Black Soil Protection and Utilization Based on Harmonization of Mountain-River-Forest-Farmland-Lake-Grassland-Sandy Land Ecosystems and Strategic Construction of Ecological Barrier

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Abstract
The black soil in northeast China presents a trend of thinning, hardening, impoverishment, and acidification under the longterm high-intensity utilization, and faces the water resources shortage and ecological environment imbalance. Thus, the coordination between soil and water resources and environment has become the bottleneck of sustainable agricultural development in northeast China. The black soil protection and utilization is not only a problem of cultivated land system itself, but also a problem of harmonization of mountain-river-forest-farmland-lake-grassland-sandy land ecosystem. To achieve the goal of sustainable use of the black soil, it is necessary to give full play to the function of soil and water conservation, wind prevention and sand fixation, and biodiversity of natural ecosystems such as woodlands, grasslands, and wetlands. Hence, in addition to taking actions to ensure the quantity of cultivated black soil and improve soil quality, a synergetic development strategy of the mountain-river-forest-farmland-lake-grassland-sandy land ecosystems should be implemented to build ecological barrier for controlling and remediation of the black soil degradation.

Keywords
black soil, mountain-river-forest-farmland-lake-grassland-sandy land ecosystem, protection, utilization, synergetic development

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Abstract: The black soil in northeast China presents a trend of thinning, hardening, impoverishing, and acidification under the long-term high-intensity utilization, and faces the water resources shortage and ecological environment imbalance. Thus, the coordination between soil and water resources and environment has become the bottleneck of sustainable agricultural development in northeast China. The black soil protection and utilization is not only a problem of the cultivated land system itself, but also a problem of harmonization of mountain-river-forest-farmland-lake-grassland-sandy land ecosystem. To achieve the sustainable use of black soil, it is necessary to give full play to the function of soil and water conservation, wind prevention and sand fixation, and biodiversity conservation of natural ecosystems such as woodlands, grasslands, and wetlands. Hence, in addition to taking actions to ensure the area of cultivated black soil and improve soil quality, a synergetic development strategy of the mountain-river-forest-farmland-lake-grassland-sandy land ecosystems should be implemented to build an ecological barrier for the controlling and remediation of black soil degradation. DOI: 10.16418/j.issn.1000-3045.20211010002-en

Keywords: black soil; mountain-river-forest-farmland-lake-grassland-sandy land ecosystem; protection; utilization; synergetic development

Northeast China (refers to Liaoning Province, Jilin Province, Heilongjiang Province, and eastern Inner Mongolia Autonomous Region unless otherwise specified) is an important distribution area of woodlands, grasslands, and wetlands in China, with a total land area of $1.24 \times 10^8$ km$^2$. This region plays a pivotal role in guaranteeing China’s food security and ecological security. It is a major grain producing area, with the grain output of $1.65 \times 10^8$ tons (accounting for 24.9% of the national total) in 2019. Meanwhile, it is a key area that integrates the ecological services of water and soil conservation, wind prevention and sand fixation, and biodiversity conservation in Major Function Oriented Zoning of China. The main soil types in northeast China include black soil, chernozem, albic soil, dark brown soil, brown soil, meadow soil, and paddy soil, which are featured by high organic matter content, good granular structure, and coordination of water, fertilizer, gas, and heat. These soils with black or dark black humus at the surface are collectively referred to as black soil in agricultural production. Therefore, the northeast China in this paper is also called the northeast China black soil area. Since the large-scale reclamation in the 1950s, the proportion of natural woodlands, grasslands, and wetlands in northeast China has declined, while that of farmlands has significantly risen. The black soil in northeast China presents a trend of thinning, hardening, impoverishing, and acidification under the long-term high-intensity utilization, unreasonable tillage, crop rotation, and fertilization, as well as the impact of wind erosion, water erosion, and corrosion \cite{1,2}. At the same time, the high-intensity cutting of forests for wood production, extensive reclamation of...
wetlands, and groundwater overexploitation for irrigation here cause water resources shortage and ecological environment imbalance. Therefore, the coordination between black soil resources and environment has become the bottleneck of sustainable agricultural development in northeast China.

