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Ensuring National Food Security by Strengthening High-productivity Black Soil Granary in Northeast China

Baoguo LI
College of Land Science and Technology, China Agricultural University, Beijing 100193, China,
libg@cau.edu.cn

See next page for additional authors

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Ensuring National Food Security by Strengthening High-productivity Black Soil Granary in Northeast China

Abstract

Food security is an important guarantee of national security. The northeast black soil region is an important commodity grain production base in China, which plays a fundamental role in ensuring national food security. However, the highly intensive, unreasonable or excessive use of cultivated land in this region has caused serious black soil degradation. Therefore, how to make the Black Soil Granary to provide efficient and sustainable guarantee for national food security is a scientific problem requiring urgent solutions. This paper systematically illuminates the agricultural development of high-productivity black soils since the reform and opening-up. On this basis, the paper systematically summarizes the problems facing the sustainable development of grain production in the black soil region. Furthermore, to meet the requirements of the central government for agricultural production in Northeast China, it puts forward the corresponding countermeasures to coordinate food security and ecological security and to enhance the sustainable development of grain production, intending to provide reference for the sustainable agricultural development in the northeast black soil region, and offer scientific guidance for the strategic planning of national food industry strategy, agricultural policy making, and strengthening of national food security.

Keywords

black soil, food security, Black Soil Granary, land degradation

Authors

Baoguo LI, Zhong LIU, Feng HUANG, Xiaoguang YANG, Zhijuan LIU, Wei WAN, Jiangkuan WANG, Yingde XU, Zizhong LI, and Tusheng REN

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Ensuring National Food Security by Strengthening High-productivity Black Soil Granary in Northeast China

LI Baoguo[1], LIU Zhong[1], HUANG Feng[1], YANG Xiaoguang[2], LIU Zhijuan[2], WAN Wei[1], WANG Jingkuan[3], XU Yingde[3], LI Zizhong[1], REN Tusheng[1]

1. College of Land Science and Technology, China Agricultural University, Beijing 100193, China;
2. College of Resources and Environmental Science, China Agricultural University, Beijing 100193, China;
3. College of Land and Environment, Shenyang Agricultural University, Shenyang 110866, China

Abstract: Food security is an important guarantee of national security. The black soil region of Northeast China is an important commodity grain production base in China, which plays a fundamental role in ensuring national food security. However, the highly intensive, unreasonable or excessive use of cultivated land in this region has caused serious black soil degradation. Therefore, how to make the Black Soil Granary sustainably guarantee national food security is a scientific problem requiring urgent solutions. This paper systematically illuminates the agricultural development of high-productivity black soils since the reform and opening-up. On this basis, the paper systematically summarizes the problems facing the sustainable development of grain production in the black soil region. Furthermore, to meet the requirements of the central government for agricultural production in Northeast China, we put forward the corresponding countermeasures to coordinate food security and ecological security and to enhance the sustainable development of grain production, intending to provide reference for the sustainable agricultural development in the black soil region of Northeast China, and offer scientific guidance for the strategic planning of national food industry strategy, agricultural policy making, and strengthening of national food security. **DOI:** 10.16418/j.issn.1000-3045.20210706003-en

Keywords: black soils; food security; Black Soil Granary; land degradation

The administrative region of Northeast China Plain (NECP) covers Liaoning Province, Jilin Province, Heilongjiang Province, as well as Chifeng City, Tongliao City, Hulunbuir City, and Hinggan League of Inner Mongolia Autonomous Region (hereafter "four eastern cities/league of Inner Mongolia"). As one of the four major black soil regions in the world, the NECP has rich fertile black soils and is an ideal farming place. Currently, the NECP has a farmland area of 3.59×10^7 ha [1,2], which produces nearly a quarter of the total grain production in China. The NECP is considered as China's First Grain Granary because approximately one third of the total grain output is exported to other regions of the country. Thus, the NECP is the corner stone for China's national food security. In recent years, the overall grain production capacity of the NECP has been improving continuously, and its role in guaranteeing China's food security is consolidated. Nevertheless, the long-term intensive exploration has resulted in serious soil degradation and associated problems in the NECP [3,4]. The scientific communities have to overcome the relevant challenges to warrant the status of the NECP as a grain granary for national food security.

