Theoretical basis and technical path for the regional all-for-one customization model of black soil granary

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Abstract: The black soil area in Northeast China serves as a “ballast” to ensure China’s food security. Unreasonable development and utilization lead to serious black soil degradation in some areas and affect regional food production and economic and social development. In the context of the intensification of the contradiction between food supply and demand worldwide, we should pay more attention to the overall situation of regional sustainable development and seek for systematic, scientific, and economic solutions. This study establishes a regional all-for-one customization model of black soil granary on the basis of the regional system of human–land relationship, customized and accurate management, agricultural system theory, and agricultural informatization with the guidance of integrated geography concept. The aim of this regional all-for-one customization model is to systematically diagnose the key problems and leading factors of black soil degradation and determine a solution that combines the commonness and individuality of black soil protection from the perspective of multiscale linkage, multifactor coupling, and multitechnology cooperation. The regional all-for-one customization model of black soil granary integrates the two perspectives of “regional” and “customization” into the protection and comprehensive utilization of black soil for the first time. It adopts zoning, grading, and classification as the main strategy and big data and artificial intelligence as the main technical approaches. This model constructs three strategies of different scales by combining the “satellite–air–ground–network” 3D monitoring system and the all-for-one customization platform driven by big data and artificial intelligence. First, the “implementing strategies by regions” are implemented at the regional scale to formulate the regional agricultural resource allocation scheme and agricultural zoning, which can provide strategies to protect and utilize black soil effectively. Second, the “determining strategies in accordance with villages” are implemented at the village scale to formulate a black soil protection and utilization model for different categories of villages, which can promote the or-

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ganic integration of black soil protection and rural revitalization. Third, a “one strategy for one field” concept is applied at the field scale to provide accurate strategies for soil restoration and yield improvement in a fixed, quantitative, and regular manner. Multiscale integrated demonstration and scheme verification of the regional all-for-one customization model of black soil granary are conducted in Qiqihar City at three scales, namely, region, village, and field, to solve the key issues in black soil protection and utilization and form a replicable and popularized system solution, thereby providing a model for the sustainable development of Chinese and global black soil agriculture. The proposed regional all-for-one customization model of black soil granary has important theoretical and practical value in promoting the high-quality development of regional agriculture and rural revitalization, and provides a demonstration model of land protection and utilization for the black soil area in China and the whole world.

Keywords: black soil granary; all-for-one customization; mode; platform; conservation tillage

1 Introduction

The global population faced with hunger reached as high as 720,000,000 to 811,000,000 in 2020, with a growth rate of 18% in comparison to that in 2019. The undernourished population accounted for about 9.9% of the total global population, which was higher than the percentage (8.4%) in 2019 (FAO, 2021). The current period is one of the periods with the severest global hunger throughout the history of mankind. The global situation of food security will be further aggravated because of the sustained evolution of COVID-19 and the global economic recession due to the epidemic. Although China is now in the best historical period of food security, it still has a long way to go to meet the strategic needs of coping with major risks and challenges, which can be handled with sufficient abilities, confidence, and conditions only by building a strong national food security defense line, ensuring the domestic food supply and sticking to the strategic factor—food security. The black soil region in northeast China undertakes the primary task of ensuring the national food security. Focusing on the black soil protection problem, General Secretary Xi Jinping has clearly suggested that “effective measures should be taken to protect the soil which is as treasurable as giant pandas.”

With the grain yield accounting for approximately one-fourth of national total grain yield, northeast China, which is the most important grain production base and marketable grain output base, is praised as a “ballast stone” of China’s food security and plays an irreplaceable role in guaranteeing the national food security (Deng et al., 2022). Despite the advantages in water and soil resource endowments needed by agricultural production, the black soil region in northeast China is subjected to weak erosion resistance of black soil and increasingly serious water and soil erosion and degraded soil fertility due to the long-term unreasonable development and utilization (Liu X et al., 2021). In the past four decades, obvious utilization-conservation imbalance and soil degradation have occurred in black soils in China, and the soil organic matter content has declined by 30%–40%, accompanied by the hardening of black soil layers in cultivated lands and the thinning of black soil layers in slope farmlands; thus, the soil protection should be further strengthened (Du and Zhang, 2021; Ge et al., 2021). The sustained degradation of black soil has seriously restricted the exertion of crop production potentials and the sustainable agricultural development in major grain producing areas in northeast China.
In recent years, China has achieved considerable progress in black soil protection and formed a series of technical systems focusing on conservation tillage for black soil protection with remarkable effects (Han and Zou, 2018). Black soil protection measures centering on cultivated lands have been popularized on a large scale. However, the overall environmental deterioration in the black soil region in northeast China has not been radically restrained, where the critical problem exists in the lack of systematic solutions adaptable to local conditions. Black soil degradation is a systematic process, which is affected by natural processes, such as wind erosion and water erosion, and results from unreasonable agricultural production activities. It is also susceptible to the regional climatic environment and socioeconomic activities and is influenced by local topographies, landforms, and production behavior of peasant households (Liu H et al., 2021). Systematic solutions should be proposed from the macroscopic perspective of regional sustainable development in addition to the protection and utilization of cultivated lands to protect and comprehensively utilize black soil.

Agricultural system is a complex macrosystem that can be improved integrally by exploring paths to solving problems from the perspectives of system factor composition, interaction mechanism, and coupling action rather than relying on single technological breakthroughs. Given the prominent problems existing in the protection and utilization of black soil in northeast China, regional all-for-one customization system solutions to the black soil protection and utilization should be constructed from different scales—region, village and field—through comprehensive and systematic thinking under the guidance of geographical theories. Efforts should be exerted to realize efficient soil conservation and create excellent agricultural products, thereby rendering a demonstration prototype for the high-quality utilization and long-acting conservation of black soil in the black soil region in northeast China and even global black soil regions.

