Degradation of Black Soil Quality and Strategies of Prevention Control in Northeast Plain, China

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Abstract: The black soil of northeast China is one of the most fertile but short-cultivated soil types globally. Currently, black soil-related research has attracted immense interest in soil geography research. This paper compares the degradation characteristics of the black soil quality in northeast China, analyzes the formation mechanism, and proposes a strategy to restore the black soil quality, an important scientific reference for national food security. The black soils in northeast China mainly cover the Liaohe, Songnen, and Sanjiang Plains. The soils have high fertility, but the natural environment and human activities have degraded them after reclamation. The degraded soils have low organic matter, low nutrient contents, damaged soil structure and deteriorated physical properties. The degradation of black soil quality in northeast China can be divided into natural and human factors. The natural factors include climatic aspects, topographic, and soil conditions, while human factors include over-cultivation, predatory management, poor farming systems and planting structure, and urbanization. Strategies for preventing and controlling black soil quality degradation include improved agricultural development planning, changing traditional management methods, and strengthening the monitoring and research on black soil degradation.

1 INTRODUCTION

Black soils are soft with a deep humus layer and rich organic matter content on the top layer (Han and Li, 2018). In this paper, black soil refers to dark soil in the black soil area with various soil types, including black soil, black calcareous soil, dark brown soil, brown soil, white pulp soil, meadow soil, and rice soil in the soil system classification. The northeastern plains of China, the plains of Ukraine, the Great Plains of the United States where the Mississippi River Basin is located, and the Pampas of South America constitute the "four major black soil distribution areas in the world". The black soil of northeast China covers the low mountains, hills, and plains of several provinces, including Heilongjiang (Hulunbeier, Xing'an, Tongliao, and Chifeng cities), Jilin, Liaoning, and the Inner Mongolia Autonomous Region (Li et al., 2019; Liu et al., 2021). The black soil area in China is a critical grain-producing zone and a strategic food reserve (Liu and Ma, 2000; Yao et al., 2020). The development of the black soil area in northeast China started mid-16th century when the Qing government set up post stations and station troops in the Songnun Plain for military supplies and later farming. For over 200 years, beginning early 19th century, large-scale reclamation involved natural, semi-artificial, and artificial ecosystems (Tao, 1983; Wang et al., 2002). However, human intervention changed these ecosystems from fishing, hunting, and nomadic agricultural to shifting agriculture, deforestation, grassland reclamation, and sedentary agricultural production. The recent predatory management has decreased the black soil resource quantity and quality, making soil degradation a major constraint to sustainable socio-economic development in the black soil region (Yang and Han, 2009; Wang et al., 2021). The overuse of black soil caused soil erosion, depleting organic matter, promoting further degradation, and exacerbating a vicious cycle of degradation (Li et al., 2021).

Currently, black soils have restricted potential for food production, endangering the "big granary" construction in northeast China and threatening food security in China. In order to improve the quality of black land cultivated land in Northeast China and protect the sustainable use of black land resources, local governments have also built local black land protection laws and regulations, such as the Outline

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of the Northeast Black Land Protection Plan (2017-2030). Therefore, there is an urgent need to evaluate the causes and mechanisms of black soil quality degradation in northeast China. This study can not only provide theoretical basis for the formulation of black soil protection policies, but also provide scientific guidance for the sustainable use and management of black soil.

2 DISTRIBUTION OF BLACK SOIL IN NORTHEAST CHINA

The black soil of northeast China comprises the Liaohe, Songnen and Sanjiang Plains (38°43′N to 53°33′N, 115°31′E to 135°05′E and 115°31′E ~ 135°05′E), measuring 1,600 km from east to west and 1,400 km from north to south (Figure 1). The area has an arc-shaped distribution from north to south, dominated by plains, diffuse and low hills (Institute of Forest soil, 1980). The climate is temperate continental monsoon with wet summers and dry, cold winters with 2.9°C, annual average temperature. Precipitation occurs from June to September, accounting for 60 to 70% of the total annual precipitation. The natural vegetation is deciduous broad-leaved forest, mixed deciduous broad-leaved and coniferous forest, coniferous forest, and grassland spanning southeast to northwest. The soil types are mainly composed of black soil, chernozem and meadow soil. The central and eastern regions are mainly black soil, and the western regions are mainly chernozem and meadow soil. The area of black soil is about 1.03 million km². The administrative area includes the four eastern leagues of Inner Mongolia Autonomous Region (Chifeng, Tongliao, Hulunbeier, and Xing'an), Liaoning, Jilin, and Heilongjiang Provinces, with a land area of 1.244 million km² (Liu and Zhang, 2006).