During an investigation in Jilin, Chinese President Xi Jinping pointed out that we should take effective measures to protect and utilize black soil, “the giant panda in arable land,” so that it can benefit the people forever. In response to decisions of the Party Central Committee and the State Council, the Ministry of Agriculture and Rural Affairs developed the Outline of Black Land Protection Planning in Northeast China (2017–2030) and Action Plan for Conservation Tillage of Black Land in Northeast China (2020–2025)①. The protection of black soil and improvement of arable land quality is not only a matter of arable land itself, but also an issue of the mountain-river-forest-farmland-land-grassland-sandy land ecosystems. We should establish the concept of a living community of mountains, rivers, forests, farmlands, lakes, grasslands, and sandy lands, transform the farming mode from centering on the area of arable land to the protection of arable land eco-environment. The existing agricultural production technologies, equipment, and products should be integrated according to local conditions for the coordinated development of natural ecosystems and farmland ecosystem. We should give full play to the functions of woodlands, grasslands, wetlands and other ecosystems in the protection of farmland, so as to ensure that the black soil does not further deteriorate and finally achieve the sustainable use of the black soil.

1 Evolution of arable black soil quality in northeast China

1.1 Type and area of arable soil

According to the National Cultivated Land Quality Grades in 2019②, the total cultivated area in northeast China was 2.99×107 hm2, mainly distributed in Songnen Plain, Sanjiang Plain, Liaohe Plain, foothills of Greater and Lesser Khingan Mountains, and low hilly areas of Changbai Mountains. The cultivated land in this region had an average quality grade of 3.59, of which high- (grades 1–3), middle- (grades 4–7), and low-grade land (grades 8–10) accounted for 52.01%, 40.08%, and 7.90%, respectively. Among different soil types, meadow soil had the largest area, accounting for 19.69% of the total cultivated area, followed by dark brown soil (16.76%), black soil (13.29%), paddy soil (11.63%), chernozem (10.35%), albic soil (9.02%), brown soil (6.15%), moisture soil (5.07%), cinnamon soil (4.28%), chestnut soil (2.79%), and saline-alkali soil and boggy soil (0.97%).

1.2 Changes of arable soil quality

In recent years, water and soil erosion in northeast China has been increasingly serious due to the restriction of natural factors and high-intensity utilization. According to the survey, an average of 0.3–1.0 cm thick topsoil is lost yearly in the black soil area. The areas with rich black soil have the topsoil layer of only 20–30 cm (Figure 1), and loess-like parent material is even exposed in some places, which decreases the soil productivity. It is estimated that the black soil layer in part of the existing cultivated land in the black soil area will completely disappear after another 40–50 years of loss. Data from the first national census for water show that the area eroded by water has reached 2.16×105 km2 in northeast China, of which the area covered by black soil and chernozem accounts for 35.5%③. The organic matter content of black soil in northeast China decreased from 60–80 g·kg−1 to 20–30 g·kg−1 after 20–30 years of reclamation, with the mean value of 30.56 g·kg−1 in 2014, which resulted in the reduction of organic carbon storage in black soil and made the soil become a carbon source④. For years, small four-wheel tractors have been extensively used for field tillage and transport in northeast China. The repeated rolling results in an increase in surface soil bulk density, soil hardening, decrease in porosity, and poor permeability and infiltration capacity. The deterioration of black soil weakens the soil capacity in water and fertilizer retention as well as drought and flood resistance and reduces the granular structure. Finally, the black soil presents a trend of thinning and hardening. A survey on 46 pieces of black soil cultivated land from Renjiang River in Heilongjiang Province to Gongzhuling in Jilin Province in 2016 showed that the arable layer of most of the cultivated land was 13–14 cm thick (34.8%), while the compact layer of black soil cultivated land was mostly 10–17 cm thick (30.4%)⑤.