1 Agricultural development in the NECP since the launching of the reform and opening-up policy

(1) With continuous increases in cropping area and grain output, the role of NECP as the largest grain production base and grain commodity base is consolidated. From 1980 to 2019, the cropping area in the NECP increased from 1.55×10^7 ha to 2.85×10^7 ha, and the total grain output from 3.70×10^7 tons to 16.54×10^7 tons (Figure 1). In 1980, the total grain output of NECP accounted for approximately 12% of the national total, and the corresponding value increased to nearly 25% in 2019. At present, the grain export from the NECP accounts for about 1/3 of the national total, making NECP the largest grain production base and commodity grain base in China.

(2) With the introduction of more high-yielding crops, the structure of cropping system has been altered significantly. At the early stage of the reform and opening-up, maize, soybean, wheat, and rice were the major crops in the NECP. Among them, maize had the largest area that accounted for 35% of the total grain crop area. As a traditional key crop,

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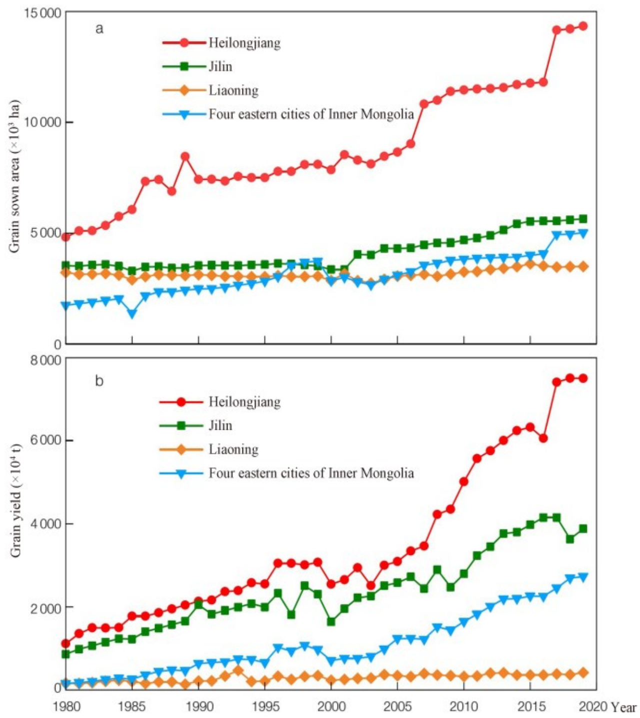

Figure 1 Changes of grain sown area (a) and grain yield (b) in Northeast China from 1980 to 2019

Data source: Statistical Yearbooks of Heilongjiang, Jilin, Liaoning, and Inner Mongolia.

soybean took about 19% of the total grain crop area, followed by wheat (16%) and rice (6%). Wheat was planted mainly in the piedmont plain of the Greater Hinggan Mountains and the Sanjiang Plain, while rice mainly in the low wetlands of Songnen Plain and Liaohe Plain. Miscellaneous grains such as sorghum, millet, buckwheat, oat, and beans accounted for about 21% of the total cropping area in 1980 (Figure 2). With the progress of the reform and opening-up, the cropping structure has been restructured dramatically because of the increasing demand for grain production in the NECP. The planting areas of productive crops (i.e., maize and rice) grew rapidly, while the areas of wheat and other cereals shrank gradually. Meanwhile, maize and rice were also planted in the newly reclaimed land. A marked decline of soybean planting area in the NECP occurred after China became a member of the World Trade Organization (WTO) in 2001. This trend was reversed slightly after soybean subsidy was introduced in 2016. In 2019, the planting areas of maize, rice, and soybean accounted for 54%, 22%, and 20% of the total crop area in the NECP, respectively, while that of wheat area accounted for less than 0.3% (Figure 2). Currently, the grain planting in the NECP is dominated by maize (with the largest area) and rice (dominant in some regions), with the recovered increase in soybean area and the shrinking area of wheat and miscellaneous grains.

