Post-print of the officially launched project "Research on Farmland Nitrogen and Phosphorus Leaching Loss Pollution and Prevention and Control Mechanisms" under the Ministry of Science and Technology' s 13th Five-Year Plan Key Special Project for Comprehensive Prevention, Control, and Remediation···

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Abstract

Intensive farmland improves crop yields through substantial inputs of chemical fertilizers and irrigation, while excess fertilizer nutrients are lost to groundwater via leaching, exerting tremendous impacts on the groundwater environment. This high-intensity anthropogenic intervention has formed a unique root zone–deep vadose zone–groundwater system characteristic of intensive agriculture. The degree of intensification and pollution load in China' s major agricultural production areas rank highest globally, making its environmental impact a typical worldwide case. Groundwater pollution in China is becoming increasingly severe, with groundwater at 80% of monitoring sites classified as Category IV and V, and the "three nitrogen forms" (ammonium nitrogen, nitrite nitrogen, and nitrate nitrogen) associated with farmland leaching constitute the primary pollution source. Black soil, fluvo-aquic soil, and cinnamon soil regions serve as China' s grain baskets, with excessive inputs of nitrogen and phosphorus fertilizers and irrigation, and are also prone and high-incidence areas for nitrogen and phosphorus leaching from farmland and groundwater pollution. Therefore, conducting theoretical research on the leaching mechanisms and control mechanisms of nitrogen and phosphorus in the root zone–deep vadose zone–groundwater system represents an urgent need to ensure national food security and ecological environment sustainability. The international development trend for controlling nitrogen and phosphorus leaching pollution from farmland involves integrated management transitioning from point pollution control in farmland

to risk control zoning for nitrogen and phosphorus leaching loss in regional farmland, combined with related nitrogen and phosphorus reduction policies and legislation. The European Union (EU-27) has established the Nitrate Directive and Water Framework Directive to regulate the application amounts and methods of fertilizers and irrigation water, improve nitrogen and phosphorus use efficiency, reduce nitrogen and phosphorus leaching loss, and implement focused prevention and control by delineating nitrate-vulnerable zones. Thus, research on nitrogen and phosphorus leaching patterns from farmland to regional scales and regional control pathways is of great significance. In response to this societal need, the Ministry of Science and Technology and the Ministry of Agriculture recently launched the first batch of key special projects for "Research and Development of Comprehensive Prevention and Remediation Technologies for Agricultural Non-point Source and Heavy Metal Pollution in Farmland," with the "Research Project on Nitrogen and Phosphorus Leaching Loss Pollution and Prevention and Control Mechanisms in Farmland" being one of the basic research projects initiated in the first batch of 2016.

Full Text

Preamble

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Launch of the National Key R&D Project "Research on Nitrogen and Phosphorus Leaching Loss Pollution and Prevention Mechanisms in Croplands" under the 13th Five-Year Plan

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Intensive croplands achieve high crop yields through heavy inputs of chemical fertilizers and irrigation, yet excessive nutrient loads leach into groundwater, causing substantial environmental impacts. This high-intensity anthropogenic intervention has created a distinctive system in intensive agriculture comprising the root zone, deep vadose zone, and groundwater. China' s major agricultural production regions rank highest globally in both intensification level and pollution load, making them a typical case of worldwide environmental impact. Groundwater pollution in China is increasingly severe, with 80% of monitoring sites classified as Category IV or V, and the "three nitrogen" compounds (ammonium, nitrite, and nitrate nitrogen) associated with farmland leaching

represent the primary pollution source. Black soil, fluvo-aquic soil, and cinnamon soil regions serve as China' s granary and are also hotspots for nitrogen and phosphorus leaching and groundwater pollution due to excessive fertilizer and irrigation inputs. Therefore, theoretical research on the leaching mechanisms and control strategies for nitrogen and phosphorus in the root zone–deep vadose zone–groundwater continuum is urgently needed to ensure national food security and sustainable environmental development.

The international trend in controlling nitrogen and phosphorus leaching pollution has shifted from point-source control to regional risk-based zoning and integration with policy instruments for nutrient reduction. The European Union (EU-27) has established the Nitrates Directive and Water Framework Directive to regulate fertilizer and irrigation application rates and methods, improve nutrient use efficiency, and reduce leaching losses, with targeted prevention and control through the delineation of nitrate-vulnerable zones. This demonstrates the significance of understanding leaching patterns from field to regional scales and developing regional control pathways.

In response to these societal needs, the Ministry of Science and Technology and the Ministry of Agriculture recently launched the first batch of projects under the National Key R&D Program for "Comprehensive Prevention and Remediation Technology for Agricultural Non-point Source and Heavy Metal Pollution in Croplands." The "Research on Nitrogen and Phosphorus Leaching Loss Pollution and Prevention Mechanisms in Croplands" project represents one of the foundational research initiatives launched in 2016.