2 Domestic (Chinese) and foreign development status of black soil protection and comprehensive utilization

2.1 Knowledge graph analysis of studies on black soil protection and comprehensive utilization

Related studies before September, 2021 were searched with the keyword “black soil protection” in China National Knowledge Infrastructure (CNKI) kernel database and “Web of Science (WoS) core collection” database. A total of 635 WOS studies and 671 CNKI studies were acquired, respectively, and the knowledge graph domains were drawn via Citespace (v.5.8.R1). The keyword clustering results of two databases were different to some extent. In the CNKI database, the keywords with the highest occurrence frequency were black soil, black soil region in northeast China, water and soil loss, and black soil in cold regions (Figure 1a). The studies regarding black soil protection in China have mainly concentrated on the black soil region in northeast China, with the main study contents of organic matter content, straw returning to the field, and soil erosion. In the WoS database, black carbon, soil, and biological control appeared at the highest frequency (Figure 1b). The worldwide studies on black soil protection have focused on black carbon, and biological prevention and control, microorganisms, and biochar have been the research hotspots.
The timeline clustering analysis of keywords shows that CNKI studies have gradually developed from single water and soil loss or conservation tillage into a multiangle multiscale comprehensive prevention and control mode (Figure 1c). Since 2013, keywords, such as “brand” and “protective utilization” have gradually emerged in studies regarding black soil protection in China, indicating that black soil protection has developed toward protective utilization, being gradually perfected from single “effective conservation” into “effective utilization and conservation.” In the WoS studies, relatively single research hotspots have focused on biochar and adsorption, which are closely related. The main research directions can be generalized into two aspects: biochar-assisted carbon capture or greenhouse gas emission reduction and biochar-based pollutant adsorption (Figure 1d).

Evident differences were observed between in the CNKI and WoS database retrieval results in terms of keyword clustering and their timelines. The black soil tillage intensity in China is the highest all over the world, in which a high-intensity tillage mode will be continued. Foreign experience and lessons cannot be directly applied to the soil protection in black soil regions of China. Hence, a regional-scale systematic solution with Chinese characteristics must be constructed to realize the efficient protection and comprehensive utilization of black soils.

2.2 Summary of technical systems for black soil protection and comprehensive utilization

Black soils in the world are distributed in four major regions in patches: Ukraine Dnepr
River Great Plain in the southwest of Russia, Mississippi River in North America, Argentina Pampas Steppe in South America, and Songnen Plain, Songliao Plain, and Sanjiang Plain in northeast China. In the 1920s–1930s, black soil regions in America and Russia were subjected to large-scale sandstorms and droughts due to excessive reclamation and utilization, which led to famines. Since the 1950s, America and Russia have alleviated the land utilization intensity and restrained black soil degradation when summarizing large-scale reclamation experience and lessons by promoting conservation tillage technologies, constructing farmland shelterbelts, and implementing grain–soybean rotation, grain–grass rotation, and fallow (Jia et al., 2010). At the beginning of the 20th century, the black soil degradation in northeast China started to gain extensive attention, accompanied by the gradual development of related technologies. In this research, the materials regarding the existing black soil protection technologies in China were collected. The following technical system (Figure 2) was investigated in accordance with the agricultural “Eight-Point Charter for Agriculture,” namely, “soil, fertilizer, water, variety, dense planting, environmental protection, management, and machinery.”

For “soil,” the soil improvement at the plough layer is the core content. Specifically, straws or exogenous carbon sources generated in agricultural production are applied to soil in cooperation with reasonable tillage measures, such as no-tillage and reduced tillage, organic matters are supplemented in black soil layers, a deep and fertile plough layer (Singh et al., 1994; Dashtpagerdi et al., 2015) is formed, soil physical properties, such as bulk density, moisture, and structure conditions are improved, and the organic carbon content in soil is increased (Xu et al., 2010). “Fertilizer” refers to reducing the excessive reliance of agricultural production on chemical fertilizers through the reasonable regulation of fertilizers, increasing the proportion of organic fertilizer application, and reducing the application of chemical fertilizers, to solve problems, such as inaccurate nutrient management, the huge drain of nutrient substances, and handling massive wastes in animal husbandry (Sui et al., 2018). For “water,” a technical system of water and soil conservation is established to solve the water and soil loss problem in black soil regions, and various erosion prevention and control measures are scientifically and optimally configured in accordance with the slope direction, slope gradient, slope length, and land utilization type in different regions with different erosion types (Liu et al., 2013; Zhang and Liu, 2020). For “variety,” rotation and high-quality and high-yield variety breeding technologies are promoted to solve problems, such as single crop varieties, biodiversity degradation, and fragile ecosystem in black soil regions, thereby recovering the biodiversity (Calegari et al., 2013). For “dense planting,” the soil fertility is regulated, and the crop yield is increased by adjusting the crop planting density or planting pattern to solve problems, such as low utilization efficiency of photothermal, water and manure resources, soil environmental degradation at seeding layers, and plough layer shallowing (Sun et al., 2018). “Environmental protection” includes plant protection technologies, such as biological prevention and control of plant diseases and insect pests, and fertilizer-pesticide double-reduction and efficiency enhancement. The quality of soil and crops is improved, whereas the input of pesticides and chemical fertilizers is reduced (Qu et al., 2020). For “management,” a management mode is constructed for the comprehensive utilization of agricultural resources to solve the waste of resources and ecoenvironmental deterioration resulting from the unreasonable resource utilization, which can increase farm-
ers’ income while solving resource and environmental problems (Feng and Zhao, 2020). “Machinery” refers to improving the efficiency of traditional agriculture and effectively promoting soils by using agricultural equipment, such as subsoilers, no-tillage seeders, returning straw crushing machines, corn kernel direct harvesters, straw picking and packaging machines, and kernel drying machines (Sun et al., 2021).

