Safeguarding the "Black Soil Granary": Innovations in Soil Conservation and Sustainable Agriculture

JIANG Ming[a*], JIA Zhongjun[a], WEN Ya[b], XU Hang[b], WANG Hongsheng[b], ZENG Yan[b], LI Lujun[a], CUI Mingxing[a], LI He[a], ZHANG Jiabao[c*]

a. Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences, Changchun 130102, China.
b. Bureau of Sustainable Development Research, Chinese Academy of Sciences.
c. Institute of Soil Science, Chinese Academy of Sciences.

Abstract: The black soil of northeast China is a "ballast stone" of the nation's food security and a crucial asset for regional ecological stability. However, it faces severe degradation due to long-term, high-intensity cultivation and soil erosion. To address this issue, the Chinese Academy of Sciences, in collaboration with the three northeastern provinces and Inner Mongolia, launched the "Black Soil Granary" campaign in March 2021. This initiative has achieved phased progress in basic theoretical research, key technology development, equipment fabrication, and technology demonstration. As the campaign continues, innovative technologies, including region-specific models for controlling black soil degradation, methods to enhance both soil health and productivity, and breakthroughs in smart agriculture, are playing a key role in protecting and sustainably utilizing black soils, thus providing strong scientific support for national food security.

Keywords: black soils, degradation control, soil health, food security, agricultural modernization, smart agriculture

Cite this article as: JIANG Ming, JIA Zhongjun, WEN Ya, XU Hang, WANG Hongsheng, ZENG Yan, LI Lujun, CUI Mingxing, LI He, & ZHANG Jiabao. (2024) Safeguarding the "Black Soil Granary": Innovations in Soil Conservation and Sustainable Agriculture. *Bulletin of the Chinese Academy of Sciences*, 38(4), 251–258. DOI: https://doi.org/10.1051/bcas/2024018

The black soil region in northeast China is one of the four major black soil regions in the world, covering a total area of 1.635 billion *mu* (~109 million hectares), with 537 million *mu* (~35.8 million hectares) designated as arable land. Of this, approximately 278 million *mu* (~18.5 million hectares) is typical black soil (Jiang *et al*., 2021), making it China's most important grain production base and a key region for commodity grain exports. However, years of unsustainable farming practices and intensive land use have led to the degradation of this vital resource, turning what was once an "ecological functional zone" into an "ecologically fragile zone," posing serious threats to both national food security and regional ecological stability (Jiang *et al*., 2021).

* Corresponding author. Email: jiangm@iga.ac.cn (JIANG M.); jbzhang@issas.ac.cn (ZHANG J.)

On July 22, 2020, Chinese President XI Jinping highlighted the urgency of protecting and utilizing black soils, referring to them as the "panda of arable land"—a resource that must be preserved for future generations. In response, the Chinese Academy of Sciences (CAS) swiftly mapped out the "Black Soil Granary" Technological Campaign in December 2020. Officially launched in March 2021, with support from the Ministry of Agriculture and Rural Affairs and the Ministry of Science and Technology, this initiative aims to safeguard and make sustainable use of black soils through technological innovation, providing essential scientific support for national food security and sustainable agricultural development.

Goals and Tasks

Focusing on the core challenges of conserving and utilizing black soils, the "Black Soil Granary" campaign uses an organizational model that integrates research with practical demonstration. Its research covers key areas such as controlling black soil degradation, advancing soil health technologies, boosting soil productivity through modern biological methods, developing smart agricultural machinery suited for black soils, establishing integrated monitoring systems using satellite, aerial, and ground data, and building intelligent management systems for the sustainable use of black soils.