The black soil in the arable layer presents a trend of acidification as the pH value declines. In northeast China, the arable land with pH<4.5, pH 4.5–5.5, and pH 5.5–6.5 account for 12.8%, 13.7%, and 43.6%, respectively⑥. Black soil, dark brown soil, brown soil, meadow soil, albic soil, and paddy soil had mean pH values of 5.98, 5.91, 6.26, 6.7, 5.84, and 6.32, respectively. Although paddy soil had nearly central pH, the area of the paddy soil with pH≤5.5 increased

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by $2.9 \times 10^4$ ha$^2$, and the decrease rate of the pH value (acidification) of rice reached 0.016 per year in 1979–2017 due to the intensive application of fertilizer. At present, the paddy soils with pH 4.5–5.5 and pH 5.5–6.5 in this region account for 61.1% and 46.7%, respectively, and the neutral paddy soil only accounts for 35.7% [5].

Figure 1 Changes of soil profile horizons and organic matter content of black soil in northeast China

With the implementation of black soil protection in northeast China, a “Lishu model” characterized by no-tillage and maize straw mulching (NTMS) has been established. The model includes three technical modes: full straw mulching and uniform rows, planting on the original ridge of straw mulching, and returning straw to field with rotary tillage of seedling strip. The whole-process mechanization of harvesting, straw mulching, soil loosening, no-tillage planting and fertilization, and prevention and control of diseases, pests, and weeds comprehensively improve the productive and ecological functions of black soil. To address the thinning of black soil layer and the thickening of plow pan, a technical system for fertile topsoil construction with organic materials returning to the field by deep tillage as the core is established, and a “Longjiang model” that combines maize-soybean rotation with tillage, no-tillage, and shallow tillage on black soil is built in Heilongjiang Province, which together breaks the plow pan and improves the organic matter and nutrient pool of black soil [2].

On the whole, the black soil in northeast China gets thinning, hardening, impoverishing, and acidification due to high-intensity reclamation and utilization and water and soil erosion. The organic matter content, black soil layer thickness, and irrigation and drainage capacity have become key factors restricting the improvement of black soil fertility (Figure 2). In the construction of high-standard farmlands, the rill erosion and the fragmentation by erosion gullies in sloping farmlands seriously affect the mechanized farming and fertilization of black soil, which makes it urgent to develop a model for erosion gully governance. Meanwhile, the cold and cool climate in northeast China affects the decomposition of organic materials such as straw and the recycling of carbon, nitrogen, and phosphorus, which restricts the improvement of soil organic matter and the replacement of chemical fertilizer by organic fertilizer. These restrictions necessitate a model for efficient recycling of organic matter and nutrients in the farmland ecosystem.

Figure 2 Key factors for improving cultivated land quality in northeast China

2 Evolution of forest resources in northeast China black soil area

2.1 Changes of forest area and quality

Forests in northeast China are key ecosystems for black soil protection. The area of existing forests in northeast China is $5.86 \times 10^4$ ha$^2$ (Figure 3a), accounting for 27% of the national total. Specifically, the natural forests and plantations in this region cover the areas of $4.55 \times 10^7$ ha$^2$ and $1.31 \times 10^7$ ha$^2$, respectively [6]. The forest coverage rate of northeast China is 47.2%, which is significantly higher than the national level (23.0%), and the area of arboreal forest is $4.87 \times 10^7$ ha$^2$. In the last four decades, the forest area in northeast China increased by 53.3% (Figure 3b). The forest area in northeast China grew rapidly in the 1990s because of the construction of major ecological projects such as Grain for Green, shelterbelts, and fast-growing and high-yield plantations, increasing by 35.2% during 1995–2015.
Figure 3  Spatial distribution of forest and farmland areas, and changes in forest area and stocking in northeast China. (a) Spatial distribution; (b) changes in forest area and stocking; data from National Forestry and Grassland Administration of China [6]