**Figure 2**  Technical system of black soil protection and comprehensive utilization

Different black soil protection technologies are interconnected and usually used together in practice rather than mutually isolated. “Lishu mode,” comprehensive water and soil loss prevention, and control in Baiquan County, and Helen “bird mode” are three typical cases integrating single black soil protection and comprehensive utilization technologies. For the “Lishu mode,” no-tillage and reduced tillage are implemented for farmlands to reduce soil disturbance as much as possible, and crop straws are used to cover the farm land surface, thereby reducing soil erosion and water erosion and enhancing soil fertility and drought resistance. Up to July, 2021, the “Lishu mode” has been popularized in 3 million ha of farm land across China, in which the soil moisture content was increased by 20%–40%, and the organic matter content at the depth of 0–20 cm of plough layers was elevated by 12.9% (Ao et al., 2021; Han et al., 2021). Located in rolling hill regions in the middle of Heilongjiang Province, Baiquan County is a representative region in the aspect of comprehensive water and soil loss prevention and control in the black soil region in northeast China. In this county, a technical system of engineering-biological integrated prevention and control has been constructed with engineering measures as the support, biological measures as the main body, topographic features as the basis, and water and soil conservation as the objective, thereby markedly reducing the soil erosion intensity. Compared with the situation in 2000, 99.5% of
intensely eroded regions evolved into moderately (or below) eroded regions in 2015. During 2011–2015, the total area of water and soil loss decreased by 193.8 km$^2$ (Sheng et al., 2015; Zhang et al., 2018). For the Helen “bird mode,” progeny selection is performed through the breeding method combining hybrid selection and pedigree method. Ten new early-maturing, high-yield, and broadly adaptable “Dongsheng” soybean varieties with superior commodity attributes have been cultivated with this mode. The direct economic benefits resulting from the transformation of series varieties amounted to 20 million yuan. This mode has been popularized in accumulatively 3 million km$^2$ of land, increasing the soybean yield by 1 billion kg and the economic benefits by 3.6 billion yuan (Han et al., 2019).

2.3 Necessity to develop a comprehensive integration model of black soil granary

China has achieved great progress in black soil protection and comprehensive utilization and formed a series of technical systems for water and soil conservation with remarkable effects by systematically combing the above domestic and foreign research status (Han and Zou, 2018; Zeng et al., 2021). A major difficulty faced in the present black soil protection exists in making scientific and reasonable decisions from numerous technologies in accordance with local conditions. As revealed by the literature analysis, no excessive attention should be paid to single practice because good effects cannot be obtained wherever possible through single practice in face of the complexity and multisidedness of nature. Hence, no blind efforts should be exerted to seek for universally applicable solutions, but the key depends on the practice fitting of the local environment and catering to the local regional development trends (Xiao et al., 2021).

Black soil protection has been lifted to an unprecedented height due to prominent problems related to global food security, thereby proposing higher requirements for black soil protection strategies. The technology model of black soil protection should be determined in accordance with local conditions rather than “one-size-fits-all approach.” Specifically, appropriate agricultural development models should be chosen for different regions with different eco-economic types under different conditions through intelligent and scientific decision making, and different technical measures should be taken.

“Adjusting measures to local conditions” efficiently remains to be solved. The paths to solving problems should be sought on the basis of the system factor composition, interaction mechanism, and coupling action from the integrated dimensions of resource utilization, operation efficiency, system flexibility, and sustainability. Resource integration and industrial convergence should be realized from a regional scale, and production factors, such as “man, soil, fertilizer, water, variety, and cultivation,” should be planned as a whole, and economic, engineering, agricultural machinery, and biological means should be comprehensively utilized to construct a rural complex black soil ecosystem model featured by the common prosperity of “man-land-industry” and establish a regional all-for-one (region-village-field) customization black soil decision supporting platform.

The progress in data science and analysis tools has provided an important opportunity to make breakthroughs regarding agricultural research and knowledge application. The development of big data, artificial intelligence (AI), machine learning, blockchain, and other technologies has provided the ability to rapidly collect, analyze, store, share, and integrate heterogeneous data and considerably strengthened the ability to solve complex problems. In
the modern intelligent agriculture, mass information about agricultural conditions can be acquired in a multiscenario and total-factor fashion via sensing technologies, such as the Internet of Things (IoT) and 3S (remote sensing, geography information systems, and global positioning systems). Many research results in related fields, such as agriculture and resources, can be applied in production practice by using information technologies, such as cloud computing and AI. Data can be automatically integrated under dynamic changes for the sake of real-time modeling so as to facilitate data-driven intelligent control (Zheng et al., 2005; Chen et al., 2021).

In countries like America and Israel, relatively mature agricultural decision management and control platforms have been formed on the basis of technologies, such as sensing technologies and IoT, including Climate FieldView™ of Monsanto Company and NETBEAT™ of Israeli Netafim Company (Table 1). These companies have provided advanced data collection and analysis technologies, which have greatly improved the agricultural production efficiency and productivity. However, most of such agricultural intelligent decision systems have been designed to serve crop growth and improve economic benefits but not linked up with black soil protection and its protective utilization. In 2005, a black soil fertility management information system of Northeast China was developed on the basis of SuperMap system. However, this system only exerted the function of managing fertility data while ignoring the complex problem, that is, current ecoenvironmental deterioration in black soil regions in addition to making intelligent decisions.

A regional all-for-one customization pattern of black soil granary should be constructed, and a regional all-for-one comprehensive customization system should be developed to ensure food security and protect the soil which is as treasurable as giant pandas. The intelligent decision model integrating black soil protection and its efficient utilization should be modernized, and comprehensive technology integration and application demonstration in typical regions should be conducted.