Project Overview

The project (No. 2016YFD0800100) is led by the Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, and brings together 15 leading institutions with long-term expertise in agricultural nitrogen and phosphorus pollution and leaching research (5 from the Chinese Academy of Sciences, 3 from the Chinese Academy of Agricultural Sciences, China Agricultural University, Northwest A&F University, and agricultural academies of Jilin, Beijing, Henan, Shanxi, and Tianjin Agricultural College). The consortium possesses over 10 provincial/ministerial-level key laboratories, including the "National Agricultural Non-point Source Pollution Monitoring Network," "Key Laboratory of Agricultural Water Resources, Chinese Academy of Sciences," and "Key Laboratory of Non-point Source Pollution Control, Ministry of Agriculture." The team has conducted extensive research on agricultural non-point source pollution monitoring and nitrogen-phosphorus leaching dynamics, providing a strong foundation for the project. The consortium has led more than 40 national research projects, including key projects from the National Natural Science Foundation, Ministry of Science and Technology support programs, and Ministry of Agriculture public welfare programs. Previous work has demonstrated the critical importance of the vadose zone in controlling and attenuating nitrogen and phosphorus leach-

ing, providing fundamental support for the proposed research.

Research Content and Structure

The project focuses on black soil, fluvo-aquic soil, and cinnamon soil regions that are prone to leaching. The main research components include four aspects: (1) spatiotemporal patterns of nitrogen and phosphorus leaching in the root zone of major agricultural regions; (2) leaching mechanisms and controlling factors for nitrogen and phosphorus in the root zone–deep vadose zone; (3) control mechanisms and effectiveness for nitrogen and phosphorus leaching in black soil, fluvo-aquic soil, and cinnamon soil regions; and (4) risk assessment and mitigation pathways for nitrogen and phosphorus leaching in typical agricultural regions.

The overall approach is based on understanding the spatiotemporal patterns of nitrogen and phosphorus leaching in black soil, fluvo-aquic soil, and cinnamon soil regions, focusing on vadose zone leaching mechanisms, with the goal of developing a comprehensive profile control system featuring "nitrogen interception and phosphorus retention in the root zone, and nitrogen removal and phosphorus fixation in the vadose zone." The implementation plan involves: utilizing vadose zone observation wells and advanced technologies such as Geoprobe and CT scanning to study leaching mechanisms; revealing spatiotemporal patterns of root zone leaching through an expanded monitoring network in typical northern croplands; proposing control mechanisms based on three integrated research bases in black soil, fluvo-aquic soil, and cinnamon soil regions; and establishing a groundwater nitrate monitoring network in typical northern agricultural regions to propose pollution risk zoning and regional mitigation pathways.

The project comprises six research topics: Topic 1, Spatiotemporal patterns and intensity of nitrogen and phosphorus leaching in major northern agricultural regions; Topic 2, Mechanisms and controlling factors of nitrogen and phosphorus leaching in typical cropland vadose zones; Topic 3, Control mechanisms and measures for nitrogen and phosphorus leaching in black soil regions; Topic 4, Control mechanisms and measures for nitrogen and phosphorus leaching in fluvo-aquic soil regions; Topic 5, Control mechanisms and measures for nitrogen and phosphorus leaching in cinnamon soil regions; and Topic 6, Risk zoning and mitigation pathways for nitrogen and phosphorus leaching in typical northern agricultural regions.

Expected Outcomes

The project' s implementation prospects are reflected in three main aspects: (1) It aims to elucidate the spatiotemporal patterns of nitrogen and phosphorus leaching in typical northern agricultural regions, develop quantitative theoretical relationships between nitrogen-phosphorus inputs, accumulation, enrichment, and leaching losses in cropland systems, reveal vadose zone leaching mechanisms, and propose a comprehensive profile control theory. These outcomes

will provide technical direction and theoretical support for other technology development and demonstration projects within the national program. (2) It aims to establish monitoring networks for nitrogen-phosphorus leaching in typical northern croplands and groundwater nitrate, along with assessment indicator systems for leaching factors under typical cropping systems, covering planting patterns such as spring maize in Northeast China, vegetable fields in Northeast China, spring maize in North China, wheat-maize rotation in North China, and vegetable fields in North China. Monitoring indicators will include: soil moisture, nitrate nitrogen, ammonium nitrogen, and available phosphorus; crop economic yield, biomass, total nitrogen, and total phosphorus; nitrate nitrogen, ammonium nitrogen, and total phosphorus in leachate at different root zone depths; and groundwater nitrate concentrations. Integrated with regional-scale models linking vadose zone leaching and groundwater pollution risk, the project will propose vulnerability zoning for groundwater nitrate pollution in black soil, fluvo-aquic soil, and cinnamon soil regions, providing scientific basis and data support for national non-point source pollution prevention policies. (3) Through common networked experiments across the three soil types, the project will study control mechanisms and technologies for nitrogen-phosphorus leaching, develop 1–2 draft standards for nitrogen-phosphosphorus loss reduction in croplands and vegetable fields in these regions, and ultimately formulate 1–2 draft regional load and reduction standards for nitrogen-phosphorus losses in northern agricultural regions. The research on nitrogen and phosphorus leaching loss pollution and prevention will support the implementation of major national policies such as the "Water Ten Articles," "Soil Ten Articles," and the "National Agricultural Sustainable Development Plan (2015–2030)," effectively reducing economic losses from groundwater nitrate pollution and health problems from drinking nitrate-contaminated groundwater, thereby improving groundwater quality in black soil, fluvo-aquic soil, and cinnamon soil regions with significant social and environmental benefits.