The forest stocking in northeast China has reached $4.6 \times 10^8$ m$^3$, accounting for 26% of the national total, of which the stocking of natural forests and plantations is $40.5 \times 10^8$ m$^3$ (87.7%) and $5.7 \times 10^8$ m$^3$ (12.3%), respectively. The forest quality keeps improving, with the stocking increasing by 53.7% from $3.0 \times 10^9$ m$^3$ in 1980 to $4.6 \times 10^9$ m$^3$ in 2015 (Figure 3b). Despite the increasing trend of the overall forest stocking in northeast China, the forest stocking per unit area in Heilongjiang Province, Jilin Province, and Inner Mongolia Autonomous Region fluctuated or showed a short-term decreasing trend before 2000 [6], which indicated the state of forest recovery in northeast China after a long period of intense disturbance. At present, the virgin forest in northeast China accounts for less than 7%, and about 70% forests are secondary forests, most of which are in the early and middle stages of secondary succession, mainly half-mature forests (34.8%) and young forests (21.9%), suggesting the low quality of forests and the great room for improvement.

2.2 Changes of farmland shelterbelt

Building shelterbelt is one of the main goals of national ecological security construction and the most direct and effective means to protect black soil. Shelterbelt can mitigate natural disasters, conserve soil, and improve microclimate and hydrological conditions, so as to create an environment conducive to the growth and reproduction of crops and livestock and ensure the stable and high yield of crop and animal farming. In 1980–2017, the area of shelterbelt in northeast China first increased and then decreased. Specifically, it developed from $6.11 \times 10^5$ hm$^2$ in 1980 to $8.52 \times 10^5$ hm$^2$ in 1990 and $9.65 \times 10^5$ hm$^2$ in 2000, increased slightly by only $4.7 \times 10^3$ hm$^2$ in 2000–2010, and then decreased by 1.57×10$^4$ hm$^2$ in 2010–2017 (Figure 4).

The overall quality of shelterbelt in northeast China declined during 1990–2017, especially that in 2010–2017. The low-quality shelterbelt area increased from $2.9 \times 10^5$ hm$^2$ in 2010 to $4.7 \times 10^5$ hm$^2$ in 2017 (Table 1), and 53% of the shelterbelt area had the age of about 30 years in 2017 [7].

Figure 4  Changes of farmland shelterbelt area in northeast China
Data in 1980 was deduced from literature, while the others were estimated from remote sensing observations

2.3 Changes of ecological functions of forest/shelterbelt

Forests in northeast China provide diverse ecological services, of which water conservation, carbon fixation, and soil retention are closely associated with black soil conservation. The water conserved in the forest area of northeast China irrigates Songnen Plain, Sanjiang Plain, and Hulunbeir farmlands and pasture where black soil is the main soil type, China’s important production bases of commodity grain and animal husbandry. The water conservation capacity in northeast China decreased from $3.63 \times 10^{10}$ m$^3$ in 1992 to $2.40 \times 10^{10}$ m$^3$ in 2000, and then increased to $3.61 \times 10^{10}$ m$^3$ in 2015. Forests can mitigate the erosion of surface runoff to conserve soil. The soil retention in northeast China dropped from $2.39 \times 10^8$ tons in 1992 to $2.17 \times 10^8$ tons, and then rose to

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3.18×10^8 tons in 2015. The forest carbon sink affects the changes of forest carbon storage. Inventory data show that the forest biomass in northeast China is a significant carbon sink. Satellite data demonstrate that the forest carbon sink in northeast China has been increasing in the past 10 years. The ecological services provided by forests are affected by multiple factors such as forest quality, spatial distribution, environment, and climate. Limited by forest quality, the functions of forests conserving black soil in northeast China still have a gap to the overall goal.

Shelterbelt protects black soil by mitigating soil erosion and improving farmland microenvironment. It can reduce the wind speed and weaken the turbulence exchange, and increase the soil moisture content to a certain extent, thereby preventing or mitigating soil erosion. Shelterbelt improves black soil by increasing soil organic matter and carbon sink. Additionally, it can form a microenvironment conducive to agricultural production. The farmland protection effect in northeast China was only 18.3% in 2010 and then rapidly decreased to 15.3% in 2017. It is urgent to increase the farmland protection effect of shelterbelt to over 50% to achieve good regional protection function.