3 Theoretical foundation and basic framework for the regional all-for-one customization model of black soil granary

3.1 Theoretical foundation for the regional all-for-one customization model of black soil granary

3.1.1 Territorial system theory of man–land relationship

Human social activities interact with the geographical environment to constitute a complex system with certain structural and functional mechanisms. In this system, the material cycle and energy conversion between human society and geographical environment are combined to facilitate the development and changes in man–land system. Human society, which is of subjective initiative, can proactively recognize, utilize, and transform the geographical environment. As a spatial carrier and material basis for human social activities, the geographical environment influences the depth, breadth, and speed of human activities. The coordination of contradictory man–land relationship has been comprehensively discussed in the comprehensive research on geography and other sciences. During the long-term research on man–land relationship, the “idea of god”-based god and spirit theory and agnosticism, plain
| System                                      | Country      | Description of main functions                                                                                     | Time  | Data–technology–application integration status                                                                 | Scope of research                  | Application scenario                                                                 | Sharing mechanism |
|---------------------------------------------|--------------|-------------------------------------------------------------------------------------------------------------------|-------|----------------------------------------------------------------------------------------------------------------|-----------------------------------|--------------------------------------------------------------------------------------|------------------|
| Regional all-for-one customization model of black soil granary | China (this research) | Whole black soil region of China—demonstration area—field data management and technology integration; construct a multicomponent and multisystem coupled regional all-for-one integrated intelligent black soil control and decision supporting system to comprehensively improve the refined, efficient, and intelligent management level of black soil utilization and conservation | 2021  | From data integration to technology integration and then system integration                                     | Regional all-for-one customization | Combination of peace-time and wartime use                                              | Open sharing     |
| Climate FieldView™                        | America      | Realize centralized data collection, help farmers to optimize farmland decision making, and improve the productivity. Provide data analysis service and help farmers to manage farmland variables more precisely | 2018  | Provide data collection and analysis services                                                                  | Specific field                     | Agricultural condition monitoring and data management                                | Payment          |
| NETBEAT™                                   | Israel       | “Soil IoT,” implement precise farmland irrigation and fertilization through ground IoT terminal without data sharing interface, and crop varieties involved are limited | 2015  | Only monitor ground data and accurately control water and fertilizer                                         | Specific field                     | Agricultural condition monitoring and water and Payment fertilizer management         |                  |
| AgEagle                                    | America      | Perform remote sensing monitoring of farmlands by using unmanned aerial vehicles (UAVs), construct a system to realize cloud management of remote sensing information, and provide crop yield prediction and warning functions for plant diseases and insect pests. | 2015  | Only UAV data integration is performed, without management and control technology or application system       | Specific field                     | Agricultural condition monitoring, diseases and pests warning, without evaluation of agricultural disasters like flood | Payment          |
| Intelligent agricultural system            | China        | Mainly includes intelligent agricultural screen, data acquisition and monitoring module, control module, traceability module, expert module, and characteristic module. | 2020  | Realize data integration and technology integration for specific field, functions to be determined in accordance with the research area, and regional all-for-one promotion is impossible | Specific field                     | Without disaster warning and intelligent decision-making functions                   | Payment          |
| Black soil fertility management system of Northeast China | China       | A black soil fertility management information system of Northeast China developed on the basis of SUPERMAP system module—VB programing, which provides a digital information platform for spatial soil fertility data processing and analysis | 2005  | Mainly realize integration management of regional fertility data, without the integration of other black soil-related data, technologies, and application systems | Specific region                    | Only applicable to soil fertility information management                               | Not shared        |
man–land relationship thought, geographical determinism, possibilism, adaptation theory, anthropocentrism, ecologism, cultural landscape theory, determinism of productive relations, theory of environmental perception, and theory of man–land coordination have emerged (Lu and Guo, 1998; Fang, 2004). The human recognition of the interaction between human activities and geographical environment has been gradually deepened.

With the modern scientific and technological progress and the development of productive forces, the global population size and economic aggregate have presented sustainable growth, accompanied by the ever-increasing land utilization intensity and engineering construction intensity, increasingly intense influences of human activities on regional resource development and utilization and environmental quality, ever-aggravated contradiction between human and the environment that human survives and develops on, and increasingly intense man–land relationship. The modern man–land relationship has three major features: 1) multiple factors, including the interaction and coupling action among natural, economic, and technical factors; 2) multiple scales, from global and regional to local man–land systems, with spatial hierarchy and territorial differences; 3) multiple objectives, including to explore man–land system coordinated territorial models and scientific approaches to cope with major challenges faced by surface environmental changes and the sustainable development of mankind. The contemporary man–land system is an open macrosystem featured by the interaction between socioeconomic system and natural ecosystem, in which the logical relations of various natural factors with humanistic society and their interaction process are exceptionally complex. Faced with the increasingly complex multi-factor, multiscale, and multiobjective man–land relationship, exploring new mechanisms, new models, and new approaches of land utilization and allocation adapting to the stage characteristics of China’s economic development is specifically important.

The proposed “regional all-for-one customization” model aims to solve the core problem—increasingly evident contradiction of man–land relationship in the black soil region in northeast China. With the continuous agricultural development, the disturbing degree caused by mankind to the natural environment in the black soil region in northeast China has been gradually deepened, and the man–land contradiction has been increasingly deepened and continuously intensified. Black soil protection appears to be a soil problem and an environmental problem, but the more critical factors depend on economy, man, and man–land contradiction.

On the basis of the territorial system theory of man–land relationship, the regional all-for-one customization model of black soil granary aims to reveal the coupling mechanism of five major geographical factors: “water, soil, climate, organism, and man,” further solve key problems in black soil protection and utilization, and realize the collaborative improvement of economic and ecological benefits. Man–land system coupling is an effective means of revealing complex man–land interaction mechanism, and the coupling degree decides the direction of system evolution (Lu and Guo, 1998). Man–land system coupling stresses the organic combination of natural processes and human processes as well as the effective knowledge-science-decision linkage. Multifactor, multiscale, multidisciplinary, multimodel, and multi-source data integration is implemented through different scales of monitoring and survey, model simulation, scenario analysis, and optimal regulation, so as to explore scientific topics, such as system fragility, resilience, adaptability, and bearing
boundary. Man–land system coupling is an important theoretical foundation for the proposed regional all-for-one customization model.

