Managing agricultural nutrients to provide a safe and secure food supply while protecting the environment remains one of the great challenges for the 21st century. The fourth International Nutrient Management Symposium (INMS), held in 2011 at the University of Delaware, addressed these issues via presentations, panel sessions, and field tours focused on latest technologies and policies available to increase nutrient use efficiency. Participants from the United States, Europe, Canada, and China discussed global trends and challenges, balancing food security and the environment in countries with struggling and emerging economics, nutrient management and transport at the catchment scale, new technologies for managing fertilizer and manure nutrients, and adaptive nutrient management practices for farm to watershed scales. A particular area of interest at the fourth INMS was nutrient management progress and challenges in China over the past 40 years. China's food security challenges and rapidly growing economy have led to major advances in agricultural production systems but also created severe nutrient pollution problems. This special collection of papers from the fourth INMS gives an overview of the remarkable progress China has made in nutrient management and highlights major challenges and changes in agri-environmental policies and practices needed today. Lessons learned in China are of value to both developing and developed countries facing the common task of providing adequate food for an expanding world population, while protecting air and water quality and restoring damaged ecosystems.

**GLOBAL FOOD SECURITY** and environmental sustainability remain among the greatest challenges for the 21st century, and both are significantly affected by the way we manage nutrients for agriculture, especially nitrogen (N) and phosphorus (P). Both nutrients are essential to the growth of plants and animals and ultimately to human nutrition and health (Galloway et al., 2008). It has been estimated that survival of nearly half of the world's population depends on the use of synthetic N fertilizers (Erisman et al., 2008), whereas lack of access to fertilizer N in most African countries is a major cause of low crop yields and food shortages (Sayer and Cassman, 2013).

Environmental impacts of N and P are also well known and of increasing concern for nearly every country. A recent international analysis of the global “challenges to produce more food and energy with less pollution” (Sutton et al., 2013) identified several environmental problems related to nutrient management, all posing long-term societal challenges. At the most fundamental level, the natural biogeochemical cycles of N and P have been altered by consistent, long-term additions of these nutrients. This has led to increased emissions of N to the atmosphere, of concern for global warming, and enrichment of N and P in soils and surface and groundwaters. In some cases, overuse of N fertilizers has led to soil acidification and lowered crop productivity (Guo et al., 2010). Some of the major driving forces for these global nutrient challenges cited by Sutton et al. (2013) included (i) ninefold increases in the use of synthetic N fertilizers since the 1960s; (ii) inefficient use of fertilizer P and/or animal manures leading to soil P accumulations and increasing risks of nonpoint P pollution of surface waters via runoff, erosion, and subsurface drainage; (iii) worldwide increases in livestock production and a growing disconnect between concentrated sites of animal production and cropland that could recycle manure nutrients; and (iv) low nutrient use efficiency in many cropping systems. Many are concerned that these trends will continue for the foreseeable future, further exacerbating our environmental problems.
The special collection of articles featured in this issue of the *Journal of Environmental Quality* (JEQ) originated as keynote papers from the fourth International Nutrient Management Symposium (fourth INMS), “Global Issues in Nutrient Management Science, Technology and Policy,” which was held in 2011 at the University of Delaware. The fourth INMS was organized by China Agricultural University, the University of Delaware, Wageningen University and Research Center, and the University of Pennsylvania to foster global discussions on nutrient management related research and policy issues pertaining to the challenge of feeding the world’s growing population while protecting our environmental resources. (All presentations made at the fourth INMS, along with the proceedings and abstracts, are available online, at http://ag.udel.edu/4hNMSymposium/index.html. For information on the first, second, and third INMS meetings, held in Wageningen, Netherlands (2007), Shijiazhuang, China (2008), and Beijing, China (2010), contact Dr. Fusuo Zhang, China Agricultural University [zhangfs@cau.edu.cn].)

The five selected papers specifically address challenges for managing nutrients for food security and the environment in 21st-century China. We focus on China because during the past four decades, it has transitioned from an underdeveloped nation into the world’s second-largest economy with a growth rate second to none. Meanwhile, hefty tolls have been placed on China’s natural resources and the environment, with some of the most serious pollution problems directly linked to injudicious and inefficient use of nutrients for crop and animal production. Therefore, we believe the food production and environmental lessons learned in China during this 40-year transition period are of value to other nations with emerging economies struggling to address food security and environmental problems. Furthermore, the fast expanding middle class in an urbanizing China now places ever greater demands for diets richer in animal products and thus on lands used for primary food production. Given its economic power and large population base (>1.3 billion), how China will meet food security and sustainability challenges in the coming decades is not only a domestic matter but one of concern to the global community.