Participating Institutions

Project/Topic 6 Leading Institution: The Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences has extensive experience in agricultural non-point source pollution research, having led 34 national research projects including the National Natural Science Foundation Key Project "Study on Denitrification Self-remediation Mechanisms of Nitrate Pollution in Thick Vadose Zone Cropland Soils"and the Ministry of Science and Technology Support Program "Integration and Demonstration of Comprehensive Pollution Prevention and Control Technologies for Intensive Croplands in Northern China." The center has received 9 awards including the Hebei Provincial Science and Technology Progress First Prize and the National Science and Technology Progress Second Prize. It possesses the national-level Luancheng Agro-Ecosystem Experimental Station, Key Laboratory of Agricultural Water Resources, and observation technologies and equipment for typical thick vadose zone regions. The center is equipped with a

large environmental sampler Geoprobe 54DT for convenient collection of intact soil cores throughout thick vadose zones, as well as ion chromatographs, flow analyzers, gas chromatographs, and isotope mass spectrometers. Additionally, a 48-meter experimental observation well will be drilled at the Luancheng Station in 2016 to support the project. The center has developed the NUFER model, which simulates regional-scale nitrogen-phosphorus leaching from cropland root zones using the reduction factor method commonly applied in the EU—also the standard approach for EU Nitrates Directive development and assessment—and is now widely used domestically and internationally.

Topic 1 Leading Institution: The Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences has led over 20 national research projects in agricultural non-point source pollution, including the public welfare program "Monitoring and Early Warning of Agricultural Non-point Source Pollution and Nitrogen-Phosphorus Input Threshold Research in Major Agricultural Regions"and the Ministry of Science and Technology support program "Integration and Demonstration of Comprehensive Pollution Prevention and Control Technologies for Suburban Intensive Croplands." The institute maintains the "National Agricultural Non-point Source Pollution Monitoring Network" and has received 2 provincial/ministerial-level awards.

Topic 2 Leading Institution: China Agricultural University has led and completed major projects including the National Natural Science Foundation project "Mechanisms of N2O Production in Typical Croplands of the North China Plain," the National Science and Technology Key Project "Research on Nitrogen Fertilizer Pollution Control Technology," and the 863 Program "In-situ Remediation Technology Using Deep-rooted Plants to Control Groundwater Nitrate Pollution." The project "Integrated Management Technology of Nutrient Resources for Coordinating High Crop Yield and Environmental Protection" received the National Science and Technology Progress Second Prize.

Topic 3 Leading Institution: The Institute of Applied Ecology, Chinese Academy of Sciences has participated in and completed major projects including the National Science and Technology Support Task "Research on Key Technologies for Efficient Organic Matter Improvement and Water-Fertilizer Regulation in Medium-low Yield Fields" and the National Water Special Project "Key Technologies and Demonstration for Non-point Source Pollution Control and Water Quality Improvement in Agricultural Areas." The institute has achieved over 480 scientific and technological results, receiving 24 national-level awards and 198 provincial/ministerial awards.

Topic 4 Leading Institution: The Beijing Academy of Agriculture and Forestry Sciences has actively conducted research on agricultural non-point source pollution and prevention since 2000, leading projects including the National Science and Technology Support Program "Research on Key Technologies for Agricultural Non-point Source Pollution Control in Lake-shore Areas," the Ministry of Agriculture industry special task "Monitoring and Nitrogen-Phosphorus Fertilizer Input Threshold Research for Non-point Source Pollution

in the Huang-Huai-Hai Semi-humid Plain Region," and the Ministry of Agriculture ecological protection project "Investigation and Monitoring of Groundwater Nitrate Pollution in North China."

Topic 5 Leading Institution: Northwest A&F University has recently led or participated in major projects including the China-Switzerland international cooperation project "Improving Nitrogen Use Efficiency and Reducing Nitrogen Loss," the China-UK cooperation project "Reducing Nitrogen Non-point Source Pollution," the Ministry of Agriculture project "Research on Nitrogen Loss Pathways in Dryland Soils," and the 973 Program "Phosphorus Migration and Environmental Effects in Cropland Ecosystems." Related research has received the 2011 National Science and Technology Progress Second Prize and the 2014 Shaanxi Provincial Science and Technology Progress Second Prize.

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