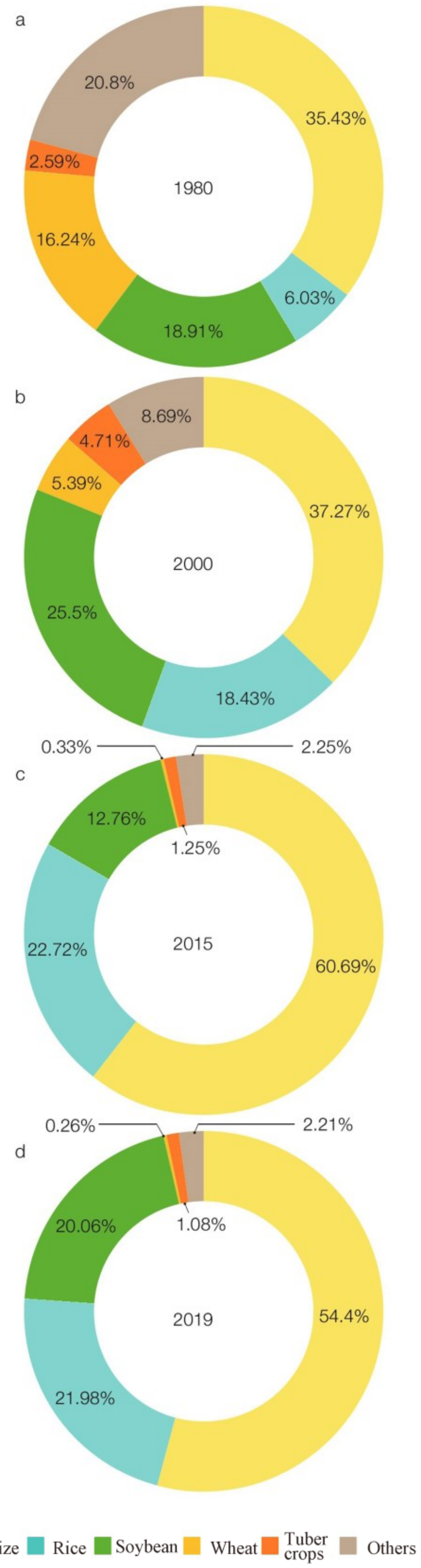

Figure 2 Changes of grain planting structure in Northeast China from 1980 to 2019

(a) 1980; (b) 2000; (c) 2015; (d) 2019; Data source: Statistical Yearbooks of Heilongjiang, Jilin, Liaoning, and Inner Mongolia.

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(3) The production capacity differentiated substantially among different regions, with much of the output increase from Heilongjiang and the four eastern cities of Inner Mongolia (Figure 1). In Liaoning, the total cropping area and the total grain output increased by 8.30% from 3.22×10^6 ha to 3.49×10^6 ha and by 98.92% from 1.22×10^7 tons to 2.42×10^7 tons during 1980–2019, respectively. In Heilongjiang, the total cropping area increased by 95.92% from 7.32×10^6 ha in 1980 to 14.34×10^6 ha in 2019, and the total grain output increased by 413.10% from 1.46×10^7 tons to 7.50×10^7 tons. In Jilin, the total cropping area increased from 3.52×10^6 ha in 1980 to 5.64×10^6 ha in 2019, and the corresponding grain output from 0.86×10^7 tons to 3.88×10^7 tons (a 351.10% increase). In the four eastern cities of Inner Mongolia, the period from 1980 to 2019 witnessed an increase from 1.39×10^6 ha to 5.02×10^6 ha in the cropping area and from 0.23×10^7 tons to 2.73×10^7 tons (1 096.70%) in the grain yield. Thus, Heilongjiang and the four eastern cities of Inner Mongolia respectively had the largest increase and the fastest increase in grain output in the NECP.

(4) Agricultural mechanization provides significant support for modern agriculture in the NECP. From 1980 to 2019, the total power of agricultural machinery increased by about 7 times from 1.79×10^7 kW to 14.61×10^7 kW in the NECP. The increase was especially obvious after 2003, which was along with the recovery trend of cereal crop area and the steady improvement of agricultural modernization thereafter (Figure 3). Nevertheless, the total power of agricultural machinery is characterized by a steady increase with slight fluctuation during that period, which differed from the trend of the total cropping area. Among the four areas, Heilongjiang had the fastest growth in the total power of agricultural machinery, while Liaoning and the four eastern cities of Inner Mongolia showed steady growth. In Liaoning, for example, the grain planting area showed no apparent difference during 1980–2019, while the total power of agricultural machinery kept increasing. This is an indication of significant improvement in agricultural mechanization in the NECP, which boosts the modernization of grain production.

