Front. Agr. Sci. Eng. 2023, 10(4): 503–509 https://doi.org/10.15302/J-FASE-2023528

EDITORIAL

STRENGTHENING NON-POINT SOURCE POLLUTION CONTROL TO PROMOTE AGRICULTURAL GREEN DEVELOPMENT

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Received October 26, 2023.

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This special issue is a compilation of papers addressing various aspects of non-point source pollution and agricultural green development in different regions around the world. Drafts of several papers were presented and discussed during a 2-day summit on Non-Point Source Pollution Control and Governance held in Dali, Yunnan Province, China, November 19–20, 2022. The workshop was complemented by a half-day field trip to visit the Agricultural Green Production and Non-point Source Pollution Control Engineering Demonstration Base, as well as the Science and Technology Backyards in Gusheng Village, Dali City. The workshop was jointly organized by the National Academy of Agriculture Green Development of China Agricultural University, Erhai Academy of Green Development, and Jiangsu Academy of Agricultural Sciences. The event included participation of over 20 scientists representing 10 different organizations, along with 40 Chinese graduate students.

The purpose of this summit is to discuss the challenging issues related to monitoring and load estimation of non-point source pollution, nitrogen and phosphorus loss control techniques, successful case studies, and policies. It aims to provide theoretical and technical support for the governance and management of non-point source pollution in China and other countries globally.

Non-point source pollution and agriculture green development is a crucial research focus at the National Academy of Agriculture Green Development of China Agricultural University and Erhai Agricultural Development Research Institute. The primary objective of this research theme is to establish a comprehensive model for the coordinated development of watershed non-point source pollution prevention and control in conjunction with green high-quality agriculture. This model aims to achieve several key objectives, including ensuring water environment safety, promoting food security, and enhancing income opportunities for small farmers. In the first and second national pollution surveys in China, the emission of pollutants from agricultural sources has exceeded that of industrial sources or domestic sources, making it to be the main contributor to non-point source pollution (Fig. 1). Promoting synergistic development of green agriculture and the prevention and control of agricultural non-point source pollution is an important approach to reducing agricultural pollutant emissions and succeeding in controlling agricultural non-point source pollution.

This editorial provides a brief introduction to the papers

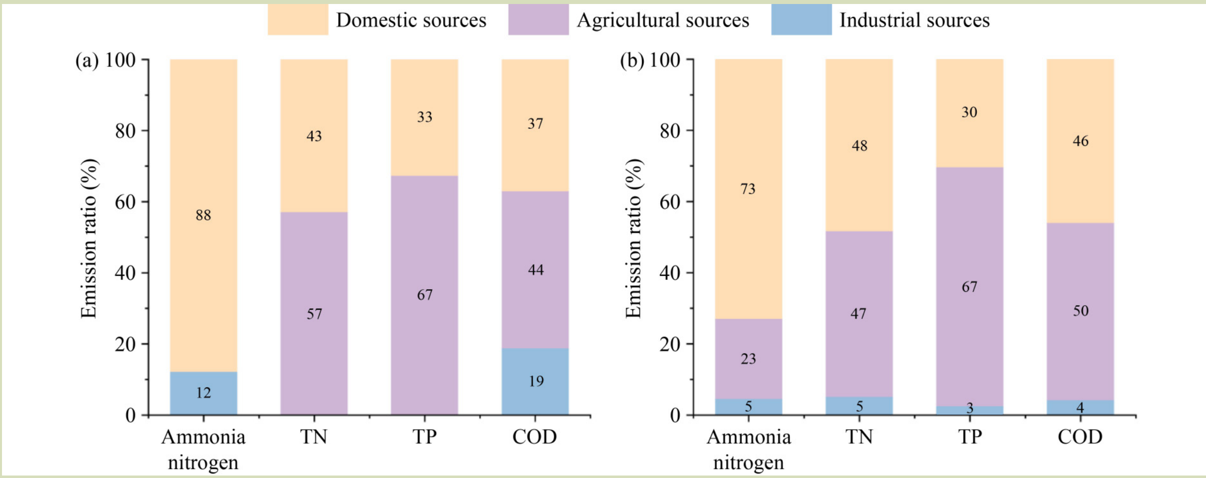

Fig. 1 Proportions of pollutants, ammonia nitrogen, total nitrogen (TN), total phosphorous (TP) and chemical oxygen demand (COD) in waterbodies in the first (a) and second pollution (b) surveys. Data sourced from the First (2007) and Second (2017) National Pollution Source Census[1,2].