The campaign includes several demonstration zones, each with specific focus areas:

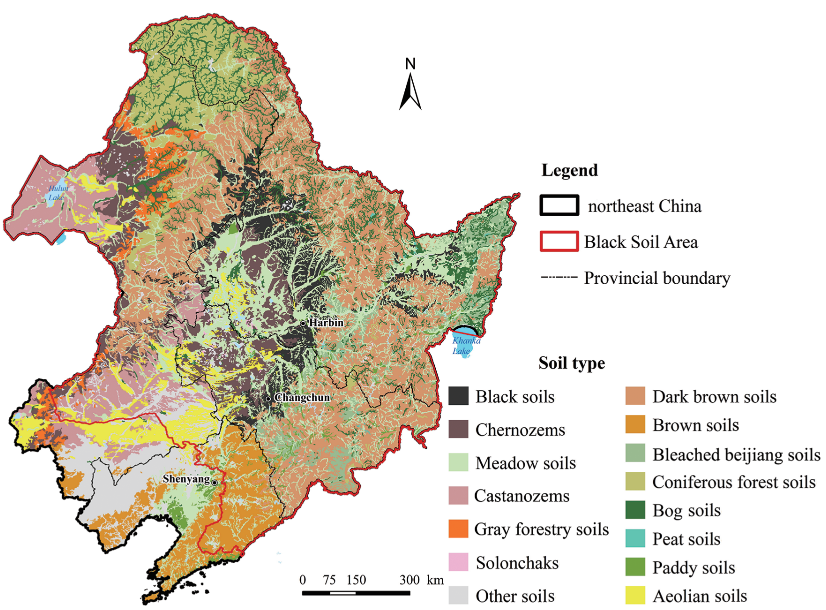
- Hailun for thick-layer black soil conservation and high productivity;
- Changchun for thin-layer black soil conservation and high productivity;
- Shenyang for restoring fertility and productivity in degraded black soils;
- Sanjiang for improving the quality and productivity of rice paddies and albic soils;
- Da'an for reclaiming saline-alkali land;
- Dahewan for integrating smart agricultural machinery; and
- Qiqihar for developing tailored solutions for black soil conservation and use.

After five years of scientific and technological (S&T) efforts, the "Black Soil Granary" campaign aims to address black soil degradation on two key levels. On the theoretical level, the goal is to uncover the rates, spatial-temporal distribution, driving mechanisms, and prevention principles of black soil degradation—specifically how it becomes "thinner, poorer, and harder".

On the technical level, the focus is on breakthroughs in soil health conservation and modern biotechnologies to simultaneously improve soil fertility and crop yields. The campaign is expected to establish an integrated monitoring system across multiple platforms, develop intelligent agricultural technologies and machinery, and create a management and decision-making platform for the long-term sustainable use of black soils.

Additionally, it will develop region-specific technical models for black soil conservation, covering over 8,333 hectares in core demonstration zones, and promote these technologies across 33.33 million hectares.

The campaign's key goals include increasing soil organic matter by 3–5 g/kg, reducing soil erosion rates by 80%, and improving cultivated land quality by 0.5 grade in core demonstration zones. Ultimately, this will solve the problem of black soils becoming "thinner, poorer, and harder," nurture a new generation of scientists, provide comprehensive solutions for sustainable black soil utilization, and contribute to national food security.



Distribution map of the Northeast black soil region.

Innovation and Features

Multidisciplinary Integrated Innovation: The "Black Soil Granary" campaign leverages the CAS' institutional strengths and its extensive experience in organizing agricultural scientific initiatives. By drawing on long-term expertise in black soil monitoring and conservation, the campaign gathers top researchers to address key S&T challenges. This includes understanding soil degradation processes, developing methods to counteract degradation, improving soil health, and advancing *in-situ* microbial straw decomposition technologies.

Technological Model Innovation: Tailored to the distinct regional characteristics of various soil types, climate conditions, and limiting factors, the campaign promotes innovative techniques to control soil degradation, improve soil health, optimize tillage practices, integrate farming and livestock systems, and manage water and soil resources. These region-specific solutions are to address critical issues such as thinning soil layers, declining organic matter, and increasing soil compaction (Hou *et al.*, 2021).

Intelligent Means Innovation: The campaign establishes an integrated monitoring system that spans satellite, aerial, and ground platforms, creating a decision-making system based on big data and artificial intelligence (AI) for managing black soils. In addition, the development of advanced smart agricultural machinery and supporting equipment has secured independent intellectual property rights, enabling real-time monitoring and intelligent farming practices.

Innovative Organizational Models: The campaign adopts a collaborative organizational model that involves CAS, local governments, and national ministries. Through strategic cooperation agreements and the establishment of joint leadership and working groups, this model ensures that technological advancements are effectively applied to the conservation and sustainable management of black soils.