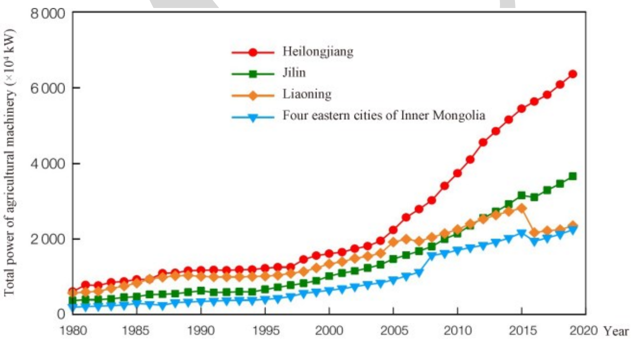

Figure 3 Changes in total power of agricultural machinery in Northeast China from 1980 to 2019

Data source:Statistical Yearbooks of Heilongjiang,Jilin,Liaoning and Inner Mongolia

2 Challenges for sustainable grain production in the black soil region of Northeast China

2.1 Serious soil degradation endangers the sustainability of grain production

After years of intensive utilization, black soils of the NECP have been facing varying degrees of degradation, depending on the locations, climates, years of exploration, resource characteristics, and modes of utilization. In general, soil degradation in the region has three common features: reduction of black soil layer thickness, decline of fertility, and increase of compaction. It has been estimated that the black soil layer is being lost at a rate of 2–10 $mm \cdot yr^{-1}$, and the organic matter content of plough layer has been reduced by more than 40% compared with that at the initial reclamation stage. About 50% of the farmland is facing problems such as the development of plow pan, salinization and alkalization, and formation of albic layer.

(1) Reduction of black soil layer thickness. Due to soil erosion from water, wind, and freeze-thaw cycles, the thickness of the black soil layer in the NECP has been reduced. On average, the thickness of the black soil layer was approximately 70 cm at the beginning of reclamation and decreased to less than 40 cm in most of the region or even less than 20 cm at present [5]. In some seriously eroded areas, a "yellow skin" appeared because the black soil layer has been lost completely.

(2) Decline of soil fertility. A second characteristic of soil degradation in the NECP is the decline of soil fertility. Before reclamation, the organic matter content in the plough layer was as high as 9% and reduced by one-third after 20 years. At present, the average organic matter content in the plough layer is 3.6%, 3.4%, 2.5%, and 1.7% in Heilongjiang, four eastern cities of Inner Mongolia, Jilin, and Liaoning, respectively [6].

(3) Increase of soil compaction. Bulk density is a direct indicator of soil compaction. For the native black soils, the bulk density generally ranged from 0.80 $g \cdot cm^{-3}$ to 1.00 $g \cdot cm^{-3}$ (with an average of 0.90 $g \cdot cm^{-3}$). The results from the second national soil survey (in 1982) showed that the bulk density of the plough layer fell in the range of 1.00–1.10 $g \cdot cm^{-3}$ (with an average of 1.05 $g \cdot cm^{-3}$). At present, the corresponding values have been increased to the range of 1.25–1.30 $g \cdot cm^{-3}$ (with an average of 1.28 $g \cdot cm^{-3}$). In some areas, the bulk density of the plough layer has exceeded 1.40 $g \cdot cm^{-3}$ [7].

The direct consequence of soil degradation in the NECP is the decline in potential productivity [8]. To sustain crop yields, the local farmers have to boost the external inputs such as chemical fertilizers. From 1980 to 2019, the amount of chemical fertilizer application has increased from 4.57×10^6 tons to 7.38×10^6 tons in the NECP. The surge of fertilizer input and continuous overdraft of soil resources not only reduce the profit of grain production, but also aggravate the degradation of black soils.

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2.2 The increase in total grain output comes mainly from the crop restructuring rather than the improvement of crop yield per unit area

In the NECP, the increase in total grain yield correlates strongly with the expansion of grain cropping area (Figure 1), which is especially true after 2003 when the proportion of low-yielding crops has been declining while that of high-yielding crops on the rise [9].

In fact, the grain production capacity and food security in the NECP are dominated by planting area and structure. Taking the case of Heilongjiang as an example, although the total planting area in 2016 remained essentially the same as in 2015, the fraction of maize area decreased to 46% (52% in 2015) and that of soybean area increased from 19% to 23%, which led to a 2.62% decrease in the total grain yield. From 2017 to 2019, the grain planting area kept increasing, which reversed the trend of grain output decline.

2.3 The simplified cropping system and insensitive practices increase the risks of soil degradation and pollution

In the NECP, the increased crop production since 2003 came mainly from the expansion of planting area and the planting of more high-yielding crops like maize and rice [9]. Currently, the area of maize and rice accounts for more than 3/4 of the total grain area. Particularly, maize area accounts for more than 54% of the total grain area, which leads to a cropping structure of maize dominating the whole NECP region while rice being concentrated in local regions.