3 Evolution of grassland resources in northeast China black soil area

3.1 Changes in grassland area

Hulunbuir grassland, Songnen grassland and Khorchin grassland in northeast China constitute the main body of the wind-prevention and sand-fixation belt in northern China, which play a vital role in ensuring the agricultural and livestock production in northeast China and north China, as well as the environmental security of the Beijing-Tianjin-Hebei city cluster and old industrial bases in northeast China.

With favorable precipitation conditions, the grassland in northeast China has high biodiversity and huge productive potential. The total area of meadow and meadow steppe in this region is 4×10^7 hm², accounting for 25% of the area of temperate grassland in northern China. The land in this region is mainly covered by chernozem, dark chestnut soil, and meadow soil, with the soil humus content much higher than that of other grassland types. The soil carbon density in this region is 2–3 times that of typical steppe and 6–10 times that of desert steppe, and the livestock bearing capacity accounts for 58% of the whole grassland area in northern China.

Under the long-term reclamation or unreasonable utilization, the structure and services of the grassland ecosystem in northeast China degrade seriously, and the grassland desertification and degradation area grow faster than other grassland areas. According to the remote sensing data, the grassland area in northeast China decreased from 1.77×10^7 hm² in 1990 to 1.67×10^7 hm² in 2015, and its proportion in the area of northeast China decreased from 14.2% to 13.4%. During 1990–2015, the grassland area in northeast China decreased by an average of 3.9×10^4 hm² annually, which mainly occurred in southeastern Inner Mongolia Autonomous Region, western Jilin Province, and southwestern Heilongjiang Province.

3.2 Changes in grassland productivity

While the grassland area was greatly reduced, the grassland productivity in northeast China kept decreasing. According to the literature statistics, the productivity (average hay yield) of natural *Leymus chinensis*-dominated grassland in northeast China decreased from 1 500–2 000 kg·hm⁻² in the 1980s to 450–600 kg·hm⁻² at present. A vicious circle emerged among population, resources, environment, and economic development, leading to grassland degradation and decline of ecological services. Thus, it is essential to strengthen the technical research and demonstration on the vegetation restoration of the desertificated grassland, the recovery of degraded grassland vegetation, and the improvement of ecological functions and comprehensively improve grassland vegetation coverage, productivity, and stability in northeast China. In this way, the grassland vegetation can fully play the role of ecological barrier and ensure the black soil resource security and ecological security in this region.
4 Evolution of water and wetland resources in northeast China black soil area

4.1 Characteristics of water and wetland resources

Water resources are short and unstable in northeast China. Statistically, the total water resources in northeast China are 1.6×10^11 m^3, accounting for only 5.8% of the national total, and the per capita water resources here is 1 599 m^3, accounting for 77.6% of the national average \(^{(19)}\). Precipitation is the main supply of surface water and underground water in northeast China, while the spatial and temporal distribution of precipitation is extremely uneven. In terms of spatial distribution, the annual precipitation decreases from 1 000 mm to less than 300 mm and transits from humid area and semi-humid area to semi-arid area from southeast to northwest. In terms of temporal distribution, the precipitation is highly concentrated (70% of the total precipitation) in the flood season (from July to September), and the runoff accounts for more than 80% of the year. Influenced by interannual variation of precipitation, the total water resources and runoff also show great interannual variations in northeast China, which affects the stability of agricultural production.