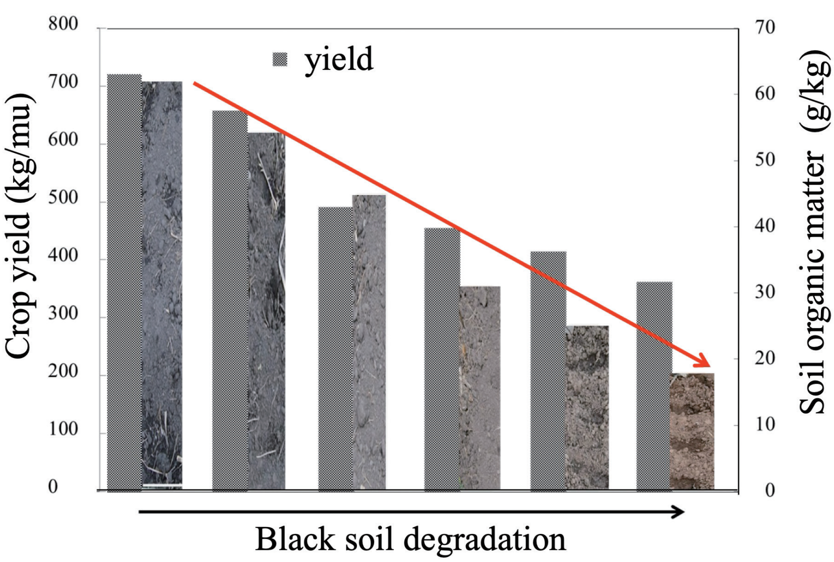
Key Achievements

Mapping Black Soil Degradation Status: The project developed an integrated monitoring system combining satellite, aerial, and ground data to track black soil conditions. Using 10-meter resolution remote sensing maps, the project assessed soil organic matter (SOM) levels and their changes in black soil regions, revealing that about 64% of cultivated land in these areas has experienced declining SOM. On average, soil organic matter has decreased by 0.065 g/kg over the past 40 years. Additionally, the black soil layer is thinning at a rate of about 0.19 cm per year in dryland areas, and soil bulk density has increased by 0.02 g/cm^3 in the last decade.

Revealing Soil Organic Matter Turnover Mechanisms: The project uncovered the characteristics and patterns of SOM depletion and proposed a dual-source control mechanism for carbon sequestration, which has been integrated into conservation tillage practices. This mechanism supports carbon sequestration at a rate of 0.8 tons per hectare per year, contributing to the National Action Plan for Conservation Tillage in northeast China.

Developing Key Technological Systems for Black Soil Conservation and Utilization: A system to regulate runoff and prevent erosion in sloped and gully areas was created, providing a model for addressing erosion in black soil regions. With this, the rehabilitation of over 10,136 erosion gullies was achieved. Additionally, soil health cultivation technologies were developed, focusing on the application of straw, organic fertil-

The relationship between black soil degradation processes and crop yield.



izers, and natural humus materials. The project also cultivated new salt-alkali-tolerant soybean and rice varieties, "*Dongsheng 118*" and "*Dongdao 122*," which are suited to local soil conditions and support the reclamation and efficient use of saline-alkali land.

Developing Smart Agricultural Machinery Systems: The "Honghu Intelligent Unmanned Electric Tractor Operation Unit" has been established as the core of a smart agricultural machinery system tailored for black soils. Achieving over 90% domestic production of critical components—such as machinery, electrical systems, hydraulics, control, and sensors—the system represents a significant technological advancement. This third-generation agricultural machinery technology incorporates a multi-dimensional data sensing system that supports AI-driven agronomic decisions and execution, enabling real-time and precision farming operations.

Proposing Solutions for Black Soil Conservation and Utilization: The campaign developed region-specific tillage and management models, including the "Longjiang Model," "Lishu Model 2.0," "Daan Model," and "Dahewan Model". These models have been successfully implemented in seven core demonstration zones, covering over 11,000 hectares, and have been promoted across a cumulative area of 21.73 million hectares, resulting in significant improvements in black soil conservation and productivity.