China is an interesting case, as it is the most populous country in the world and has limited land and water resources. Agricultural production in China is highly intensive, while N and P use efficiencies are low and the environmental effects of agricultural production and N and P losses are large (Vitousek et al., 2009; Zhang et al., 2005). The country’s agriculture uses far more fertilizer per unit of crop production than comparable systems in Europe or North America (Sayer and Cassman, 2013). For example, in 2010 Chinese agriculture used 28.1 Tg N as synthetic fertilizer, exceeding that in North America (11.1 Tg N) and the European Union (10.9 Tg N) combined (Zhang et al., 2013). Likewise, there is a high degree of inefficiency in P use. According to a national-scale analysis (Wang et al., 2011), only 18% of the P entering the food chain was captured in food for human consumption with the greatest inefficiency associated with large accumulations of soil P (52% of P inputs). In addition to nutrient efficiency issues with its main cereal crops, China’s vegetable production sector has experienced a rapid growth in recent years, resulting in excessive use of animal manures and chemical fertilizers in vegetable fields and a range of production and environmental challenges. Moreover, animal production has increased greatly in China in recent years, especially establishment of large-scale concentrated animal feeding operations (CAFOs) instead of the country’s traditional mixed small-holder farming systems. The rapid increases in animal numbers, the changing nature of production systems, and the lack of appropriate manure management or recycling facilities have created many environmental risks, including N and P pollution of air, soils, and waters throughout China (Miao et al., 2011; Wang et al., 2010).

In an effort to address these food security and environmental challenges, China is implementing a wide-ranging package of integrated nutrient management practices to increase N and P use efficiency (Ma et al., 2013b). The papers in this special issue, summarized below, give an overview of some major nutrient management issues in China and highlight recent and long-term progress in managing nutrients for crop and animal production. They also offer possible solutions to ensure food security while preventing, or even reversing, environmental problems associated with national-scale nutrient pollution issues.

Ma et al. (2013b) open this JEQ special collection with an analysis of developments and challenges in nutrient management in China. The authors provide a brief analysis of the status and needed changes in the organizational structure and national support for China’s agricultural “advisory system.” They address recent developments and progress in nutrient management practices for the crop and animal production sectors and identify major nutrient management challenges ahead, in the context of the whole food chain—“crop production–animal production–food processing–food consumption by households.” A need for more coherent national policies and institutional structures to support and better link research and extension–education efforts is emphasized. Some key steps forward include (i) the need for a holistic approach to nutrient management for China’s food chain and a shift in objectives from food security only to food security, resource use efficiency, and environmental sustainability, (ii) improved animal waste management, with policies, practices, and a national infrastructure to firmly link nutrient use by China’s animal and crop production systems, and (iii) new and innovative methods for technology transfer to more rapidly integrate advances in agri-environmental science into practice, via education, training, demonstration, and extension services.

Hou et al. (2013) report original research on use of the NUFER (NUtrient flows in Food chains, Environment, and Resources) model (Ma et al., 2010) to quantify and better understand the socioeconomic factors affecting nutrient flows and management in China during the past 30 years, as the country experienced fast economic expansion and became more open to the world. Key trends observed included fivefold increases in food nutrient consumption in urban settings, accompanied by declines in rural areas. In China’s large and growing cities, population growth and changing urban diets—towards a greater emphasis on consumption of animal products—were major drivers for changes in nutrient flow. For agriculture, nutrient inputs and losses in crop and animal production systems steadily increased during this period, although variations were clearly noted between decades. Demand for more food initially (1980s) drove increases in N and P inputs and losses in crop production, but this trend has been at least partially offset by improved nutrient management practices in the 2000s, as evidenced by
critical values of 46 to 58 mg P kg⁻¹.

China’s expanding vegetable industry, along with excessive use of animal manures, has led to serious production (salinity, acidification) and environmental challenges, primarily accelerated pollution of nearby streams and lakes. By 2009, which is more than 50% of the global vegetable production, unfortunately, gross over-application with chemical fertilizers was not matched by financial support for nutrient management advisory services, leading to fertilizer overuse and nutrient pollution problems throughout the country. Li et al. (2013) point to the need today for innovative national and regional policies and programs that provide the fertilizers needed for food security in a sustainable manner, one that protects air and water quality.

