Soil Science Theory and Technological Innovation Promoting Regional Agricultural Sustainable Development and Local Economic Construction: Postprint

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Abstract

The Huang-Huai-Hai region constitutes China' s second largest plain and holds an irreplaceable strategic position in national food security and economic development. The Huang-Huai-Hai Plain was primarily formed through alluvial deposition from multiple sediment-laden rivers including the Yellow River, Huai River, and Hai River, and has historically faced persistent agricultural challenges such as drought, waterlogging, salinization, and wind-blown sand. In this context, a research team led by Academician Xiong Yi from the Institute of Soil Science, Chinese Academy of Sciences (Nanjing), established a presence in the Huang-Huai-Hai Plain in 1963, creating the core technology of "well irrigation and well drainage"for salinity control. In the early 1980s, a research team primarily from the Institute of Soil Science, Chinese Academy of Sciences, reconvened in Fengqiu to address drought and flood disasters and improve low-yield soils, thereby establishing the Chinese Academy of Sciences Fengqiu Agro-ecological Experimental Station (hereinafter referred to as "Fengqiu Station"). Since its establishment, particularly over the past decade, and with substantial support from the Ministry of Science and Technology, the National Natural Science Foundation of China, the Ministry of Agriculture, and the Chinese Academy of Sciences, domestic researchers have conducted systematic research and technological development using Fengqiu Station as a field base, achieving a series of significant research outcomes. In fundamental theoretical research, the mechanisms of fluvo-aquic soil constraint formation and soil quality evolution have been elucidated, the turnover dynamics of soil organic matter and the formation mechanisms of soil structure have been deciphered, and targeted strategies for soil fertility improvement have been proposed. In technological development and application, methodologies for soil fertility cultivation and large-scale balanced

yield enhancement have been established and demonstrated across more than 20 key grain production counties in Henan Province. Through collaborations with local governments and enterprises, standardized and efficient cultivation techniques for authentic honeysuckle and raspberry have been developed, and a development model of "enterprise + research + base + farmers" has been established, making important contributions to the construction of the national food security system and local economic development.

Full Text

Theory and Technique Innovation in Soil Science Promoted Sustainable Development of Agriculture and Local Economy in Huanghuaihai Plain

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Abstract

The Huanghuaihai Plain is one of China's three major plains, spanning seven provinces and municipalities with a total area of 300,000 km^2 and accounting for one-sixth of the nation's cultivated land. As China's most important production base for grain, cotton, oil crops, meat, and fruit, it holds an irreplaceable strategic position in national food security and economic development. Formed from alluvial deposits of sediment-rich rivers including the Yellow, Huai, and Hai Rivers, the region historically suffered from drought, flooding, salinization, and sand drift that hindered agricultural development. Beginning in 1963, a large team of researchers led by Academician Xiong Yi from the Institute of Soil Science, Chinese Academy of Sciences (CAS), established a presence in the Huanghuaihai Plain, creating the "well irrigation and well drainage" technology for water and salinity control. From the Sixth Five-Year Plan period, regional governance of the Huanghuaihai Plain was incorporated into national science and technology programs. In this context, the Institute of Soil Science, CAS established the Fengqiu Agro-Ecological Experimental Station (Fengqiu Station) in Panshi Township, Fengqiu County, Henan Province in May 1983. Focusing on agricultural production and rural economic development, the station has conducted long-term and effective scientific research and production practices, gradually forming a technical system for controlling drought and flood disasters and improving low-yield soils, effectively mitigating the hazards of drought, flooding, and salinization.

Despite tremendous achievements in comprehensive agricultural improvement, medium- and low-yield farmland still accounts for two-thirds of the region, with several factors limiting further yield increases: (1) low soil organic matter content, with soil organic carbon at only 6.40 g kg^{-1}, below the national dryland

average of 9.60 g kg^{-1} [3] and just one-third of U.S. farmland levels; (2) imbalanced soil nutrient supply due to heavy chemical fertilizer use, especially nitrogen, and insufficient organic manure input; (3) low water and nutrient use efficiency, with wheat and maize nitrogen use efficiency averaging only 24% (11-45%) [4], far below Western developed countries (>50%) and the national average (30–35%) [5]; and (4) persistent potential salinization threats, as salts have been leached to subsurface layers where improper irrigation can induce secondary salinization, particularly in coastal areas.