included in the special issues, summarizing the main advancements in creating a coordinated model for the prevention and control of non-point source pollution and the high-quality development of agriculture in the Erhai Lake basin in Yunnan Province. In addition, it offers relevant suggestions for effectively coordinating non-point source pollution control and promoting high-quality agriculture in China.

1 OVERVIEW OF THE SPECIAL ISSUE

Water quality issues are a growing global concern that pose risks to human health, water security, and ecosystem functioning. Non-point source pollution, closely associated with agricultural activities such as crop production, livestock breeding and sewage, is a major contributor to water quality degradation. In Yunnan Province, the Erhai Lake basin is a crucial body of water facing these challenges. Currently, a team of experts is actively working on developing an innovative approach to address non-point source pollution control and promote agricultural green development in this region. The main objectives of this special issue are to provide a comprehensive overview of the latest advancements in the field, including: (1) analyzing agricultural non-point source pollution in the Erhai Lake basin and other watersheds; (2) identifying the occurrence and characteristics of non-point source pollution; (3) exploring effective technologies and treatments for non-point source pollution control; (4) evaluating policy-driven approaches to prevent and control non-point source pollution; and (5) promoting the adoption of sustainable agricultural practices and green development in the Erhai Lake basin and other similar areas. This special issue comprises six papers that were presented at the summit in Dali, as well as four papers from invited authors offering reflections on different aspects of non-point source pollution and agricultural green development. Here, we provide a brief overview. Two articles discuss the relationship between agricultural rural development and non-point source pollution control at both national and typical watershed scales. Hou et al. have examined the case of the Erhai Lake basin to address the contradiction between non-point source pollution control and the development of green agriculture. They contend that the key to reversing the current situation lies in implementing scientifically sound environmental protection policies and adopting practices for agricultural green development (https://doi.org/10.15302/J-FASE-2023524). At the national scale, Feng et al. reviewed the historical development and future prospects of crop-livestock integration for sustainable agriculture in China (https://doi.org/10.15302/J-FASE-2023525).

Four articles offer new perspectives on monitoring and load estimation of agricultural and rural non-point source pollution. Xu et al. studied soil nitrogen mineralization patterns in intensively managed agricultural areas in Dali. They found that the rate of nitrogen mineralization and nitrification varied significantly across croplands, primarily influenced by soil factors like total nitrogen, dissolved organic carbon, and dissolved inorganic nitrogen (https://doi.org/10.15302/J-FASE-2023515). Li et al. conducted a systematic review to analyze the crucial processes and major factors influencing the transport of nitrogen from agricultural fields to surface water bodies (https://doi.org/10.15302/J-FASE-2023518). Chen et al. presents a modified wash-off model to improve rainfall-runoff pollution modeling in a typical rural residential area (Gusheng Village) in Erhai Lake basin. They found that 12% of the total runoff contained 80%–95% of the total load for COD, TN, and TP (https://doi.org/10.15302/J-FASE-2023519). Liu et al. evaluated the comprehensive temporal and spatial distribution pattern of water quality and algal biomass in Erhai Lake from 1994 to 2021. They reported that currently the water environment of Erhai Lake is improving significantly owing to the implementation of control measures resulted in lower pollutant loads (https://doi.org/10.15302/J-FASE-2023520). Aslıhan et al. developed a new MARINA-Nutrients model for Europe to calculate inputs of nitrogen and phosphorus to land and rivers, nitrogen emissions to the atmosphere, and nutrient export to the ocean by river basins. They found that agriculture was responsible for 55% of nitrogen and sewage for 67% of phosphorus in rivers. Over 25% of river export of nitrogen ended up in the Atlantic Ocean and of phosphorus in the Mediterranean Sea (https://doi.org/10.15302/J-FASE-2023526).