The sustainable exploitation and utilization of water resources are of vital importance to the agricultural development and ecounvironment of wetland in northeast China. According to statistics, the agricultural water consumption in northeast China in 2016 was 5.51×10^10 m^3, accounting for about 78% of the total available water resources in the region, higher than the national average (65%). The groundwater withdrawal in this region was 3.22×10^10 m^3, accounting for about 46% of the water consumption in the region, 82% of which was used for irrigation \(^{(20)}\). In addition, the vast wetlands are mainly distributed in Greater Khingan, Lesser Khingan, Changbai Mountains, Sanjiang Plain, Songnen Plain, and Liaohe Estuary Delta, with a total area of 7.5×10^4 km^2 (14.1% of the national total). Wetlands have a wide range of ecological functions such as water conservation, biodiversity conservation, flood water storage, and local climate regulation, while large-scale reclamation of wetlands and unreasonable exploitation of groundwater will lead to shrinkage or disappearance of wetlands and imbalance of ecounvironment. In northeast China, the area of marsh wetlands accounts for 48.3% of the national total wetlands.

4.2 Changes in water resources quantity

In the past 50 years, the mean temperature in northeast China increased linearly. Correspondingly, the evaporation increased significantly, while the precipitation decreased slightly. From the perspective of water balance, the water resource supply in northeast China has little change, while the water shortage intensifies.

The irrigation demand for grain crops in northeast China is on the rise. As arable land transits from dry land to paddy land, water demand for rice determines the irrigation demand of farmland. According to statistics, the rice cultivation area increased by 3.63×10^4 hm^2 in Heilongjiang Province, Jilin Province, and Liaoning Province in 1990–2017. Specifically, the areas in Jilin Province and Heilongjiang Province increased by 4.0×10^3 hm^2 and 3.27×10^3 hm^2, respectively, while that in Liaoning Province decreased by about 5×10^3 hm^2 \(^{(21)}\).

The increase in irrigation water consumption directly leads to the increase in groundwater withdrawal, which results in a significant decline in the groundwater level. According to statistics, the groundwater withdrawal in northeast China reached 2.65×10^10 m^3 in 2016, increasing by 16% compared with that for agriculture in 2001, while the regions with increased groundwater depth were mainly in central and northeastern Songnen Plain, eastern Sanjiang Plain, and western Liaohe Plain \(^{(20)}\). In recent years, the local governments have taken a series of measures for water resources management. Some of the over-exploitation areas have been under control, whereas the over-exploitation in local areas tends to be intensified due to agricultural production. Therefore, how to adjust the grain cultivation structure and improve the productivity of irrigation water becomes the key to balancing the alleviation of water shortage and the maintenance of high and stable crop yield.

4.3 Changes of wetland area and ecological functions

The pressure of food production and insufficient understanding of wetland functions have led to the narrowing of the wetland area in northeast China. In Sanjiang Plain, after nearly 60 years of reclamation, the wetland area has been reduced to 1.0×10^4 hm^2, less than 20% of its area before 1949. According to the latest remote sensing data, the wetland area in northeast China was 7.66×10^4 hm^2 at the end of 2020, which was 11% less than that in 1975 \(^{(22)}\). In addition, influenced by climate changes and human activities, the scale of wetland conversion varies among different stages, while reclamation remains the major conversion pattern at present. In this region, 1.15×10^6 hm^2 natural wetland and only 2.5×10^4 hm^2 constructed wetland were converted into arable land in 1990–2000, and only 5.35×10^3 hm^2 natural wetland and 2.0×10^3 hm^2 constructed wetland were converted into arable land in 2000–2013.

The wetland ecosystem plays a vital role in regulating runoff, replenishing groundwater, and maintaining water balance of the drainage basin. However, wetlands in northeast China have been greatly reduced due to climate changes and human activities, leading to the weakening of these functions and the buffer capacity of northeast China against drought or flood disasters. A typical example is a catastrophic flood in the Songnen basin in 1998. In the semi-arid area of central and western China, the construction of water engineering leads to such problems as the reduction of surface water supply and over-exploitation of groundwater,
exacerbating the wetland shrinkage caused by climate changes and further deserting the land. Compared with the semi-arid area, the large areas of marsh wetlands in Sanjiang Plain with rich water resources decrease and the constructed wetlands increase, resulting in the fragmentation of marsh wetland landscape and the loss of biodiversity. In Liaohe Plain abundant in light and heat resources, the disordered development of rice planting intensified the contradiction between supply and demand of local water resources and induced groundwater pollution and other environmental problems.