Addressing these challenges, Fengqiu Station has systematically conducted theoretical and technological innovation to support national needs and regional agricultural development.

Keywords: theory and technique innovation in soil science, Huanghuaihai Plain, soil fertility, improvement of medium- and low-yield field, high-yield crop production technique

1. Building Long-term Experimental Systems for Theoretical Innovation and Technology Development

Soil development and fertility formation are long-term processes, making soil science research highly dependent on long-term experimental plots. The world's first long-term experiment was established at Rothamsted in 1843 and has contributed significantly to theory for over 170 years—for example, Jenkinson and Rayner [6] developed the world's first soil carbon cycle model based on long-term experiments and preserved soil samples, while also providing direct guidance to local farmers, effectively promoting agricultural and ecological development in the UK. From its establishment, Fengqiu Station has prioritized the construction of long-term experiments, planning systematically around two missions: (1) serving as CAS's primary field experimental base in the Huanghuaihai Plain, particularly along the Yellow River and its floodplains, for research on agriculture, resources, ecology, and environment; and (2) serving as a key monitoring station in the Chinese Ecosystem Research Network (CERN) for long-term monitoring of ecological environment evolution in the Yellow River region. Experiments have been implemented in phases (Figure 1 [Figure 1: see original paper]). The station currently maintains major facilities including a large underground water-salt dynamics simulation laboratory, a group weighing lysimeter system, rain-fed farmland production potential experiments, long-term organic/inorganic fertilizer application experiments, water-nutrient synergy experiments, and tillage mode experiments (Figure 2 [Figure 2: see original paper]), providing a solid foundation for research output and sustainable development.

2. Revealing Fluvo-aquic Soil Quality Evolution Patterns and Fundamental Fertility Nature

Based on long-term organic/inorganic fertilizer experiments, research has revealed that balanced chemical fertilizer application enables sustained high crop yields and continuous improvement of soil fertility, correcting the internationally prevalent but oversimplified view that "long-term chemical fertilizer application is unsustainable" [16]. Using in-situ measurement techniques, researchers have clarified the stability and turnover rate of soil organic matter in China's drylands, as well as the intrinsic mechanisms and dual effects of rapid organic matter decomposition in fluvo-aquic soils: efficient nutrient provision and inhibition of organic matter accumulation [17-19].

The formation mechanism and key controlling factors of soil aggregates in fluvo-aquic soils have been proposed, primarily controlled by organic carbon content in micro-aggregates and silt-clay fractions. As organic carbon in silt-clay fractions increases, these fractions continuously aggregate to form micro-aggregates or macro-aggregates, while micro-aggregates form macro-aggregates through self-aggregation or combination with silt-clay fractions [20]. Soils with higher aggregation degrees exhibit higher proportions of pores smaller than 4 m, reducing soil oxygen effective diffusion coefficients, inhibiting aerobic bacteria growth, promoting facultative and anaerobic bacteria proliferation, decreasing the aerobic/anaerobic bacteria ratio, and making *Bacillus asahii* the dominant microorganism [21], thereby slowing the decomposition rate per unit of organic carbon. This demonstrates the linkage between organic matter, aggregates, and microbial communities in fluvo-aquic soils [22]. Using carbon-13 tracing technology, studies found that exogenous carbon residual rates are higher in soils with high organic matter content than in low organic matter soils, indicating that soils with low fertility face greater difficulty in organic matter improvement. The underlying mechanism is that microbial communities in such soils are dominated by aerobic bacteria that efficiently decompose exogenous carbon [23], leading to proposed countermeasures for effective fluvo-aquic soil organic matter enhancement [24].

