Toward Sustainable Use of Nitrogen Fertilizers in China

Fredrich Kahrl, Li Yunju, David Roland-Holst, Xu Jianchu, and David Zilberman

Nitrogen fertilizer use in China is an environmental problem of global proportions, but unique aspects of China's farm sector and the fertilizer industries will make this problem difficult to tackle.

China is the world's largest consumer of inorganic nitrogen fertilizers, accounting for about one-third of total global consumption. The use of nitrogen fertilizers has played an important role in maintaining food security in China by allowing large increases in both grain and non-grain yields. Despite claims that it would starve the world, China has continued to be relatively self-sufficient in food production over the last three decades.

Since the 1990s there has been growing recognition that high levels of nitrogen fertilizer use in China are contributing to local, regional, and global environmental problems, including: deteriorating water quality, soil acidification, greenhouse gas (GHG) emissions, and a substantial perturbation of the global nitrogen cycle.

China's first national pollution survey, completed in early 2010, identified agriculture as a major polluter, increasing domestic pressure on policymakers to limit the environmental consequences of fertilizer use. As policymakers weigh options for reducing GHG emissions growth in China, improving the efficiency of nitrogen fertilizer use could be a cost-effective mitigation strategy.

Reconciling the food security and environmental dimensions of nitrogen fertilizer use will pose unique challenges for China because of the distinctive nature of China's farm sector and fertilizer industry. Although the U.S. and Chinese agricultural sectors are quite different, there is an important role for U.S. research institutes and extension services in assisting China to develop the technological and institutional innovations to address its fertilizer challenges.

Nitrogen Fertilizers and the Environment

The vast majority of the Earth's nitrogen resides in the atmosphere as an inert gas, an essential ingredient for life but for most of the planet's history only available to plants and animals on a limited scale through nitrogen-fixing bacteria and algae. Since the early 20th Century, the use of inorganic fertilizers and fossil fuel combustion have greatly increased the amount of nitrogen transferred from the atmosphere to terrestrial and aquatic ecosystems, with the amount of nitrogen fixed by humans now exceeding natural fixation by almost a factor of two.

Inorganic nitrogen fertilizer use in China is an important part of the anthropogenic transformation of the global nitrogen cycle, contributing to an estimated 15% of anthropogenic nitrogen creation in 2005. To put the scale of fertilizer-derived nitrogen flows in China in perspective, in 2008 the amount of fertilizer-nitrogen lost to the atmosphere through volatilization in China was larger than the total amount of nitrogen fertilizer consumed in all of Africa.

Massive inputs of nitrogen fertilizer in China are having local, regional, and global impacts. Nitrogen run-off and leaching into lakes and rivers has had severe impacts on water quality. Many of China's major lakes are badly degraded as a result of nitrogen and phosphorous pollution, with five of China's largest freshwater lakes either eutrophic or hypotrophic. Red tides, resulting from the run-off of fertilizer nutrients, are increasingly commonplace in China's coastal waters. Several studies have shown high levels of fertilizer-derived nitrate in groundwater in China, with measured values as high as 30 times U.S. EPA-allowed levels in a large study in northern China.

Ammonia-based (e.g., ammonium nitrate) or ammonia-forming (e.g., urea) fertilizers can affect soil acidity by increasing hydrogen ion concentrations in the soil. Analysis of data from China's national soil surveys indicates that the average pH of soils in China declined sharply from the 1980s to the 2000s, with nitrogen fertilizer use as the main culprit. Soil acidification will have longer-term impacts on crop yields if not corrected.

Nitrogen fertilizer production and use in China is also a major source of GHG emissions. For reasons we describe below, China's nitrogen fertilizer industry is significantly more energy- and carbon-intensive than the global average. In a recent paper, we estimated that the application of nitrogen fertilizers in China led to mid-range GHG emissions (embodied CO_2 and N_2O) of 400 million tons CO_2 equivalent in 2005, equivalent to 8% of China's energy-related CO_2 emissions. To a greater extent than in other countries, improving the efficiency of nitrogen fertilizer production and use in China could be an important GHG mitigation strategy.

China's Nitrogen Fertilizer Industry

China's nitrogen fertilizer industry is unique in three respects. First, small- and medium-sized manufacturing plants have historically accounted for a significant share of output, whereas in most of the world nitrogen fertilizer is manufactured in large, centralized facilities. Second, ammonium bicarbonate, a low analysis (17% N) and relatively unstable nitrogen fertilizer, has