3.1.2 Theory of customized precise management

“Customization,” which originates from the clothing industry, refers to tailoring for individual customers. With the development of times, the importance of “customization” has been gradually enriched, generally containing the following three features. (1) Difference: The core of customization depends on meeting the different demands of different customers who are classified on the basis of demand difference and provided with different services. (2) Modularization: Modularization is required to realize customization without any additional cost, that is, different functions of products or services are modularized, and individualized demands are satisfied through the autonomous combination of such modules. (3) Interaction: Immediate reaction to user demands is an indispensable factor of customization, and modules can be optimized and user experience can be improved through interactions (Shao et al., 2001).

The regional all-for-one customization of black soil granary, which is based on demand, goal, and problem orientations, is expected to solve the black soil protection and utilization problems of different regions, scales, and types. Specifically, the regional all-for-one black soil protection and comprehensive utilization status are hierarchically classified by regions. The existing technologies and products related to black soil protection and comprehensive utilization are modularized, and the demands of different types of users, such as government, enterprises, and peasant households, are identified. Modules conforming to customized demands are then assembled through interactive dialogs to output efficient soil conservation and high-quality agricultural product production strategies of different scales, thereby forming system solutions to black soil granary engineering. The theory of customized precise management serves as another important theoretical foundation for the regional all-for-one customization model.

3.1.3 Agricultural system theory

Agricultural production is a process of natural reproduction and economic reproduction. An agricultural system is formed by combining agricultural departments or the production factors of various crops in different means under certain natural and socioeconomic conditions. The agricultural system is restricted and comprehensively influenced by natural environmental factors, such as climate, terrain, hydrology, soil, and microorganisms, and by social needs and economic and technical levels. The agricultural system is of multilevel and multiscale features, including multiple levels, such as ecosystems, communities, populations, organisms, tissues, and cells, and multiple scales, such as the globe, country, province, county, village, and peasant household. The materials, energy, and information are exchanged among different levels and scales (Zhen et al., 2015).

The agricultural system theory highlights the interactions and overall functions among different components, which rely on the combination of multiple disciplines and their extensions rather than on single technologies. Modern practical science and technology are assembled and matched to directly serve land users, solve concrete production problems, improve the comprehensive productivity and resource conversion rate in the agricultural system, increase the income of land users, and obviously improve the ecological environment.
In the past 100 years, the agricultural productivity has always been improved by introducing new technologies and using better insecticides and chemical fertilizers, which further contributes to the steady income growth of farms. However, the cost input into agriculture has been continuously rising. Responding to such a situation, the agricultural system theory featured by the coordination between agricultural production and ecological environment has emerged, that is, various decisions—tillage measures, utilization of pesticides and chemical fertilizers, and selection of crop varieties—of land users should not destruct the broad environment of the whole agriculture. The shortage of one resource should not be compensated by increasing the supply of another resource. The agricultural system theory encourages land users to better utilize their own lands through rotation, conservation tillage, and biological prevention and control, thereby reasonably utilizing resources and optimizing the system structure.

The degradation problem of black soil regions is a complex degradation problem of natural environmental factors and refers to the imbalance in the total-factor, whole-process, and whole-industrial-chain agricultural system. The regional all-for-one customization model of black soil granary aims to improve the comprehensive productivity of the agricultural macrosystem, facilitate the local agricultural economic development without destructing the ecological environment, all of which are inseparable from the support of agricultural system theory. Abiding by the agricultural system theory, the regional all-for-one customization model of black soil granary gives full play to regional resource advantages and adjust measures to local conditions with the aim at the growth of agricultural production, rural development, and ecoenvironmental governance and protection in black soil regions. In accordance with the principles of “integration, coordination, recycling, and regeneration,” this model performs comprehensive planning by using system engineering theory and reasonably regulates the production, operation, management, and service of the whole agricultural industrial chain to realize high-yield, high-quality, high-efficiency, and sustainable development and collaboratively improve economic, economic, and social benefits in black soil regions.

3.1.4 Agricultural informatization theory and technology

Agricultural informatization refers to comprehensively developing and utilizing modern information technologies, such as computer technologies, network and communication technologies, and electronic technologies in a variety of fields, such as agricultural production, operation, management, and service. It integrates digitalized, networked, precise and intelligent characteristics, with its contents, including agricultural production informatization, agricultural operation informatization, agricultural management informatization, and agricultural service informatization, that is, extensively applying modern information technologies in the agricultural production, operation, management, and service processes so as to improve their efficiency (Kayad et al., 2021; Spati et al., 2021).

As an important path to transforming the traditional agriculture using modern high and new technologies, agricultural informatization refers to acquiring, storing, transmitting, processing, and analyzing natural, economic, and social information in agricultural production, operation, management, and service processes by using information technologies, thereby providing agricultural researchers, producers, operators, and managers with services, such as information inquiry, technology consulting, and assisted decision making. Agricul-
tural informatization technologies, such as 3S, have become important modern agricultural production and management means because they can acquire multiscale data in a real-time, low-cost, fast, and high-precision fashion and realize efficient data management and spatial analysis (Sun et al., 2021).

Agricultural informatization theories and technologies provide the regional all-for-one customization with core technical means. Intelligent, automatic, and systematic agricultural informatization has effectively improved the agricultural production level, reduced the production cost, and facilitated the agricultural development toward precise, environment friendly, and sustainable directions. The agricultural resources in black soil regions are scientifically evaluated, integrated, and optimized via informatization technologies, such as big data, AI, cloud computing, and IoT, so as to improve the production efficiency, production and marketing channels, and quality safety of agricultural products, and enhance the agricultural operation efficiency. In this way, the sustainable utilization of black soil can be realized and the rural economic level and farmers’ income can be increased.

In summary, the regional all-for-one customization model of black soil granary is established on the basis of four major theories: 1) territorial system of man–land relationship, which stresses classification by regions and factor coupling; 2) customized precise management, which highlights adjusting and implementing measures precisely in accordance with local conditions; 3) agricultural system theory, which emphasizes total-factor, whole-process, and whole-industrial-chain systematic processes; 4) agricultural informatization, which underlines the support of modern information technologies.