3. Evaluating Regional Water Resources and Developing Irrigation Strategies

Regional water resource characteristics have been evaluated through the development of a distributed hydrological cycle model (INHAW) with independent intellectual property rights [7], using the Tianranwenyanqu small watershed (2,514 km^2) as a case study. The watershed' s average annual water resources total 2.35$\times10^{9}$ m^3, including rainfall of 1.408$\times10^{9}$ m^3 (equivalent to 559 mm), Yellow River irrigation water of 6.27$\times10^{8}$ m^3 (249 mm), and Yellow River lateral seepage of 6.93$\times10^{8}$ m^3 (275 mm). Average runoff at the Dacheji outlet is 3.78$\times10^{8}$ m^3 (149 mm), making available water resources 934 mm—sufficient for high-yield production in irrigated areas along the Yellow River. However, fluvo-aquic soil regions suffer from low rainfall and uneven seasonal distribution, resulting in low agricultural water use efficiency. Long-term observations using large lysimeters at Fengqiu Station have clarified crop water consumption patterns, revealing that wheat-maize rotation systems require 830 mm annually to achieve yields above 1 t per mu, with the maize season requiring 358 mm (currently met by rainfall) and the wheat season requiring 473 mm (requiring 311 mm of irrigation supplementation).

Soil hydraulic properties are critical inputs for soil hydrological process models. Due to high spatial variability, obtaining accurate soil hydraulic property distributions in the field is a key constraint for simulation. To address this, a horizontal infiltration method was developed for rapid determination of disturbed soil hydraulic parameter models [8-10], and new theory was established for determining soil hydraulic parameters through vertical infiltration experiments [11,12], enabling rapid in-situ measurement of soil hydraulic properties at different scales and providing new technologies for related research.

A new soil moisture sensor and wireless farmland moisture monitoring network system were developed (Figure 3 [Figure 3: see original paper]) [13], enabling automatic spatiotemporal monitoring of soil moisture, precipitation, evaporation, groundwater level, and forecasting of farmland moisture conditions. A regional water-nitrogen management model [14] was established, and regional farmland irrigation strategies were proposed [15], optimizing regional agricultural water resource utilization.

4. Creating Technical Systems for Farmland Fertility Improvement and Efficient Crop Cultivation

Improving organic matter content is key to targeted fertility cultivation in fluvo-aquic soils. Long-term experiments show that applying only organic manure efficiently increases soil carbon but affects crop yields, while combining organic and inorganic nitrogen fertilizers at a 1:1 ratio achieves both yield and soil carbon improvement. Although no-tillage is generally considered to increase soil carbon, in the Huanghuaihai Plain it causes surface accumulation of soil carbon, offsetting carbon sequestration benefits. Fengqiu Station therefore proposed a reduced tillage technique of "five consecutive seasons of no-tillage with one deep plowing." Using natural carbon-13 abundance techniques, research found that biochar made from crop straw has negative priming effects, slowing decomposition of active organic carbon in fluvo-aquic soils and enabling rapid soil organic carbon enhancement and efficient recycling of agricultural organic waste resources [25], though reducing biochar production costs remains critical for large-scale application.

Under the support of CAS-Henan Province cooperation projects including the "Cultivated Land Conservation and Sustainable High-Efficiency Modern Agriculture Pilot Project—Fengqiu Experimental Area,""High-Yield and High-Efficiency Modern Agriculture Demonstration Project," and "Modern Agriculture Demonstration and Regional Innovation Integration Plan," researcher Zhang Jiabao organized scientists from CAS and Henan Province to create the "Farmland Fertility Improvement and Large-Scale Balanced Yield Increase Technology for the Huanghuai Region" (Figure 4 [Figure 4: see original paper]). With Fengqiu County as the core demonstration county and 22 additional counties and one municipality as extension areas, the technology was demonstrated across 1.459 million mu from 2011–2013, increasing grain production by 8.75×10^{8} kg and generating 4.02 billion yuan in additional income and cost savings, comprehensively enhancing regional grain production potential and agricultural levels. This achievement received the second-class National Science and Technology Progress Award.

