading to extensive contamination, compaction and degradation in general.

19 | National Implementation Plan for Black Soil Protection

Black soil monitoring, Nenjiang County of China.

Soil management is sustainable if the supporting, provisioning, regulating and cultural services provided by soil are maintained or enhanced without significantly impairing the soil functions that enable those services or biodiversity. Conservation tillage is a sustainable soil management (SSM) practice that uses crop straw mulching and no-till, which can effectively reduce wind and water erosion of soil, enhance soil fertility, increase moisture retention and drought resistance, and improve agro-ecological and economic benefits.

The Chinese Government plans to vigorously promote SSM practices in terms of conservation tillage and other technologies on black soils in the northeast region. The Ministry of Agriculture and Rural Affairs (MARA) launched a national action plan for conservation tillage in black soil areas in 2020, aiming to implement SSM on 7.3 million hectares in two years (MARA, 2020).

The MARA and relevant departments published the "National Implementation Plan for Black Soil Protection (2021–2025)" (MARA, 2021). The plan provides guidance for black soil protection and utilization in the next five years, specifying the target tasks of implementing 16.7 million hectares of black soils following the guidance, mitigating 25 000 erosion ditches and improving the quality of arable land by 2030.

20 | Black soil protection legislations

Black soil monitoring, Nenjiang County of China

The Black Soil Protection Law of the People's Republic of China, was enacted on August 1, 2022 (Xinhua News Agency, 2022; Lawinfochina, 2022). According to this law, black soils refers to arable land with a black or dark black humus topsoil layer with good properties and high fertility within the relevant areas of Heilongjiang, Jilin, and Liaoning provinces and Inner Mongolia Autonomous region. The agricultural and rural authorities of the State Council shall determine the scope of black soil protection taken into account the history of black soil reclamation and the currently status. The protection of black soils should be in a scientific and reasonable manner and adjusted in accordance with the principle most conducive to comprehensive protection, integrated management, and systematic restoration. This law specifies that China shall implement a scientific and effective policy for the protection of black soils. Financial investment in black land protection shall be guaranteed, and engineering, agronomic, agricultural and biological measures shall be taken to protect the productivity of black soils and maintain the total area of black soils. In addition, the law emphasizes that anyone who steals or indiscriminately digs or buys black soils shall be punished severely in accordance with the provisions of the relevant laws and regulations on soil management.