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Post-print after Official Launch of the Ministry of Science and Technology 13th Five-Year Plan Key Research and Development Special Project on Comprehensive Prevention, Control and Remediation Technologies for Agricultural Non-point Source and Heavy Metal Polluted Farmland: Study on Heavy Metal M...

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Abstract

The migration and transformation of heavy metals in farmland systems and their safety thresholds constitute fundamental and complex core issues in the research field of heavy metals in soil environments. Compared with international efforts, previous investments and achievements in research on heavy metals in farmland soils in China have predominantly focused on soil heavy metal pollution investigation and remediation technologies, whereas studies on speciation transformation, risk assessment, and threshold values have been relatively limited. In recent years, the role and importance of research on soil heavy metal speciation transformation, risk assessment, and thresholds in soil pollution prevention and remediation have become increasingly prominent. For instance, multi-year research findings have demonstrated that the current environmental quality standards for soil heavy metal lead are overly lenient, indicating that establishing soil environmental quality standards for agricultural land in China based solely on ecological environmental effects cannot effectively ensure the quality and safety of agricultural products. Precisely because China previously lacked sufficient basic data and methodologies for research on safety thresholds of soil heavy metals, and because soil environmental quality standards have not fully considered the characteristics of substantial variations in soil properties at agricultural product production sites and the diversity of crop types and varieties, the scientific validity and operability of China's soil heavy metal environmental quality standards urgently require improvement and enhancement to

effectively safeguard the safe production of agricultural products and ecological security of farmland.

Full Text

Preamble

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National Key R&D Program of China During the 13th Five-Year Plan Period: “Research on Heavy Metal Migration, Transformation, and Safety Thresholds in Farmland Systems” Project Officially Launched

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Introduction and Background

Heavy metal migration, transformation, and safety thresholds in farmland systems represent fundamental and complex core issues in soil environmental research. Compared with international efforts, previous research in China has primarily focused on soil heavy metal contamination surveys and remediation technologies, with comparatively less investigation into metal speciation transformation, risk assessment, and threshold determination. However, the role and significance of speciation transformation, risk evaluation, and threshold research in soil pollution prevention and remediation have become increasingly prominent. For instance, multi-year research findings have demonstrated that existing environmental quality standards for soil lead are overly lenient, indicating that relying solely on ecological environmental effects to establish soil quality standards cannot effectively guarantee agricultural product safety. Due to insufficient foundational data and methodological frameworks for soil heavy metal safety threshold research in China, current soil environmental quality standards have failed to adequately account for the country’s highly variable soil properties and diverse crop types and varieties. Consequently, the scientific rigor and practical applicability of these standards require substantial improvement to effectively safeguard national agricultural product safety and farmland ecological security.

Project Overview

The project “Research on Heavy Metal Migration, Transformation, and Safety Thresholds in Farmland Systems” (Project No.: 2016YFD0800400) is led by the Institute of Agricultural Resources and Regional Planning, Chinese Academy

of Agricultural Sciences, in collaboration with premier research institutes and universities under the Chinese Academy of Sciences, Ministry of Environmental Protection, Ministry of Agriculture, and Ministry of Education. The research team comprises distinguished principal investigators including recipients of the National Science Fund for Distinguished Young Scholars, Young Thousand Talents Program, and Excellent Young Scientists Fund, all possessing solid research foundations and expertise in heavy metal migration and safety thresholds in farmland systems. Addressing China's challenges of weak systematic research, difficult quantification, and insufficient integration with technology and management in this field—alongside pressing needs for soil pollution prevention, food safety, and ecological security—the project focuses on establishing quantitative relationships between heavy metal bioavailability (in rice, wheat, and vegetables) and toxicity (to plants, microorganisms, and animals) with metal content, speciation, and controlling factors. It also aims to develop ecological risk assessment methodologies and determine safety thresholds for agricultural products and ecological systems.