In terms of control technologies for non-point source pollution, Xue et al. reviewed the 4R chain technology system, which includes source reduction, process retention, nutrient reuse and water restoration. They proposed a full-time and space governance strategy that prioritizes source management as the primary control measure and end control as the secondary measure (https://doi.org/10.15302/J-FASE-2023522). Wang et al. assessed the ecological function of ditch and pond systems in a typical watershed in China. They found that these systems can be effectively utilized for ecological engineering in mountain and hilly watersheds to balance drainage and intercept pollutants (https://doi.org/10.15302/J-FASE-2023517). Liu et al. conducted an analysis on the primary pollutants in the Yong-An River and the efficiency of pollutant removal by the surrounding constructed wetlands. They concluded that constructed wetlands are effective in removing nitrate-nitrogen and phosphorus, but their ability to remove ammonium nitrogen and organic pollutants is limited due to inadequate disposal of aquatic plant residues in a timely manner (https://doi.org/10.15302/J-FASE-2023516).

As guest editors, we acknowledge the substantial contributions made by all authors and reviewers to this special issue. Based on the progress discussed in the special issue, we have identified several prominent issues in the prevention and control of non-point source pollution in China. These include unclear identification of pollution sources, lack of key technologies and products for source reduction, persistent conflicts between agricultural development and environmental protection, and a lack of comprehensive solutions for regional and temporal prevention and control of non-point source pollution. Therefore, it is an urgent need to focus on key river basins and establish integrated pilot zones for synergy between basin environmental protection and high-quality agricultural development. This approach will involve the integration of basic theories, key technologies and widespread application of science and technology, while encouraging scientists to work closely with local governments and producers. Together, scientists will work toward success in controlling non-point source pollution and strive to create a new model of high-quality development that integrates production, livelihood and ecology in river basins. Below we present the major progress that has been made in coordinating the prevention and control of agricultural non-point source pollution and promoting high-quality agricultural development in the Erhai Lake basin.

2 NON-POINT SOURCE POLLUTION AND AGRICULTURAL GREEN DEVELOPMENT IN THE ERHAI LAKE BASIN

The Erhai Lake basin, the second-largest freshwater lake basin in Yunnan Province is recognized as a typical area for high-quality agricultural development and environmental protection[3]. However, it is also impacted by agricultural non-point pollution. Several studies have indicated that the significant loss of nitrogen and phosphorus originating from crop and livestock production is the primary factor contributing to the severe eutrophication and algal blooms in Erhai Lake[4,5]. To address this issue, the local government has implemented a range of water quality protection policies since 2018. These measures include mandatory actions to reduce the application of chemical fertilizers, promote the use of manure instead of chemical fertilizers, restrict the cultivation of crops that require excessive fertilizers and water (e.g., garlic), and close down intensive livestock farms[6]. As a result, the Erhai Lake basin is currently undergoing a gradual transition toward an early stage of water quality improvement[7]. However, the prevention and control of non-point source pollution and the promotion of green agricultural development in the Erhai Lake basin continue to encounter specific challenges: (1) sources and contributions of non-point source pollution remain unclear; (2) low agricultural output values result in a decline in farmer income; and (3) lack of synergy between pollution reduction efforts and the growth of farmer income.

To address these challenges, a collaborative effort was initiated in 2022 with strong support from the Yunnan Provincial Party Committee and Provincial Government, as well as the Dali Prefectural Party Committee and Prefectural Government. Academician Zhang led a consortium of over 30 national institutions and more than 300 researchers, focusing on joint research areas such as prevention of non-point source pollution, construction and optimization of high-value crop systems, and science and technology institutions and rural revitalization. With Gusheng watershed in the Haixi region of the Erhai Lake basin as a representative example, there has been significant progress in the prevention and control of agricultural non-point source pollution and the construction of a green high-value crop system.