By December 2023, the project had developed and promoted 52 key technologies, including the "Fertile Cultivated Layer Construction and Conservation Technology of Black Soils," "Straw No-tillage Mulching and Return-to-Field Technology," "Rapid Construction of Cultivated Layer and Quick Fertilization Technology for Newly Reclaimed Farmland". Among these technologies, 14 were selected as major agricultural promotion technologies by the Ministry of Agriculture and Rural Affairs, while 38 were recognized as promotion technologies by provincial agricultural departments. These technologies have played a pivotal role in supporting national and local initiatives, such as the National Black Soils Protection and Utilization Project and Jilin Province's "100 Billion Kilograms of Grain" Productivity Construction Project.

Demonstration Zone Case Studies

Lishu Model 2.0: Designed to address the challenges of soil degradation and low agricultural efficiency in thin-layer degraded black soil regions, the Lishu Model 2.0 builds on traditional conservation tillage techniques while integrating innovations to suit local conditions. This model emphasizes regional technical adaptation, precise optimization of farming parameters, advanced machinery development, and integrated management, all of which contribute to higher productivity. It effectively balances the goals of soil conservation and grain production improvement. The model has since been implemented at 12 demonstration sites across Jilin Province, resulting in an average yield increase of over 10%, and has been promoted across 4.37 million hectares.

Longjiang Model: Aimed at overcoming the challenges posed by the heavy clay texture, shallow tillage layers, and thick plow pan in the medium and thick black soils of the mid-to-north Songnen Plain, this model incorporates deep mixing of straw or organic

Lishu Model 2.0 operation process (left) and effects (right).

fertilizers into the soil, coupled with a corn-soybean rotation system, to enhance soil structure and fertility. By addressing the technical difficulties of fully incorporating straw into the soil, the model achieves both soil conservation and higher productivity. So far, it has been applied across 5.28 million hectares as part of the Heilongjiang Black Soil Conservation Project Implementation Plan. In the demonstration areas focused on building thick fertile black soil layers, the tillage layer thickness increased from 17.5 cm to 32~34 cm. The Longjiang Model reduced chemical fertilizer use by 10% and pesticides by 20%, while improving crop yields by over 10%. It has been included in the National Black Soil Conservation Project Implementation (2021–2025), and two of its core technologies have been recognized as key recommendations by the Ministry of Agriculture and Rural Affairs. The model has also earned a first-class prize in the National Harvest Award for Agriculture, Animal Husbandry, and Fisheries, as well as a second-class *Shennong* China Agricultural Science and Technology Award.

Dahewan Model: Developed to tackle the challenges of low automation levels in the southeastern foothills of the Greater Khingan Range, the Dahewan Model leverages new-generation information technologies, intelligent equipment, artificial intelligence (AI), and big data to monitor various aspects of black soil, including water, soil, air, and biological factors. By integrating scientific expertise with AI-driven simulation and predictive analytics, the research team can formulate optimal decisions for the conservation and utilization of black soils under diverse conditions. These decisions are executed with precision and efficiency using smart agricultural machinery.

The core of the Dahewan Model is a comprehensive system that combines "digital decision-making + intelligent execution + targeted conservation tillage," significantly enhancing the precision and automation of agricultural production. To date, the model has been implemented over an area of 2.4 million hectares, resulting in notable cost reductions and efficiency gains. In recognition of its innovative approach, the Dahewan Model received the Gold Award at the World Internet of Things Exposition in 2022.

The Longjiang Model involves the deep incorporation of straw or organic fertilizers into the soil to improve its structure and fertility.

Technical Pathways and Innovations

Soil Erosion and Its Control Techniques in Black Soil Regions

Soil erosion poses the greatest threat to black soils in northeast China, leading to thinner soil layers and declining fertility, which jeopardizes grain production. In these regions, soil erosion manifests in several forms, including wind erosion, water erosion, and snowmelt erosion, often occurring concurrently in some areas. Wind erosion primarily impacts the western black soil areas, while water erosion is prevalent in undulating plains and low hills.

Conservation tillage techniques, such as the "Lishu Model 2.0," effectively combat wind erosion. However, water erosion remains the most significant challenge to black soil conservation and national food security. Historically, erosion control measures on sloping farmland have often been disjointed from soil cultivation efforts, with erosion control projects relying on singular strategies.