Research Scope and Framework

The project targets nine heavy metals/metalloids (Cd, Pb, Hg, As, Cr, Cu, Zn, Ni, and Sb) across three agricultural products and production soils (rice, wheat, and vegetables), addressing both food safety and ecological security. Following a priority risk control principle, these elements are divided into two categories: those primarily threatening agricultural product quality (Cd, Pb, Hg, As, and Cr) and those posing primary ecological risks (Cu, Zn, Ni, Cr, and Sb). The research systematically investigates the entire migration and transformation process of heavy metals in typical farmland systems—from solid phase to solution to biological systems to assessment endpoints (agricultural product safety and ecological security)—to develop quantitative models and evaluation methods, establishing a scientific methodology for determining farmland soil heavy metal safety thresholds.

Research Structure: Three Components and Seven Tasks

The project comprises three research components and seven specific tasks. **Component 1** focuses on heavy metals affecting agricultural product quality (Cd, Pb, Hg, As, Cr), investigating speciation transformation and bioavailability. This includes: Task 1 on migration, transformation, and bioavailability of Cd, Pb, and Hg; Task 2 on As and Cr migration, transformation, and bioavailability; and Task 3 on heavy metal interactions and bioavailability in co-contaminated soils. This component aims to elucidate migration processes and bioavailability/toxicity mechanisms, establish mechanistic quantitative models, and resolve the challenge of quantifying heavy metal bioavailability in farmland systems—providing scientific foundations for threshold determination and effective support for pollution prevention and remediation.

Component 2 addresses ecologically risky elements (Cu, Zn, Ni, Cr, Sb), examining soil heavy metal ecotoxicological mechanisms, models, and standardized ecological risk assessment methods. This encompasses Task 4 on ecotoxicological effects and mechanisms, and Task 5 on ecological risk assessment methodology standardization. The objective is to establish rapid, precise, mechanism-based risk assessment methods to support accurate diagnosis of farmland heavy metal pollution risks.

Component 3 concentrates on safety threshold determination for agricultural product quality and ecological security, including Task 6 on cationic heavy metals (Cd, Pb, Hg, Cu, Ni, Zn) and Task 7 on anionic heavy metals (As, Cr, Sb). This component aims to establish universal safety thresholds for Chinese farmland soils based on heavy metal content/speciation-effect relationships, integrating agricultural product safety, ecological security, bioavailability/toxicity, and species sensitivity distribution to enhance threshold certainty and applicability.

Expected Outcomes and Significance

The project is expected to establish quantitative relationships between heavy metal speciation transformation, interfacial processes, controlling factors, and agricultural product safety; investigate ecotoxicological mechanisms and develop rapid, precise, standardized risk assessment methods; and determine methodologies for establishing soil heavy metal thresholds based on food safety and ecological risks. These findings will advance comprehensive understanding of heavy metal behavior in farmland systems and prove significant for assessing agricultural product safety and soil ecological risks. Application of these results to threshold establishment will yield more scientific, reasonable standards with reduced uncertainty.

The project will propose draft standards for heavy metal safety thresholds and risk assessment methods for rice, wheat, and vegetable production systems. These outputs hold major significance for all aspects of soil environmental protection—including contamination surveys, risk assessment, safe production in moderately polluted farmland, soil remediation, and post-remediation evaluation—providing robust support for China's Soil Pollution Prevention and Control Law. Scientifically sound safety thresholds and environmental quality standards will enable effective implementation of soil pollution prevention and remediation, thereby enhancing national agricultural product quality assurance capabilities and promoting agricultural ecological environmental improvement.

Consequently, this project's findings will yield substantial scientific value and socio-ecological benefits. Scientifically rational heavy metal safety thresholds are essential for pollution assessment, classification, and management, enabling proper identification of remediation sites, appropriate remediation extent, and acceptance criteria while ensuring rational and effective use of national financial resources. Moreover, such thresholds are necessary for cultivating the soil remediation market. In summary, this project's results will facilitate effective

soil pollution prevention and remediation, enhance agricultural product quality safety assurance, and promote agricultural ecological environment improvement.

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

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