Rice is the second largest crop after maize, with the area accounting for 22% of the grain area in the NECP. In 1980, rice was mainly planted in the south of Liaohe Plain, with small areas in the east of Songnen Plain and Sanjiang Plain, where the annual precipitation was 400–550 mm. Currently, the eastern Songnen Plain and the Sanjiang Plain have become the main rice producing regions in the NECP. In the past 40 years, 80% of the expanded areas of rice were distributed in the eastern Songnen Plain and the Sanjiang Plain with the annual precipitation less than 500 mm. In Songnen Plain, a significant increase (22%) in rice planting area even appeared in the areas with annual precipitation less than 350 mm. It is apparent that the expansion of rice planting area has no correlation with the spatial and temporal precipitation pattern in the NECP [10]. The large-scale expansion of rice cultivation has brought about the challenge of balancing water use between crop production and ecological demand. Because of the surge in agricultural water consumption, the natural wetlands in the NECP have been narrowed to half of that before the rice was introduced and fragmented into smaller ones. Meanwhile, with the shortage of ecological water, the pollution of surface water and shallow groundwater becomes a problem that threats the sustainability of grain production. Finally, because the paddy fields in the Songnen Plain are distributed mostly in saline-alkali lands, large-scale salt washing and drainage, in addition to soaking, evaporating, and drainage, are required before transplanting, to ensure the growth of rice seedlings. Thus, the frequent wetting/drying cycles in the rice cultivation area of Songnen Plain produce more non-point source pollutants, which makes the output pollution load per unit area 521 times of that in dryland [11].

The continuous cropping of single crops is another driving factor that not only aggravates unbalanced absorption of soil nutrients but also deteriorates soil structure, which accelerates degradation of soil and water quality in the NECP.

2.4 Excessive exploitation of water resources in local areas endangers regional ecological security

In the context of global change, the precipitation in the NECP decreased in the last 30 years, with considerable fluctuations within and among years [12]. The extremely unstable precipitation and water resources directly regulate the available water for crop production. In the NECP, Liaoning has the largest inter-annual difference in surface and total water resources, followed by Heilongjiang and Jilin. In the last 20 years, the proportion of agricultural water consumption has been declining in China while increasing in the NECP, which directly reflects the growing importance of agriculture in the NECP (especially in Heilongjiang and the four eastern cities of Inner Mongolia). The rapid expansion of irrigation area is the major cause of the increasing agricultural water consumption. Meanwhile, due to the out-of-date irrigation techniques, a large amount of irrigation water is being lost in the field. According to the statistical data, the share of irrigated farmland has been increased by 57% in the NECP, whereas that of water-saving irrigation area in the total irrigation area only increased by 28%. Despite the obvious increase, the crop water efficiency still needs to be improved.

The water productivity of cereal crops has been improved significantly in the past 20 years, with the overall increase rate greater than 50% in the NECP. In general, Liaoning and Jilin have the water productivity of 600–700 m^3 per ton of grain, which is higher than that in other areas. The water productivity of Heilongjiang is expected to be reduced to 1 000 m^3 per ton of grain. Comparing the water productivity among major crops, we find that the water productivity of maize, with an increase of 40%–70%, has the most significant change in the past 20 years. Soybean, a key crop in the black soil region of Northeast China, showed insignificant change in water productivity, while its planting area and total output are in decline during the past 20 years. Under the "dual-cycle" development plan, soybean planting area is expected to be increased again in the NECP. To meet this need, we need to explore additional water resources for irrigation and develop new technologies capable of improving the water productivity of soybean as a high water-consuming crop. In the four eastern cities of Inner Mongolia, the amount and distribution of precipitation generally mismatch crop

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water demand, and thus farmland irrigation has been expanded at a fast rate in recent years, which has led to excessive groundwater exploitation and a series of environmental consequences [13]. We consider it is time to take action to reduce the area of irrigated farmland in this region.