(1) **Establishing a precise monitoring system for non-point source pollution.** To explore the sources, formation process, and impact of surface pollution on water bodies, we have established the six-vertical and seven-horizontal monitoring system in Gusheng area of the Erhai Lake basin. The main sources of pollution in the area are agricultural, stemming from farmland cultivation and village activities. The six-vertical and seven-horizontal monitoring system comprehensively addresses the emission, transfer, and impact of surface source pollution on the lake in the area. The vertical line represents the migration pathways of six different types of pollution from the Cangshan Mountain water source to Erhai Lake. The seven horizontal lines correspond to various key points such as the lake water-quality response, ecological corridor outlet, lake inlet, planting core demonstration area outlet, Dali Road node, National Highway 214 node and the clear water source. In the 2022 rainy season, we engaged over 1000 personnel in routine and stormwater monitoring and collected more than 3000 samples to provide an initial characterization of pollutant discharges in the Gusheng watershed. Our findings revealed that Point 4 of the five lake inlets in the area was the primary channel for pollutants entering the lake, accounting for 48% to 66% of the total inlet load. Based on our monitoring results, we discovered that the contribution from farmland was only 35% to 55%, while the contribution from the villages was 39% to 51%. During the monitoring cycle, we observed seven typical rainfall events, which accounted for 33% to 49% of the total pollution load. Notably, these events only lasted 14% of the total time (22 days). Our results indicate that these rainfall events are a significant contributor to the overall pollution load in the area.

(2) **Creating a non-point source pollution control demonstration project.** Based on the analysis of non-point source pollution sources, we established a demonstration project for controlling agricultural non-point source pollution. This project follows the principles of source reduction, process interception, nutrient recycling and ecological restoration. It integrates multiple technologies, including the application of green intelligent fertilizers to reduce fertilizer usage and increase efficiency, the use of ecological interception ditches, water conservation and reuse, and ecological pond purification. For example, we have constructed over 1 km of ecological ditches to reduce the concentration of pollutants in agricultural runoff. We have also built two reservoirs to collect and further purify the water from the ecological ditches, which are then used for irrigation purposes in agricultural production. Since the operation of the project between July and October 2023, the monitoring of water inflow and outflow, as well as pollutant concentrations in ecological ditches and ponds under varying rainfall conditions, has revealed significant reductions in total nitrogen and total phosphorus loads in the Gusheng watershed source pollution demonstration project. Specifically, the project has achieved a reduction in the total nitrogen load of about 1500 kg and a reduction in the total phosphorus load of about 117 kg.

(3) Constructing green high-value cropping systems. Source control is the core of agricultural non-point source pollution management. Based on the previous analysis of non-point source pollution sources, it has been determined that agricultural nitrogen and phosphorus pollution contribute 55% to the pollution load in the lake. As contributors to this pollution, vegetables and maize have greater pollutant flow intensity per unit area, while tobacco and rice have relatively low intensity. To effectively reduce pollution from farmland and simultaneously increase annual crop yields, a preliminary development of green high-value cropping systems incorporating rice and rapeseed as the primary components has been undertaken. Furthermore, six innovative green intelligent fertilizer products, specifically designed for various crops such as rice and oilseed rape, have been successfully developed (Fig. 2). Additionally, a revolutionary green high-value technology model, which revolves around the utilization of these intelligent fertilizers, has been introduced. This model has effectively achieved multiple objectives, including minimizing fertilizer consumption and emissions, enhancing crop yields and ultimately boosting farmer income for a diverse range of crops.