To address these challenges, a comprehensive approach is essential. This includes using small watersheds as units to integrate high-standard farmland construction, national conservation tillage action plans, and erosion gully management projects. The focus

Intelligent agricultural machinery operation and command platform in Dahewan demonstration zone.

should be on building a coordinated system that encompasses water retention, drainage system construction, erosion prevention, and soil cultivation at the watershed level. This holistic strategy aims to achieve systematic and effective soil conservation in black soil regions (Zhang *et al*., 2024).

To address slope erosion in the black soil farmland, which features long, gentle slopes and marked seasonal variations in water and heat, an integrated soil and water conservation tillage technique has been developed. This approach combines conservation tillage, optimization of ridge-furrow geometry, and the intercropping of green manure within the ridges and furrows. Field monitoring indicates that after implementing this technique, the soil erosion rate is reduced by over 80%. This method not only controls slope erosion but also minimizes runoff into gullies and inhibits the onset and progression of gully erosion.

For small-scale erosion gullies, a restoration technique was designed based on the principles of critical runoff hydrodynamics related to gully formation, the infiltration characteristics of black soil, and the decomposition of crop residues. This technique allows for 93% of runoff to be drained underground, effectively preventing the reformation of gullies. As a result, it leads to the disappearance of erosion gullies, the reconstruction of arable land, improved connectivity between farmland plots, unobstructed movement of farm machinery, and the restoration of cultivation practices (Liu *et al*., 2023; Zhang *et al*., 2019).

For medium and large-scale erosion gullies, a comprehensive management model has been developed that integrates conservation tillage, straw burial, and flexible check dams, prioritizing ecological restoration while incorporating supplementary engineering measures (Guo *et al*., 2024; Zhang *et al*., 2021). This technique eliminates the need for slope-cutting, achieving the smoothing of small gully sections and stabilizing active erosion zones. Following the treatment, the soil erosion rate in the catchment areas of these gullies is reduced by at least 80%. It is estimated that this technique could treat approximately 200,000 erosion gullies in the northeastern black soil region, potentially reclaiming over 130,000 hectares of farmland and increasing grain production by 600 million kilograms (Qi *et al*., 2020).

Application of Big Data and Intelligent Equipment in Black Soil Conservation

The campaign has innovatively integrated big data and intelligent equipment into black soil protection, addressing the entire grain production chain from land preparation to storage. Large-scale intelligent agricultural machinery designed for conservation tillage has been developed, along with a comprehensive data sensing system that incorporates satellite, aerial, ground, human, and machine data. By accumulating agricultural big data, algorithms and models have been created to extract valuable insights. Information technology has been leveraged to streamline data flow throughout the agricultural production chain (Gao *et al*., 2024). This led to the establishment of an artificial intelligence-based decision-making system for agricultural practices and a smart execution system, achieving the following outcomes:

- **Two Precisions:** Precision

Effects of the integrated runoff regulation and erosion control technology for slope and ditch.

land preparation and precision seeding

• **Three Variabilities:** Variable-rate water application, variable-rate fertilization, and variable-rate pesticide application

• **Three Reductions:** Reduced losses during harvesting, transportation, and storage

• **One Utilization:** Effective utilization of crop residues

The integration of big data and intelligent equipment is transforming traditional agricultural practices in the black soil region, opening up significant potential for the future. The research team plans to further promote the convergence of the digital economy with traditional agriculture, aiming to extract greater value from data at every stage of production. They will continue developing and applying intelligent agricultural machinery, utilizing it as a key platform for collecting precise, plot-level data throughout the agricultural process.

To enhance agricultural practices, they aim to establish data collection standards and a common platform for agricultural big data, aggregating information from different regions. Agricultural simulators will be developed to facilitate the combination of agricultural big data with artificial intelligence, maximizing the value derived from this data. Finally, they intend to create regulations and standards for the collection, transmission, storage, and access of agricultural data, improving data governance and ensuring the security of agricultural big data.

Future Outlook

The mission to "protect and utilize black soil effectively" holds significant national importance. Over the past four years, substantial progress has been achieved in the conservation and utilization of black soils, fueled by strong legal protections and scientific support. The multifunctionality of the black soil ecosystem is gradually being restored, with regions implementing technology showing either stable or increasing soil organic matter content.