2.5 Global climate change increases agricultural production uncertainties in the NECP

In the context of global climate change, the total solar radiation and average annual temperature in Northeast China in the last 30 years have been increasing at a rate of 29.5 MJ m^{-2} and 0.38 °C per decade, respectively, which are significantly higher than the global and national mean values. Accordingly, the accumulated temperature (≥ 10 °C) in crop growing season increased by 46.7 °C·d per decade, while the precipitation showed a declining trend with increasing inter-annual fluctuations. Consequently, the extreme weather events, such as drought, flood, high and low temperatures, and strong wind, have become more frequent and intensive. Specially, the frequent landfall of typhoons in July and August often leads to serious crop lodging every year, which seriously affects agricultural production [14–16].

Climate change has both positive and negative effects on agriculture in the NECP. If no appropriate measures are taken, the overall impact of climate change on crop production will be negative. Studies have demonstrated that in the scenarios of climate change, the potential yields of spring maize, rice, and soybean in the NECP will decrease by 0.33, 0.26, and 0.06 t·ha^{-1} per decade, respectively [17,18]. Meanwhile, the frequent extreme weather and climate events will increase the fluctuation and uncertainty of crop yield, posing higher risks to crop production. However, if appropriate measures are adopted, the overall impact of climate change on agriculture could be favorable in the NECP. For instance, the increase of heat resources would extend crop growing season, and the areas of maize and rice could be expanded northward and toward high-altitude areas. Specially, the planting area of middle and late maize varieties can expand northward, which brings new opportunities for optimizing the cropping system.

3 Strategies for sustainable grain production by synchronizing food and ecological security

As President Xi Jinping noted in July 2020, the black soil in the NECP is a "giant panda of cultivated land", and it is important to take measures to protect and make good use of it so as to benefit the human being forever. President Xi has also emphasized many times that "China must ensure national food security, and Chinese people's rice bowls must be firmly in their own hands." According to the National Agriculture Sustainable Development Plan (2015–2030), Northeast China is the priority region in agricultural development. On the premise of ensuring a steady increase in the comprehensive production capacity of grain and other major agricultural products, it is essential to protect agricultural resources and ecological environment for the achievement of stable development of agricultural production, sustainable resource utilization, and ecologically-sound environment.

In terms of productivity potential, if the high-quality black soils are well preserved and water resources effectively supplied, there are still some yield gaps to be filled in the NECP. It was estimated that in the past 30 years, the average potential yield of spring maize was 22.4 t·ha^{-1} (ranging from 16.1 to 26.7 t·ha^{-1}). With the current average value set as 8.4 t·ha^{-1}, further improvement of maize yield by 62.5% is expected [19,20]. For rice, the potential yield was 20.4 t·ha^{-1} (with a range of 15.8–25.1 t·ha^{-1}) in the cold region of the NECP in the past 30 years. Based on the current average yield of 10.5 t·ha^{-1}, rice yield can be further increased by 48.5% [18]. For soybean, the current yield was 1.9 t·ha^{-1}, and the potential yield was 5.5 t·ha^{-1} in the past 30 years (with a range of 3.3–6.9 t·ha^{-1}), leaving a 65.5% yield gap to be filled.

We have compared the compatibility between precipitation and crop water demand in the NECP during the growing season. For maize, the water demand is 383–633 mm, and the average annual precipitation varies within the range of 337–871 mm in the growing season. In general, the areas with precipitation lower than 540 mm cannot fully meet the water demand of maize. For soybean, the average water demand and precipitation are 510 mm and 464 mm, respectively, and there is a 46-mm water deficit. Generally speaking, the areas with less than 500 mm of precipitation during the growing season (such as the west and north of NECP) cannot fully meet the water demand of soybean. For rice, the average precipitation in the growing season is 432 mm, and 740–1020 mm and 274 mm supplementary irrigation is needed in the waterlogging management system and the dry/wet alternative management system, respectively [21]. Apparently, if the quality of black soil is ensured, the achievement of grain production potential in the NECP is largely determined by the supply of agricultural water resources. It is vital to balance the grain production improvement plan with the compatibility and supply capacity of local water resources.

To summarize, two conflicts have to be resolved to maintain stable or sustainable grain production in the NECP. The first is between utilization and protection. For decision makers, it is of vital importance to balance the relationship between utilization and protection in terms of the scope, scale, and execution time. The second is between state goals and farmers' demands. At the state level, the governments should consider both food security and long-term ecological security. At the household level, however, the farmers usually focus on short-term yield and net profit of crop production, with food security, ecological security, and agricultural sustainability being external effects of their operation. Thus, there is only a small portion of overlap but more conflicts between the state goals and farmer goals, which bring about

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challenges for the implementation of sustainable development strategy in the NECP.