5. Research, Demonstration, and Industrial Development of Standardized Honeysuckle Cultivation

With the deepening of agricultural structure adjustment in Henan, Fengqiu Station focused on the goals of "ensuring food security, improving agricultural growth quality and efficiency, and increasing farmer income." Targeting honeysuckle—a characteristic economic crop with comparative advantage in Fengqiu County—the station collaborated with local governments to develop efficient planting models, forming a regionally distinctive agricultural leading product and pillar industry. Through comparative studies of honeysuckle species and germplasm, superior varieties were selected. Systematic research on honeysuckle biological characteristics and growth patterns identified key factors affecting yield and quality, leading to the development of standard operating procedures for standardized honeysuckle cultivation and quality evaluation standards. A high-yield and high-quality honeysuckle cultivation technology system was created and demonstration bases established. Using Fengqiu County' s radio and television network, training series on standardized honeysuckle production were conducted, training over 50,000 farmers and distributing more than 100,000 training manuals and video discs. The "enterprise + research + base + farmer" development model was established, making Fengqiu County a honeysuckle medicinal source base for Harbin Pharmaceutical Group, Jinling Pharmaceutical, Zuojinming Pharmaceutical, and others. The planting area has reached over 100,000 mu with an annual output value of 1.1 billion yuan, providing a model for standardized production of Chinese medicinal materials like honeysuckle (Figure 5 [Figure 5: see original paper]).

6. Raspberry Industrialization Technology Development and Demonstration

Focusing on raspberry industrialization in Fengqiu County and collaborating with local government, Fengqiu Station developed an integrated planting-processing industry system. Through introduction and screening of 16 blackberry varieties, five superior varieties were selected for propagation and promotion. Standardized raspberry planting technical procedures and organic planting standards were formulated, training 15,000 farmers and providing technical extension services for over 40,000 mu (Figure 6 [Figure 6: see original paper]). "Fengqiu Raspberry" has obtained organic product certification and national geographical indication protection product status, while Fengqiu County has received titles including "National Raspberry Planting Comprehensive Standardization Demonstration Zone," "Agricultural Science and Technology Experimental Demonstration Base," and "Hometown of Chinese Raspberry." Collaborating with Henan Meirikang Agricultural Development Co., Ltd., a raspberry planting and processing base was established, producing concentrated juice, beverages, fruit wine, dried fruit, jam, dried wine, fruit tea, essential oil, and other products, solving post-harvest concerns for farmers. Currently, Fengqiu County has over 40,000 mu of raspberry cultivation, planned to expand to 150,000 mu within five years. Fresh raspberry yields per mu exceed 10,000 yuan in output value with over 7,000 yuan net profit. Henan Meirikang Agricultural Development Co., Ltd. has an annual output value of 1.9 billion yuan with 300 million yuan in taxes and profits.

7. Conclusion

Since its establishment in 1983, Fengqiu Station has conducted long-term and effective monitoring, research, technology development, and demonstration around core issues in agricultural production and ecological environment in the Huanghuaihai Plain, making important contributions to national food security and ecological environment construction. Through undertaking major national and provincial projects, the station has revealed soil quality characteristics and evolution patterns, advanced basic soil science theory, and led research in China' s soil fertility field with broad international impact. Collaborating with local governments, the soil fertility improvement and balanced crop yield increase technology system has been applied and demonstrated at large scales, comprehensively enhancing grain production potential, improving regional agricultural levels, and increasing farmer income. Through enterprise cooperation, the "enterprise + research + base + farmer" development model has been established, enhancing enterprise profits and farmer benefits. Currently, Fengqiu Station is focusing on advancing research-oriented field station infrastructure construction, cultivating and introducing outstanding talent, and further improving academic research and technology development capabilities to better serve as a platform for knowledge and technology innovation, integration, and transfer, making greater contributions to regional agricultural sustainable development and local economic construction.

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Note: Figure translations are in progress. See original paper for figures.