3 OUTLOOK FOR NON-POINT SOURCE POLLUTION CONTROL AND AGRICULTURAL GREEN DEVELOPMENT

Based on the experience gained from our work in the Erhai

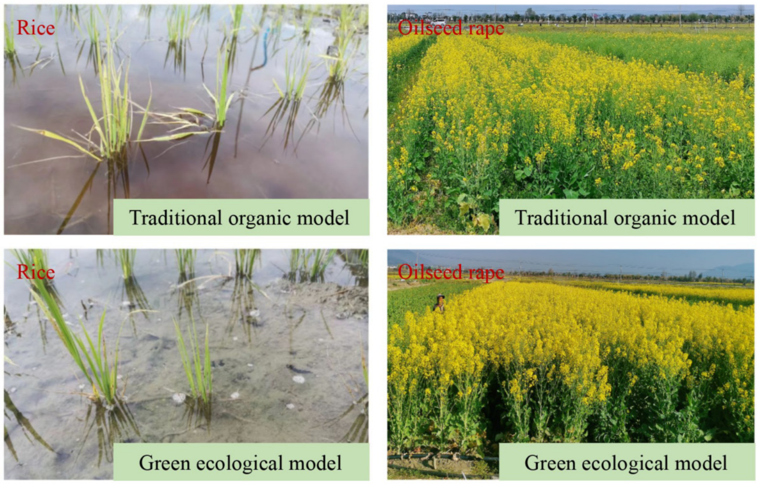

Fig. 2 Comparison of water pollution and crop growth in traditional organic fertilizer application mode and green intelligent fertilizer application mode.

Lake basin, it is now possible to effectively balance the prevention and control of agricultural non-point source pollution with the high-quality development of agriculture. To achieve the synergy between them, the following three aspects should be prioritized.

(1) **Enhancing technological innovation to significantly improve resource utilization efficiency and continuously reduce agricultural non-point source pollution.** Technological innovation is essential for effectively preventing and controlling agricultural non-point source pollution. The key areas of focus include source reduction, the development and precise use of sustainable inputs, and the implementation of emissions reduction technologies[8]. For this, it is crucial to foster innovation in source reduction technologies for inputs like fertilizers, pesticides and plastic films. The implementation of an environmental capacity indicator system and the adoption of quota control for resources required in national and regional agricultural production are highly recommended[9]. By identifying key breakthroughs based on environmental thresholds, independent innovation of essential technologies can be accomplished to systematically achieve source reduction and overall control objectives[10]. However, it is also imperative to drive innovation in green input products for agriculture and enhance the development of precise use technologies[11]. Given the current decline in the usage of chemical fertilizers and pesticides nationwide, it is crucial to intensify research and development efforts toward the creation of novel sustainable fertilizers and pesticide products that exhibit qualities such as low emissions, minimal residue and intelligent features. The promotion of mechanized, intelligent, and precise fertilization and pesticide application technologies should be prioritized.

(2) **Building comprehensive solutions throughout the entire agricultural production chain to enhance the capacity for emission reduction and efficiency improvement**. Managing agricultural non-point source pollution requires a comprehensive approach that considers the entire agricultural production chain, from resource input to consumption[12]. Each step in this chain, including farming practices and processing, has the potential to contribute to environmental emissions. If not managed properly, these emissions can have a significant impact on the environment. To address this issue, it is crucial to identify the key areas and interfaces where major pollutants are released into the environment. By implementing targeted technological innovations, it is possible to reduce these emissions and improve the efficiency of resource utilization. This involves using environmental-friendly inputs, adopting sustainable farming practices, integrating crop-livestock systems, promoting green consumption and recycling organic waste.

(3) **Establishing a regional integrated green development model that integrates government, industry, research, and smallholders.** To create a regional green development model, it will be necessary to focus on the idea of balancing human needs with the well-being of the environment. The main goals are to use resources efficiently, protect the ecological environment, and ensure food security. This involves considering various factors such as natural resources, environmental capacity, agricultural goals, and social needs[13].

The scale, structure and technology of agricultural production should be designed systematically, taking into account the adjustment of supply-side structure and spatial layout. It will also be necessary to identify key obstacles to promoting and implementing green emission reduction and pollution control technologies, and address them through government guidance, market regulation and social actions. Collaboration among different departments and stakeholders at the local level is essential in developing a regional green development model that integrates government, industry, academia, research, and application[8]. This will help in effective control and monitoring of agricultural non-point source pollution, and the transition toward a greener agricultural sector.

Overall, the control of agricultural non-point source pollution is a long and challenging process, and breakthroughs in treatment technologies are crucial for addressing this issue. However, to fundamentally solve the problem of agricultural non-point source pollution, it requires the cooperation of all stakeholders involved, as well as strong support from the government, social forces and active participation from the public. This collective effort is necessary to ensure the successful control of agricultural non-point source pollution, and to provide guarantees for the sustainable development of agriculture, improvement of rural ecological environment and the construction of an ecological civilization and a well-off society in China.

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