As a key grain granary of China, the NECP has to meet the demands of national development plan in the face of profound global changes unseen in a century and under the "dual-cycle" development pattern. In the following section, we propose five suggestions for promoting system and mechanism innovation in the NECP, with the purpose of 1) supporting grain production and agricultural and rural modernization, 2) achieving the national food crop production strategy based on farmland management and technological application, and 3) strengthening national food security, the foundation of national security.

3.1 Putting emphasis on the trinity of policy, market, and technology to expand farm size and develop large-scale agricultural production systems

At present, governments of different levels, scientists, and producers in the NECP have reached the consensus that it is urgent to protect the black soils from further degradation. However, there are different views on resolving the conflict between black soil conservation and utilization, and a key factor that restricts the implementation of black soil protection is the scattered land management systems. The current household-based land management systems, which usually result in unstable productivity and are vulnerable to natural disasters, do not favor the execution and promotion of soil conservation practices as well as the sustainable agriculture in the region. Therefore, it is urgent to emphasize the trinity of policy, market, and technology, and to establish a long-term mechanism that ensures sustainable grain production in the NECP, which will speed up land circulation to more capable farmers and promote the development of large-scale and high-profit farmers.

In recent years, some progress has been made in land circulation in the NECP, as indicated by the emergence of professional cooperatives and other forms of associations as well as the good performance of large-scale production system. However, there are still difficulties in land circulation and operation. The greatest challenge is the lack of a social security system and the shortage of employment opportunities for the farmers with their land transferred. In the traditional rural system of China, land is not only the most important assets for crop production but also the center of farmers' social and psychological security. To encourage farmers to transfer their lands, it is important to provide them certain forms of social security so that they will do land transfer without any worry about the future. Meanwhile, the local governments need to create more job opportunities for the farmers by extending the chain of grain production with the regional advantages in the NECP.

For the establishment of a long-term mechanism that promotes sustainable grain production in the NECP, it is essential to explore the pilot role of policies, the resource allocation role of markets, and the promotion role of advanced science and technology (in improving quality and efficiency). In terms of research development, research institutions are encouraged to work together with professional cooperatives to produce down-to-earth achievements. In terms of market, it is important to make innovations in the financial, insurance, and information systems, which are essential for the stable and healthy grain production in the NECP. In terms of policies, the governments should strengthen the current agricultural subsidy and minimum purchase-price policies that provide guidance for land transfer, cropping structure, and implementation of conservation tillage. At the same time, the government should bring together the different sectors and coordinate the different goals, so as to achieve a win-win scenario for the state and farmers, and for crop production and ecosystem protection.

3.2 Coordinating policy, research, marketing, and operational elements to accelerate the extension of conservation tillage in the black soil region

In 2017, the Ministry of Agriculture and Rural Affairs, the National Development and Reform Commission, the Ministry of Finance, the Ministry of Land and Resources, the Ministry of Ecology and Environment, and the Ministry of Water Resources jointly formulated the *Guideline on Protecting Black Soil in Northeast China* (*2017–2030*). According to this guideline, integrated conservation technologies will be applied in large scale in the NECP by 2030, covering about 250 million mu (1 mu = 667 m^2) of black soils. In February 2020, the Ministry of Agriculture and Rural Affairs and the Ministry of Finance jointly formulated the *Action Plan of Conservation Tillage in Black Soils of Northeast China* (*2020–2025*). This plan further specifies that maize is the key crop for the application of conservation tillage, and soybean, wheat, and related crops will also be covered. The target is that, by 2025, conservation tillage will cover an area of 140 million mu, which accounts for approximately 70% of the total cultivated land area in the NECP. To bring the above national plans into reality, more detailed and targeting plans and policies are required, including a complete set of subsidies, incentives, finance, industries and organization. These measures will encourage farmers, farmer cooperatives, large family farms, and other agricultural organizations to adopt the new conservation technologies such as the "Lishu model" [22], and finally achieve a win-win goal between the state and farmers.