3.2 Connotation and framework of regional all-for-one customization for black soil granary

“Regional all-for-one,” which is of integral and comprehensive characteristics, refers to taking the target region as a specific territorial complex. Black soil protection and comprehensive utilization seems to be a problem in soil or a smaller plot on farmlands, in fact, it is a concentrated reflection of unreasonable regional resource allocation and unbalanced resource scheduling and the loss of core factors in rural development and rural decline rather than a simple degradation problem of natural environmental factors. Hence, the problems appearing in black soil protection and comprehensive utilization should be solved from the “regional all-for-one” perspective.

“Customization,” which has the practical nature, is an optimization strategy of solving practical problems based on goal orientations. The core problem of black soil protection and comprehensive utilization is due to the ever-intensified man–land contradiction, which varies from region to region and from scale to scale. Different contradictions should be solved by using customized strategies.

Geographical research is of regional, comprehensive, and practical characteristics. Resource integration, whole-industry convergence, all-round service, total social participation, and complete-flow guarantee are needed to solve regional comprehensive problems due to the geographical spatial heterogeneity and problem complexity. Boundary barriers should be broken and cross-border cooperation should be strengthened by considering every aspect and direction (Fang, 2004; Zheng et al., 2005; Chen et al., 2021). “Regional all-for-one customization model” has whole-space, total-factor, whole-period, and multiscale character-
istics. Regional strategic measurement, practical technical paths, and pertinent optimization schemes are required to solve single, dispersed, and regional black soil utilization and protection problems.

In this research, a regional all-for-one customization model of black soil granary was innovatively proposed to cope with bottleneck problems (e.g., serious soil degradation and carbon loss, unmatching planting and breeding resources, low agricultural benefits, and the lack of systematic solutions to the regional development) in the black soil region in Northeast China. Specifically, a regional all-for-one customized dataset was established on the basis of the regional all-for-one customization monitoring system and technical system. System solutions in three scales—“implementing strategies by regions,” “determining strategies in accordance with villages,” and “one strategy for one field”—were formed from region, village, and field levels with zoning and hierarchical classification as the main strategy and big data and AI as the main technical means.

The territorial potentials were mined on the basis of geographical thoughts to explore the interaction mechanisms among five major geographical factors—“water, soil, climate, organism, and man”—in the black soil region and promote the organic integration of total production factors. Next, critical scientific and technological problems in black soil protection and utilization were broken from region, village, and field levels by comprehensive and interdisciplinary means, thereby realizing high-efficiency and localized precise application of black soil protection and utilization technologies, and forming hierarchically classified regional precise strategies and system solutions covering the whole city with multiscale territorial characteristics.

4 Technical scheme and realization path of regional all-for-one customization model for black soil granary

Located in the hinterland of Songnen Plain—one of world four major black soil belts, Qiqihar City adjoins Lesser Khingan Mountains in the east and leans against Greater Khingan Mountains in the west, in which black soil, chernozem, and meadow soil are the main soil types. Qiqihar is a reliable grain production base in Heilongjiang Province and even the whole country, with its grain production capacity averagely stabilized above 10 billion kilograms per year, accounting for one-fifth of the total grain production capacity throughout Heilongjiang. However, the black soil in this city is faced with the plight of “reduction in quantity and degradation in quality” due to long-term unreasonable tillage and high-intensity utilization. The black soil layer containing organic matters is thinned because of water and wind erosion, and the soil hardening problem becomes prominent due to unreasonable utilization modes and excessive use of pesticides and chemical fertilizers. During the agricultural development, Qiqihar is faced with numerous bottleneck problems, such as serious soil degradation and carbon loss, unmatching planting and breeding resources, low agricultural benefits, and the lack of systematic solutions to the regional development, endowing this city with strong typicality and representativeness. Hence, Qiqihar was selected as a representative region to expound the technical scheme and realization path for the regional all-for-one customization model of black soil granary.
4.1 Construct a “satellite–aviation–ground–network” stereoscopic monitoring system and develop a big data and AI-driven regional all-for-one customization system platform

A “satellite–aviation–ground–network” stereoscopic regional all-for-one customization monitoring system was constructed through medium and high-resolution satellites, UAV aerial photography, ground sensor monitoring, and IoT technology. Satellite-based monitoring focused on medium and high-resolution resources and meteorological satellites; aviation-based monitoring depended on self-developed UAV platform and corresponding loads; ground monitoring aimed at the integral transformation of the existing stations. New automatic observation stations were added to accurately acquire information, such as soil moisture content, in combination with intelligent agricultural equipment.

A regional all-for-one customization database and an intelligent decision platform were constructed on the basis of the monitoring system to continuously collect, organize, process, and integrate heterogeneous black soil data from multiple sources (including satellite remote sensing, UAV, ground observation, ground survey, and experimental analysis) in the region to form a regional all-for-one dataset. On the basis of this dataset, intelligent recombination and efficient matching of black soil protection and comprehensive utilization technologies were performed with the black soil protection and comprehensive utilization technology system as the knowledge base and traditional machine learning models (such as random forest and decision tree) and deep learning models (convolutional neural network and graph neural network) as the main algorithms.

On the basis of the regional all-for-one customization monitoring system and decision supporting platform, three-level (“implementing strategies by regions,” “determining strategies in accordance with villages,” and “one strategy for one field”) customization strategies were implemented in Qiqihar as a case area. A regional all-for-one customized system solution (Figure 3) was obtained, thereby realizing the final goals of the “efficient utilization and conservation” of regional all-for-one customization for black soil granary.