The Northeast black soil area is important for commercial grain production in China, with 3.6×10^7 hm^2 of arable land, accounting for a quarter of the acreage and producing a quarter of the grains for the country. Commercial grain accounts for a quarter of the grain for the country. The Northeast region has a cold climate with a short land reclamation period. Black or dark black humus is prevalent on the surface of the soil. Although the natural soil is relatively fertile, the black soil has undergone rotational fallow, low-intensity utilization (by humans and animals) and high-intensity utilization (by mechanization after reclamation), lowering the natural fertility of the black soil yearly. The nutrient reduction and soil erosion sharply decreased organic matter in the soil layer, thinned the cultivation layer, and thickened the plough bottom, deteriorating the physical and biological properties of the black soil.

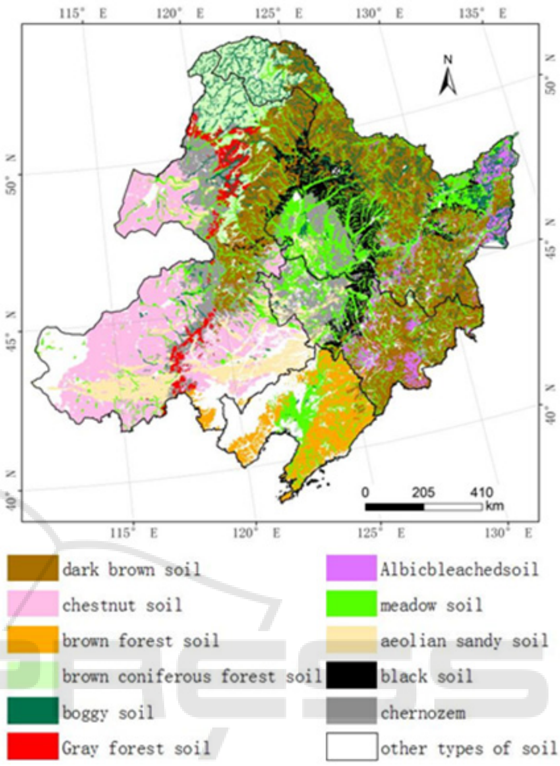

Figure 1: Distribution of black soil in Northeast China.

3 CURRENT STATUS OF BLACK SOIL QUALITY DEGRADATION IN NORTHEAST CHINA

3.1 Declining Soil Organic Matter

Crop stubble is an energy source for many farmers using the traditional tillage systems. For many years now, <5% of the crop stubble is returned to the field. In most black soil areas, root stubble is the only source of organic matter. However, root stubble only replenishes about 1000 kg/hm^2 of soil organic matter, far below the mineralization rate of soil organic matter. Therefore, conventional tillage accelerates soil organic matter depletion. During the 3 to 5 years after the reclamation of black soil, the organic matter of cultivated soil decreased rapidly. Long-term monitoring data of dark brown soil showed that conventional cropping (fertilizer application only) decreased the soil organic matter in the cultivated layer by 8.00% (between 34 a and 0.23% a^{-1}) (Kang et al., 2016). The reduced soil organic matter content and quality and long-term nutrient content deficit caused a continuous decline in soil quality.