3.3 Balancing agricultural production and ecosystem conservation and optimizing the planning of production, living, and ecological water consumption

In 2019, the black soil region had the total grain yield of 16.54×10^7 t, the water consumption of 830 m^3 per ton of grain, and a total water consumption of 13.73×10^{10} m^3 for grain production, in which about 3.14×10^{10} m^3 was provided by irrigation. Considering the fact that the region has an irrigation water use efficiency of 0.598, the gross irrigation

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water use was 5.25×10^{10} m^3 in 2019, which is equivalent to the agricultural water consumption of 5.20×10^{10} m^3 in the black soil region. As a key commodity grain base for ensuring national food security, the NECP needs to strengthen gain production, which leads to a key question: Is there enough water resources to guarantee the grain production? Our estimation, taking 105% grain yield (i.e., 17.37×10^7 tons) in 2019 as the upper limit of grain output and some improvement in irrigation water use efficiency and water productivity, showed that the annual irrigation required for grain production will be within the range of $2.92–4.74 \times 10^{10}$ m^3. The estimates are within the national water use red line for the black soil region in 2035. Thus, as long as no extreme climate change occurs in the future, the water resources in the NECP can fully meet the water demand for grain production increase. Nevertheless, to achieve the multiple goals of food security, ecological harmony, and social and economic development, it is important to coordinate the water demands for production (industry and agriculture), eco-environment (ecological civilization), and living (e.g., urbanization), and to optimize the overall planning of production, living, and ecological water use. For the eastern four cities of Inner Mongolia, it is important to establish an agricultural system that is in accordance with water carrying capacity and can sustain the eco-environment and grain security. For this reason, agricultural planning should follow the principles of water-adapted development and planting, and it is recommended to reduce the grain crop area (especially the irrigated area).

3.4 Formulating and implementing crop production strategies in response to climate change and establishing disaster warning, prevention, and control systems

It is expected that the NECP will have more heat resources, less solar radiation and precipitation, and larger uncertainties in extreme weather and climate events. Although the heat condition is beneficial to grain production, the frequent extreme climate associated with climate warming will certainly increase the frequency of drought and cold damage on crop production. Thus, a new crop production strategy that integrates soil conditions, crop varieties, production levels, and other factors should be formulated to cope with climate change.

In view of the aggravation of agrometeorological disasters due to climate change, it is of great practical significance to establish and improve the early warning and prevention systems in response to meteorological disasters. First, an improved weather and climate forecast system can avoid agricultural production losses caused by climate change. For this purpose, it is necessary to establish a complete indicator system for agricultural meteorological disaster monitoring and evaluation to understand trends, scale, and degree of impaction of major agricultural disasters, to improve the accuracy of disaster monitoring and warning, and to establish emergency plans that can effectively reduce the production and economic losses due to extreme events. In the future, the construction of high-standard farmland (whether paddy fields or arable lands) should give the priority to the building and maintenance of drainage system, which is the most effective measure for preventing and control waterlogging and soil water erosion. Meanwhile, an early prediction and warning system for the occurrence and development of potential diseases and insect pests due to climate change [23] should be built for coping with future climate changes.

3.5 Advancing science and technologies for sustainable agricultural development in the NECP

In terms of basic research, scientists are encouraged 1) to focus on the important basic theories and principles about the interaction among conservation, nurturing, and utilization of black soils; 2) to develop key technologies for prevention and control of soil degradation, improving soil fertility, and increasing crop yield and resource use efficiency by integrating agronomy, agricultural machinery, and water management practices; and 3) to establish an integrated space-air-earth monitoring network that serves black soil conservation and production.

It is expected that the above actions and the joint efforts of all the partners can curb the trend of soil degradation, reduce the soil erosion rate, and increase soil organic matter to some extent in the NECP in the next five years. In terms of quantitative indicators, soil fertility is expected to be increased by 0.5 grade, total grain output by 2.50×10^7 tons, and the economic profit by 5%–10%. By 2030, the degradation of soil and water resources in the NECP will be fully under control, and grain production capacity will be increased at least by 5% compared with that in 2025. By then, the black soil areas of the NECP will become the first grain granary of China, with high and stable yield, efficient resource use, and ecologically sound environment, which will serve as a key player of national food security and ecological security.

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LI Baoguo, corresponding author, Distinguished Professor and Dean of the College of Land Science and Technology at China Agricultural University. Dr. Li is a fellow of the Soil Science Society of America and American Society of Agronomy. He works on quantifying the soil-plant system and utilization of soil and water resources. As a principal investigator, he has presided over multiple research projects including Monitoring and Prognosis of Regional Water and Salt, Water-saving Agriculture of North China Plain, Optimization Model of Comprehensive Desertification Control in Northwest China, Modeling Technology in Precision Agriculture, and Conservational Management of Black Soil in Northeast China. E-mail: libg@cau.edu.cn

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