Figure 3 Regional all-for-one customization model of black soil granary with Qiqihar as an example
4.2 Implement “implementing strategies by regions” and accelerate black soil systematic protection and high-quality industrial development

From the regional scale of Qiqihar, a diagnosis and evaluation system of regional black soil degradation was established on the basis of natural, resource, and human factors. In accordance with basic information, such as resource endowments, hydrothermal conditions, plantation system, economic development, and soil degradation, Qiqihar was divided into moderate development region, reparative development region, protective development region, and sustainable region to form a subregional utilization and management scheme (Figure 4) for mining production potentials and preventing and controlling soil erosion.

![Figure 4](image_url)

**Figure 4** Procedure of “implementing strategies by regions” concept

A batch of organic cultivation bases was built to implement high-quality agricultural development strategies in regions with low soil erosion and high production potentials. Under the technical support of the Chinese Academy of Sciences, Yi’an County created an eco-
county, produced organic grains, and constructed a large high-end kitchen for food supply, attracting agricultural leading enterprises, such as Feihe Dairy and Yitai Biotechnology companies, which cocreated a 7000 ha organic cultivation demonstration base. In this way, the soil quality was improved, and agricultural benefits were increased. In regions with high soil erosion and high production potentials, protective development strategies were performed, and conservation tillage technologies were promoted in combination with systematic mountain-water-forest-farmland-lake-grass governance. In Longjiang County, leading intelligent agricultural machinery enterprises were introduced by Chaoyue cooperatives, the total no-tillage sowing area in the whole county reached 117,000 ha, accounting for 40% of total cultivated area in the whole county. Thus, production and income were increased, and soil erosion was effectively prevented. In regions with low soil erosion and low production potentials, moderate development strategies were implemented, resource potentials were mined, and soil fertility was improved by increasing the amounts of organic fertilizers, thereby becoming land reserves for the local agricultural production. In regions with high soil erosion and low production potentials, the emphasis was laid on mountain-water-forest-farmland-lake-grass system restoration and refined agroecosystem management, thereby restoring them into high-quality agricultural production bases.

4.3 Perform “determining strategies in accordance with villages” and promote long-acting black soil protection and rural revitalization and development

On the village scale, given rural system problems, such as black soil degradation, agricultural inefficiency, and rural decline, the interaction mechanism and coupling type between black soil utilization and rural socioeconomic development were revealed. The collaborative optimization mechanism of rural “man–land–industry” in the black soil region in northeast China was explored. A technology model organically integrating protective black soil utilization and rural revitalization was assembled, thereby realizing the organic unity and integrated promotion of black soil protection and rural revitalization, and connecting the technology linkage between protective black soil utilization and rural construction planning. Related technical systems were integrally used to form a technical scheme for realizing protective black soil utilization and facilitating rural revitalization, which promoted the protection and sustainable utilization of black soil.

The regional all-for-one customization system was used to intelligently diagnose and evaluate the black soil degradation state, identify rural development types, and diagnose the black soil protection and utilization problems in villages of different regions and different types. All villages were divided into nine different protection and development types. Different land operation modes, protective black soil utilization technologies, and industrial development paths were customized for different villages, and the mutual promotion mechanism between black soil protection and rural revitalization was explored to seek the fundamental measures for promoting the balance between black soil utilization and conservation (Figure 5).

For example, Yanjiang Village in the east of Yi’an County belonged to a moderate degradation-aggregation improvement type, with its main problems deriving from three aspects: land degradation threat, inefficient agricultural development, and serious hollowing problem. Accordingly, five pertinent strategies, namely, taking conservation tillage measures, con-
structuring an ecological safety network, promoting land scale management, developing green organic agriculture, and accelerating industrial integration development, were proposed, and a black soil protection-centered village construction plan was formulated. The lands in the whole village were uniformly managed in a large scale by field and farmers’ cooperatives through farmland circulation. Protective measures, such as straw returning to field, multi-source carbon pick-up, subsoiling, and deep tillage were taken to improve the black soil quality and agricultural benefits, the corn yield was increased by 1125–1500 kg/ha, and the income increment was approximately 9000/ha yuan.

4.4 Implement “one strategy for one field” and promote precise black soil protection and efficient resource utilization

Qiqihar has multiple black soil types, with varying soil degradation characteristics and degrees, and the difference in organic matter contents between land plots can be fivefold. Most of the currently implemented black soil conservation tillage technologies have been developed and applied separately while lacking precise conservation tillage schemes specific to different soil types and degradation degrees. “One strategy for one field” was implemented, and each field was subjected to problem diagnosis and hierarchical classification based on their basic information to solve the above problems. Black soil protection and comprehensive utilization technologies were optimally selected with the goal of simultaneously improving the economic and environmental benefits, thereby providing system decision schemes for “one strategy for one field.”
A soil parameter-driving factor paired sample dataset was established on the basis of the multifactor (water, soil, climate, organism, and man) data of the regional all-for-one comprehensive dataset. Traditional machine learning models (such as random forest) and multiple convolutional neural network models were combined to simulate the soil degradation scenarios of each land plot and comparatively analyze different model results, provide field-scale black soil protection and utilization schemes for peasant households and push them intelligently, and realize field-scale black soil protection and intelligent plantation management.

With Taidong Village in Yi’an County as an example, an index system including site conditions, soil properties, and crop types was established, and cultivated lands in this village were classified into five types for the sake of respective problem diagnosis, optimal technology selection, and system solution output (Figure 6). For the mild water erosion type with low nitrogen and phosphorous contents, the main problem is caused by soil fertility degradation and evident yield drop due to water erosion and excessive tillage. Problem-oriented black soil protection technologies were developed to mitigate water erosion, improve the soil fertility, and increase the crop yield. No-tillage straw mulching and returning to field+ protective carbon pick-up remediation technology (deep directional organic fertilizer application no-tillage technology and supporting agricultural equipment) was used, thereby reducing surface runoffs by 79.1% and topsoil loss by 95%, improving the soil structure, increasing the aggregate diameter by 0.10–0.15 mm, and increasing the total nitrogen content by 18.5%. The corn yield was elevated from 7500 kg/ha to 8400 kg/ha by 12%. For cultivated lands with good soil quality but comprehensive benefits to be improved, the high-quality variety breeding + organic plantation transformation model was chosen, which can markedly improve agricultural comprehensive benefits (10%).