3.2 Soil Nutrient Loss

Soil erosion depletes cultivated land, reduces soil nutrients, causing soil infertility. Soil erosion also thins the black soil layer, decreasing the fertilizer performance and water retention. In the sloping land reclaimed for 60~70 years, the thickness of the black soil layer was reduced by half. The black soil area losses 2 x 108m^3 of soil annually. The lost nitrogen, phosphorus, and potassium nutrients account for 5 x 10t of chemical fertilizer. Although soil is a renewable resource, soil regeneration capacity is limited (Whitbread et al., 2000). Therefore, human predatory management and intense cropping with little or no soil nutrients replenishment destabilize the soil nutrient balance.

3.3 Damage to the Soil Structure

The deep humus layer of black soil guarantees good structure and configuration, yet over 80% of the soil structure and configuration in the black soil area are destroyed (Zouet al., 2018). Unreasonable tillage compacts the soil and forms a layer of plow-bottom barrier that obstructs nutrient transport and water supply. The humus layer of natural black soil is generally 30 ~ 70cm thick and >100cm deep (Qiu et al., 2020). And soil water erosion and wind erosion keep stripping the humus layer of black soil. However, years of cultivation, soil, and wind erosion thinned the black soil layer into a shallow strip. Wind erosion exposed the coarse soil texture leading to the sanding of the black soil layer.

3.4 Deterioration of the Physical Properties of the Soil

Thinning of the black soil humus layer decreases the humus content and deteriorates the physical and chemical properties of the soil. Deterioration of soil physical properties causes compaction, which weakens the water and fertilizer retention, reducing resistance to droughts and floods in the black soil area (Fan et al., 2018). The deterioration of physical properties has weakened water and fertilizer retention, reduced resistance to drought and flooding, increased soil consolidation and deteriorated arable properties. Such deteriorated soils have poor nutrient adsorption and transformation, affecting nutrient uptake by plant roots and ultimately affecting the fertilizer utilization rate (Hesung and Li, 1978). Consequently, the chemical nitrogen fertilizer utilization rate in the northeast China black soil area is a mere 30%. Yet, the Great Plains black soil area of the United States has a 50~60% utilization rate of nitrogen fertilizer.

4 DISCUSSION

4.1 Natural Factors of Black Soil Quality Degradation

4.1.1 Climatic Factors

The black soil area belongs to the north temperate semi-humid continental monsoon climate, with 500mm average annual precipitation. However, 70%~80% of the rainfall is concentrated in June through September (Wang et al., 2010). Water erosion mainly occurs in this season as the rains fall with high intensity, easily producing surface runoff and soil erosion. In spring, the black soil area receives little rain and much wind (Fan et al., 2004). The thin black soil cover in spring and wind erosion hazard increases drought yearly.

4.1.2 Topographic Conditions

The topography of black soil areas is mainly high plains and terraces that rise in the middle of the neotectonics (Sun et al., 1997). They include undulating mangoes with relatively open topography and undulating terrain with 3 to 10° slopes 500 to 4,000m long and wide. The slope ridges have masses that increase the catchment area so that the surface runoff moves speedily and the scouring force on the soil aggravates soil erosion (An et al., 2014).

4.1.3 Soil Conditions

Black soil comprises Quaternary loess-like clay deposits with a loose surface layer, clayey and heavy subsoil with low permeability and weak erosion resistance, which easily causes soil erosion and salinization (Zhang, 2010a). For example, the Quaternary geological environment in western Jilin is the soil-forming parent material, and young volcanic rocks are widely distributed in the surrounding Daxinganling, Xiaoxinganling, and Changbai Mountains. The weathering of aluminous silicate igneous rocks form bicarbonates of calcium, magnesium, potassium, and sodium, which dissolve in the surface and underground runoff and subsequently pool in the plains or low-lying areas (Zhai and Xu, 2011). These bicarbonates transform into carbonate precipitates, and the remaining potassium and sodium bicarbonates become labile carbonates (Gao et al., 2020).