Yan et al. (2013) provide a detailed analysis, based on original research and a comprehensive national survey, of the impacts of overfertilization by China’s intensive vegetable production systems on soil P enrichment. The rapid expansion of vegetable production in China, much of which has occurred as greenhouse production in peri-urban regions, has been impressive. Total production increased ninefold since 1980, exceeding 525 million Mg by 2009, which is more than 50% of the global vegetable production. Unfortunately, gross over-application with chemical fertilizers, along with excessive use of animal manures, has led to serious production (salinity, acidification) and environmental challenges, primarily accelerated pollution of nearby streams and lakes. Summaries of more than 100 publications and ongoing research from 2003 to 2009 showed that the over-application of P occurred in both greenhouse (571 kg P ha⁻¹) and open field (117 kg P ha⁻¹) vegetable production systems, compared with P removal in harvested crops (44 and 25 kg P ha⁻¹). This inevitably led to soil enrichment and leaching of labile P, as evidenced in survey results showing mean Olsen-P values (0–20 cm) of 179 (greenhouses) and 100 mg P kg⁻¹ (open fields), compared with critical values of 46 to 58 mg P kg⁻¹, with P leaching to the 40- to 60-cm soil layer (Bai et al., 2013a). New policies, management practices, and educational systems for vegetable farmers are sorely needed to ensure adoption of science-based nutrient management practices and to improve the sustainability of China’s expanding vegetable industry.

Finally, Bai et al. (2013b) critically analyze the nature of and trends in milk production and consumption in China in recent decades. The goal was to use simulation modeling and database development to examine N and P use efficiencies in China’s four main dairy farming systems (traditional, grassland-based, collective feedlot, and industrial feedlot systems) and three related beef production subsystems. Results indicate that average N and P use efficiencies varied between the dairy herd (15 and 16%) and whole system levels (24 and 25%) and differed significantly between the four dairy systems (11, 11, 18, and 20%) for traditional, grassland-based, collective feedlot, and industrial feedlots, respectively. Major pathways for N losses were found to be NH₃ volatilization (33%), discharge to surface waters and landfills (27%), denitrification (24%), NO₃⁻ leaching and runoff (16%), and N₂O emission (1%). Additionally, traditional systems used less cropland and fertilizer to produce 1 kg of milk than the feedlot systems, because the former uses low-quality crop residues and household waste as feed, which were assumed to have no land and fertilizer costs. In contrast, industrial feedlots, dependent on high-quality feed from fertilized cropland, use less feed to produce 1 kg milk but have poor recycling of manure nutrients to cropland, leading to many environmental problems. Continuing to increase milk production, while preventing N and P pollution of air and water, will require an integrated strategy for China, one that differs between the various dairy production systems and that fully links animal and crop production to optimize the use of N and P.

All contributors to this special collection believe it is an important summary of China’s nutrient management progress and challenges as the country has transitioned from a closed to open economy in the past 40 yr. Together, the papers show that if China is to achieve the marked increases needed in N and P use efficiency while meeting food security needs—and to address the unique challenges associated with a growing urban population and diets richer in animal products—further research, new national policies, and greater educational efforts are essential. The papers also make it clear that future research on nutrient management for China must follow a systems approach for all agricultural sectors, one that emphasizes international collaborations and shared learning:

1. For crop production, the integrated crop-soil system management approach advocated by Ma et al. (2013a) should be the foundation for applying knowledge from fundamental research in crop and soil sciences to the development of soil-specific strategies for China’s diverse cropping systems. One specific need is for more innovative research farms throughout the country that can conduct, monitor, and demonstrate new advances in crop production to farmers.

2. For animal agriculture, research must focus on demonstrating and enhancing the value of manure as a soil amendment that can improve soil quality and thus long-term food security, to foster greater recycling of animal wastes from CAFOs to China’s croplands.

3. A food-chain approach, one that fully links agricultural production sectors with China’s increasingly urbanized consumers, must be used. Meeting the changing nature
of food consumption in China will require sustainable intensification of production that can provide the types of food demanded by consumers with minimal environmental impacts.

4. An effective national nutrient monitoring system encompassing all environmental sectors, as is common in many developed countries, must be implemented throughout China. This national monitoring network can both track progress due to implementation of new nutrient management practices and aid in modeling and forecasting future problems.

Clearly, all of these efforts must be well coordinated and build on recent advances in fundamental and applied research on nutrient management and lead to new tools and technologies that increase nutrient use efficiency in China for all systems and scales. At the same time, consistent feedback is needed from the national policy arena and China’s agricultural industries, to forge new avenues of research that make these scientific advances even more useful. The nutrient management story of China should not be considered a blueprint toward success in every setting. However, we believe the lessons learned in China will be useful to scientists, policymakers, and practitioners in many other rapidly developing countries as they design and implement policies and practices to meet their food security and environmental goals.

Acknowledgments

We greatly appreciate the support of all speakers and other participants for their efforts to make the 4th International Nutrient Management Symposium a success, one that led to the papers published in this JEQ special collection. Particular thanks go to the universities and institutes of authors of papers in the special collection: China Agricultural University, Agricultural University of Hebei, University of Delaware, University of Pennsylvania, and Wageningen Agricultural University and Research Centre. Finally, we thank the University of Delaware’s College of Agriculture and Natural Resources, Institute of Global Studies, and Environment Institute for financial support of the 4th INMS and extend special appreciation to Maria Pautler and Rachael Dubinsky for their assistance in organizing the symposium and field tours.

References