The regional all-for-one customization model of black soil granary constructed a multiscale (“implementing strategies by regions,” “determining strategies in accordance with villages,” and “one strategy for one field”) customization system to facilitate the information exchange and material flow between upper and lower scales of the black soil protection system. The field scale provided village and region scales with information, such as soil physiochemical properties, degradation degree, and grain yield, from bottom to top and influenced the village-scale and regional strategy making. The region scale transmitted information, such as gross domestic product, urban and rural planning, and infrastructure level to village and field scales, from top to bottom and participated in village classification and technical decisions of field. The village scale accepted the information input simultaneously from region and field scales, and the division results supported the decision making of region and field scales. Specifically, the regional-scale development goals determined by “implementing strategies by regions” directly decided the main keynote of “determining strategies in accordance with villages” and the main technology categories of “one strategy for one field.” The village development model determined by “determining strategies in accordance with villages” provided the land utilization and land planning-related parameter input of “implementing strategies by regions” and served as the basis for the crop selection of “one strategy for one field.” Soil protection technologies and agricultural input products determined by “one strategy for one field” rendered the parameter inputs and information feedback for “implementing strategies by regions” and “determining strategies in accordance
with villages.” The strategies precisely implemented at the three scales were closely associated and supported each other, thereby forming a running-through overall plan.

5 Conclusions and discussion

Cultivated lands are essential for grain production, and protecting cultivated lands refers to protecting grain production. At present, cultivated land resources in China are insufficient. Under the new development pattern, how to protectively develop and utilize cultivated lands and improve their comprehensive quality have become agricultural development problems to be urgently solved. Black soil thinning and hardening problems in the northeast region praised as the granary of China cannot be underestimated. Black soil, which is as treasurable as giant pandas, is still faced with problems, such as nonsystematic top-level design, nonpertinent middle-level decision making, and the lack of initiative of implementation subjects in its protective utilization, all of which have seriously restricted the precise implementation of black soil protection strategies. Hence, measures must be adjusted more efficiently in accordance with local conditions through total-factor and multiscale integrated management to form system solutions to black soil granary engineering and to meet the individualized demands of land users.

This research proposes a regional all-for-one customization model of black soil granary to guide the development of agricultural technologies through scientific and technological innovation for the sake of black soil protection and utilization; provide science and technology support and system solutions to black soil protection and regional development of Qiqihar City; promote regional agricultural high-quality development and rural revitalization on the premise of improving black soil fertility; provide a demonstration prototype for protective black soil utilization in China and even around the world. This research will be of great theoretical values and practical significance.

(1) Black soil protection, which is a highly comprehensive, systematic, and policy-oriented project involving many departments, is related to the immediate interests of the general public. The efficient black soil protection is a technical problem and a systematic problem covering multiple aspects, such as technology, policy, and management. The proposed regional all-for-one customization model, which is different from the existing black soil protection strategies, covers the whole target region from the geographical concept and highlights the systematic and multiscale full consideration for the regional black soil protection. With the man–land relationship as the primary optimization objective, the main causes for the unbalance of black soil utilization and conservation are deeply analyzed from the comprehensive perspectives of territorial system structure and functions of man–land relationship. The human factors driving black soil degradation are explored, and the key problems and bottleneck difficulties restricting the regional sustainable black soil utilization are systematically revealed. From the comprehensive goals of farmers’ development rights and interests, local economic growth, and national food security, the man–land relationship coupling mechanism is investigated, and black soil protection and comprehensive utilization strategies are proposed to realize the goal of “utilizing” and “conserving” black soil efficiently.

(2) The degree and causes of black soil degradation present evident spatial heterogeneity, black soil protection measures fail to completely curb soil degradation trends for extremely
different reasons, and finding universal and once-for-all technologies or strategies is difficult. Faced with the contradiction, that is, the individualized need for black soil protection is greater than the supply, the proposed regional all-for-one customization innovatively introduces the concept of “customization.” Measures are adjusted in accordance with regional conditions from regional, village, and field scales, and related strategies serving black soil protection and comprehensive utilization are pertinently outputted through status evaluation, problem diagnosis, and objective analysis.

(3) Informatization, which is the general trend of the development of times, represents advanced productivity. Big data and AI denote the new stage of information age. In the next 10–15 years, great economic contributions will be made if information technologies are integrated into new products of different industries, new forms of business providing individualized products and services, and new models realizing cross-border fusion of industrial chains. Similarly, black soil protection and comprehensive utilization are inseparable from two major tools: big data and AI. The proposed regional all-for-one customization model fully utilizes advanced technologies, such as digital agriculture and AI with data, as the basis, platform as the means, and application as the orientation. Multiscale problem diagnosis and strategy output are integrated into a regional all-for-one customized comprehensive application platform to realize the regional all-for-one customized “one-stop services” of black soil granary. Traditional black soil protection technology transformation and upgrading are promoted via big data.

For the first time, the proposed regional all-for-one customization model integrates two perspectives—“all for one” and “customization”—into black soil protection and comprehensive utilization to construct a total-factor, whole-industrial-chain, intelligent, and precise black soil protection and comprehensive utilization innovation model featured by regional classification and measure adjustment in accordance with local regional conditions. With hierarchical classification by regions as the main strategy and big data and AI as the main technical means, pertinent technical solutions are proposed on the basis of regional strategic consideration, and the system solutions of “implementing strategies by regions,” “determining strategies in accordance with villages,” and “one strategy for one field” are formed from field, village, and regional scales to realize efficient soil conservation, production of high-quality agricultural products, and regional socioeconomic development. A basic theoretical framework for the regional all-for-one customization of black soil granary is formed. The proposed regional all-for-one customization model of black soil granary based on comprehensive geographical thoughts will be perfected and developed in accordance with the existing theoretical framework and the demonstration prototype of Qiqihar.

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