4.2 Anthropogenic Factors of Black Soil Quality Degradation

4.2.1 Over-cultivation and Predatory Management

The degradation of black soil results from excessive reclamation, predatory management, and overuse rather than cultivation (Han and Zou, 2018). The continued population growth and economic development have dramatically increased food demands and inspired the "food as the platform" notion. The increased food demands are inappropriately alleviated by deforestation, land clearing, and single-mode food production methods leading to blind arable land expansion and the vicious circle of "population-arable land-grain"(Yu and Zhang, 2004). These destructive production methods of extensive planting, thin harvesting, farming downhill, predatory management, heavy use than nourishment, and monoculture have continuously caused soil nutrient loss and decline in quality in the black soil areas (Li et al., 2005).

4.2.2 Tillage Systems and Cropping Structures

The decentralization of land management, which happened 20 years ago, has led to land fragmentation, reduced use of large agricultural machinery and technology, and shallow land depth (Yu et al., 2004). The plow bottom layer moved upwards, deteriorating the soil physical properties and decreasing the water storage capacity (Liang et al., 2016). The situation is worsened by the poor planting structure, which solely pursues food quantity and encourages planting excessive proportions of specific crops, heavy stubble, which further reduces the tilled area.

4.2.3 Urban Expansion

The rapid developmental reform in the Chinese economy has profoundly impacted land use patterns. The urbanization rate has developed the black soil area of northeast China to the industrial and agricultural area in northeast China (Han et al., 2005). However, unreasonable land use patterns during the expansion of cities and towns have encroached on many black soils and aggravated the soil pollution problem in the black soil area. The expansion of rural construction has also illegally encroached on a large amount of black land, further aggravating the problem.

5 STRATEGIES FOR PREVENTION AND CONTROLLING THE DEGRADATION OF BLACK SOIL QUALITY

5.1 Improve Agricultural Development Planning

The black land is divided into agricultural economic protection zones, which are further divided into quality classes (Lu, 2001). The policies of agricultural economic protection zones strictly control the occupation of agricultural land for commercial land uses, prohibiting the illegal occupation of basic farmland and guaranteeing the unchanged total amount of basic farmland, quality, and nature. Relevant departments lead the unified planning of planting, animal husbandry, forestry, and water conservancy constructions that vigorously develop extension-type intensive and advanced technologies to allow land rotation and cultivation(Zhang, et al., 2005).

5.2 Changing the Traditional Way of Management

Practical application of organic fertilizers and crop straw return to the fields are methods used to curb the irrational utilization of farming technology, development, and farmland construction (Zhang, 2010b). The basic goal is to cultivate good seeds, discover new varieties suitable for crop rotation, and readjust regional crop rotation systems to prevent pollutants and harmful chemicals from entering the arable land.

5.3 Strengthening Monitoring Research on Black Soil Degradation

The "3S" technology, satellite remote sensing, and GIS positioning establish the geographic information database of soil erosion and its impact (Zou et al., 2020). The GIS data, combined with field observations and model calculations, monitor the dynamic changes of arable land to establish a digital model of soil degradation and soil fertility. The purpose is to monitor the ecological environment, spatial and temporal evolution laws and trends in the black soil area. The data will be collected to establish a digital model of soil degradation and soil fertility (Zhang et al, 2009).

6 CONCLUSIONS

The main reason for the decline in the black soil quality is traditional farming methods that emphasize planting rather than nurturing. More planting lowers the natural production capacity of the land, forcing farmers to rely on large amounts of chemical fertilizers to maintain food production. The capital investment in chemical fertilizers accounts for over 50% of the overall production investment, but the benefit of increased fertilizer application is declining annually. Urban and rural construction and development have taken up a large amount of high-quality arable land. Low and medium-yielding land is the main reserve arable land resource for agricultural production to maintain arable land. However, the arable land area remains unchanged, but the quality has declined, and more investments are required, increasing the production costs.

More efforts are needed to improve farmland production conditions to reduce the input costs of agricultural production materials, especially chemical fertilizers, and improve the quality and efficiency of agricultural products in the black soil area of northeast China. To simultaneously solve the food security problem, systems must advance from "store grain in the treasury" to the concept of "store grain in the soil". The strategic thinking of grain production requires adjustment to focus on soil protection and the construction of soil function, attention shift from the production of grain reserves to the production capacity of grain reserves to realize the sustainable development of grain production in China.

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