As the "Black Soil Granary" scientific campaign continues to evolve, region-specific technological models are becoming more refined and widely adopted. Emerging advancements, including techniques for soil health conservation and productivity enhancement, intelligent agricultural technologies and equipment, and smart management and decision-making systems, will further enhance the conservation and sustainable utilization of black soils.

This vital region, often referred to as the "Granary of China," is entering a new era of vitality and productivity, contributing to the success of modern agriculture in unprecedented ways.

Conclusion

The formation of black soils is a lengthy process, and their conservation cannot be achieved overnight. The "Black Soil Granary" scientific campaign is inherently a long-term endeavor. As a pivotal force in national strategic scientific initiatives, CAS remains committed to the critical national strategy of black soil conservation and utilization, as well as to advancing the global frontiers of science and technology.

The Academy aims to achieve breakthroughs in theoretical innovations for black soil protection, enhance region-specific conservation technologies, comprehensively remediate and utilize saline-alkali land, apply modern crop breeding techniques, and integrate key intelligent agricultural technologies. Additionally, the Academy will strengthen international cooperation in agricultural science and technology, sharing the outcomes of its scientific innovations.

These efforts will contribute China's expertise and solutions to the sustainable development of

2024 International workshop on mollisols erosion and degradation.

global agriculture and help achieve the United Nations' 2030 Sustainable Development Goals, fostering the building of a community with a shared future for humanity.

Acknowledgments

The study was supported by the Strategic Priority Research Program of the Chinese Academy of Sciences (XDA28000000). The authors would like to acknowledge the scientists who have made great contributions to the "Black Soil Granary" scientific campaign.

References

Gao Shuqin, Hu Zhaomin, Wang Hong sheng, Zhang Xiaobo, & Zhang Yucheng. (2024) Nine-Step Approach of smart agricultural helps grain production reduce costs, increase yield and efficiency. *Bulletin of Chinese Academy of Sciences*, 39(1): 198–209. (in Chinese)

Guo Mingming, Zhang Xingyi, Xu Jinzhong, Chen Zhuoxin, Yang Qingnan, & Zhang Shengmin. (2024) Methods for Treating Erosion Gullies, 202410580467.1, Invention Patent, China.

Hou Jianguo. (2021) Science and technology innovation supporting sustainable use of black soil. *Bulletin of Chinese Academy of Sciences*, 36(10): 1123–1126. (in Chinese)

Jiang Ming, Wen Ya, Sun Ming, Wang Hongsheng, Zeng Yan, Han Yongbin, Li Xiujun, Wu Haitao, Li Lujun, & Xu Shangqi. (2021) Thinking and implementation approach of science and technology strategy of well raising black soil. *Bulletin of Chinese Academy of Sciences*, 36(10): 1146–1154. (in Chinese)

Liu Lichun, Dou Jiagang, Sun Tao, Zhang Xingyi, Zhang Guanghui, & Wang Chunying. (2023) A Method for Rehabilitation of Erosion Gullies, ZL201310652348.4, Invention Patent, China.

Qi Zhi, Han Xing, Ding Chao, Hu Wei, & Zhang Xingyi. (2020) Drainage function and straw decomposition rate of landfill reclamation erosion gully. *Transactions of the Chinese Society of Agricultural Engineering*, 36(23): 85–91.

Zhang Xingyi, Hu Wei, Li Jianye, GuoMingming, & Liu Xiaobing. (2024) Control of soil and water losses is the critical issue for black earth conservation. *Chinese Science Bulletin*, 69(11): 1401–1405.

Zhang Xingyi & Liu Xiaobing. (2021) Current scenario of gully erosion and its control strategy in Mollisols areas of Northeast China. *Transactions of the Chinese Society of Agricultural Engineering*, 37(3): 320–326.

Zhang Xingyi, Qi Zhi, Zhang Shengmin, Li Hao, Du Shuli, Hu Wei, Ding Chao, & Han Xing. (2019) Rehabilitation engineering of gully filling in the Mollisols farmland of Northeast China. *Science of Soil and Water Conservation*, 17(5): 128–134.