5 Suggestions for black soil protection and utilization in northeast China

The Chinese government has launched relevant science and technology projects and engineering projects for the protection of black soil in northeast China. However, there are still some deficiencies in the coordination of water and soil resources and environment. The surveys on the evolution of woodlands, grasslands, wetlands, and water resources in northeast China show that only by protecting black soil in the mountain-river-forest-farmland-lake-grassland-sandy land ecosystem can we control and restore the degraded black soil and achieve a sustainable utilization. Attention should be paid to the following five aspects in the formulation of relevant national policies and development plans.

(1) Controlling the degradation of black soil and the reduction of obstacle factors. The comprehensive control of water and soil erosion should be strengthened in northeast China. In the rolling hilly area with black soil, the technical measures for soil fixation and water retention, such as contour planting and vegetation restoration in the ridge zone can be taken. In the hilly area, we can take measures for slope treatment in a small watershed, such as slope-to-terrace and blind ditch and mole-pipe drainage. For erosion gully treatment, measures such as gully head protection, check dam, small reservoir and dissected gully landfill can be taken. Conservative tillage should be promoted to contain the thinning of surface black soil. The straw can be directly returned to the field directly or composted before returning to the field. Manure can be used for farming to ensure the cycling of organic materials, which will ensure the stable increase of organic matter in black soil. Efforts should be made to improve the construction of high-standard farmlands, promote balanced fertilization and soil remediation, and curb the soil acidification. In the medium- and low-yield fields, especially sandy and saline-alkaline areas, ecosystem restoration and biological improvement of soil should be carried out to improve the soil quality.

(2) Restoring forests and reconstructing the new agroforestry system. Ecological barriers, especially the forest and grass ecosystems breeding black soil and the shelterbelts protecting farmlands, are essential to black soil protection. We should vigorously restore the vegetation of woodland and meadow in the critical zones of black soil protection, such as water source regions and riparian zones. For the cropland on steep slope with black soil vulnerable to erosion, priority should be given to protect and restore forest vegetation. For the black soil cropland on slopes of 8°–15°, restoration of vegetation in woodland and meadow should be considered. Shelterbelt/shelter network for ecological protection of farmland should be constructed to optimize the forest-farmland landscape pattern. The shelter network should be built with different grids according to the degree of soil erosion (Figure 5). An ecological compensation mechanism for shelterbelt should be established to improve the motivation in the construction of shelterbelt.

Figure 5 Sketch map for the construction of mountain-river-forest-farmland-lake-grassland-sandy land ecosystem

(3) Strengthening the monitoring and optimizing the allocation of water and soil resources. While adhering to the “three redlines” of water resource management and the redline of wetland protection issued by the State Council in 2013, we should follow the principle of basing land development on water resources, and balance the water resources for farmland and wetland in northeast China. In the semi-arid area of central and western China, we should control the proportion of paddy fields and carry out ecological water compensation of wetlands appropriately. In Sanjiang Plain, we should reasonably arrange paddy fields and protect the biodiversity of wetlands. In Liaohe Plain, the allocation of paddy-planting should be adjusted for controlling nitrogen and phosphorus output and curbing ecoenvironment deterioration.

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(4) Optimizing the ecosystem allocation on the watershed scale. The areas with pivotal ecological functions, such as biodiversity conservation, and the fragile regions should be included in the ecological conservation redline. The integrated development strategy for mountain-river-forest-farmland-lake-grassland-sandy land ecosystem should be implemented, and the construction of black soil ecological protection (barrier) model be carried out.

(5) Strengthening the research on the functioning mechanism of the mountain-river-forest-farmland-lake-grassland-sandy land ecosystem. It is suggested to comprehensively evaluate the contribution of mountain-river-forest-farmland-lake-grassland-sandy land ecosystem to black soil protection, and study the basic theory and technology for the ecological barrier construction in northeast China.

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