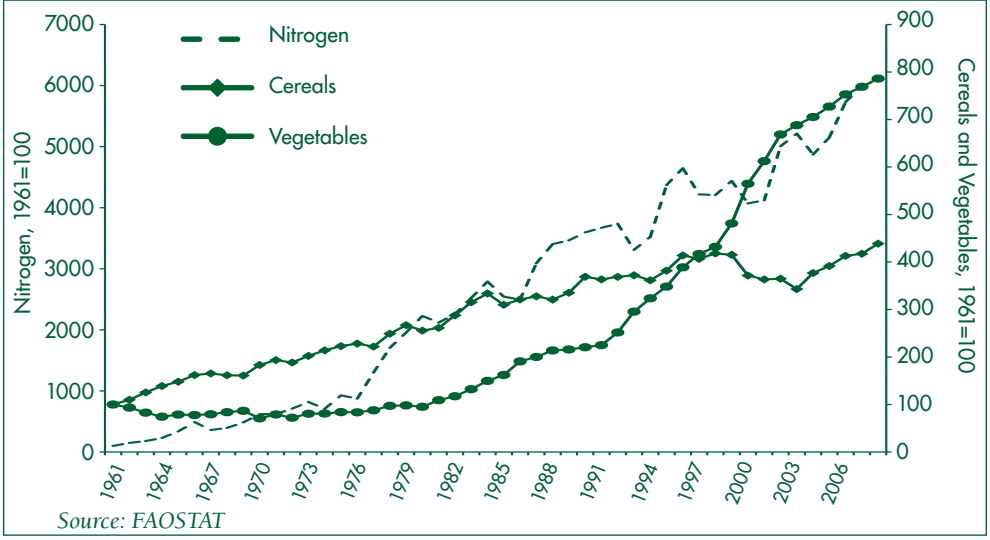
historically been an important fertilizer in China but was never widely used elsewhere. Third, in China coal has been the primary feedstock for producing ammonia, the source of nitrogen in chemical fertilizers, while the rest of the world has relied primarily on natural gas since the early 1960s.

The evolution of China's nitrogen fertilizer industry was driven in large part by resource and political constraints. Decentralized, small-scale production allowed China to overcome constraints on investment capital, foreign exchange, lead time, and distribution requirements characteristic of larger plants—all reinforced by the country's diplomatic isolation during the 1960s. The invention by Chinese chemists in the early 1960s of a relatively simple, low-cost process to produce ammonium bicarbonate allowed rapid deployment of small-scale, decentralized production facilities. Finally, coal-intensive ammonia production accords with China's resource endowments; only 1% of the world's proven natural gas reserves, but 14% of the world's coal reserves. This unique trajectory has allowed China to create the world's largest nitrogen fertilizer industry, but has also meant that this industry is significantly less energy and carbon efficient than the world average.

Fertilizer and Farming in China

Unlike the land-abundant and labor-scarce U.S., China's agricultural sector is highly labor- and input-intensive, with around 200 million small, poor farmers cultivating plots of land that are often smaller than an acre. The terrain and quality of farmland in China vary dramatically, from subsistence grain production on steep mountain slopes to triple cropping on some of the world's most productive farmland. Because of the scarce availability of high-quality farmland, food security and the need to achieve ever-higher yields have long been a preoccupation in Chinese agriculture.

Figure 1. Growth in Nitrogen Fertilizer Consumption and Cereal and Vegetable Output, 1961–2008 (1961=100)



Source: FAOSTAT

China's agricultural sector has undergone a radical transformation over the last three decades. Beginning with collectivization in the 1950s, agriculture was governed by a procurement system that kept crop prices and returns to agriculture artificially low to maintain a supply of cheap food for cities. In the early 1980s, the government relaxed this procurement system to allow farmers to sell above-quota output at higher prices. By 1992, the procurement system had been largely dismantled and since then the government's role in agriculture has been increasingly indirect.

Agricultural input markets were reformed using a similar strategy. Under central planning, fertilizer was allocated under a rationing system that supported priority crops in high-yield regions. The price system implicitly subsidized fertilizer producers, but did not provide fertilizer subsidies to farmers. As a result, under this government allocation system, inorganic fertilizer use remained relatively low. With the scaling back of central planning, government fertilizer allocation was first supplemented with a dual track system and then more completely liberalized.

Fertilizer subsidies are still directed primarily at producers, largely through preferential electricity and natural gas prices that range from 30–50% below those paid by other industrial producers. As a result of producer subsidies and controls on retail prices, nitrogen fertilizer prices in China are lower than world prices, but the influence of subsidies on retail prices is difficult to gauge because China's nitrogen fertilizer industry is so different from other countries. One example is farm prices for urea in China which were around US$0.12–0.13 per pound in early 2008, whereas farm prices for urea in the U.S. spiked to $0.28 per pound in the same period.

In the past two years, China's central government has begun efforts to curtail fertilizer producer subsidies, restructure the fertilizer industry, and liberalize retail fertilizer prices. As part of these efforts, the government will aim to shift fertilizer subsidies from producers to farmers through a "general agricultural input subsidy," which was created in 2006 and is intended to offset increases in input prices for grain farmers.

Nitrogen Fertilizer Use Efficiency in China

Since the late 1970s, growth in nitrogen fertilizer use has outpaced grain production in China (Figure 1). While this aggregate relationship might suggest declining use efficiency, in fact most of the increase in nitrogen fertilizer use can be explained by sustained

increases in yields and significant growth in non-grain acreage. Early market reforms gave Chinese farmers more discretion in planting decisions, and they shifted rapidly to crops with higher value and income elasticities. Vegetable production, for instance, has grown nearly eight-fold since the early 1980s (Figure 1).

The expansion of fruit and vegetable acreage in China has important implications for nitrogen fertilizer use because these crops tend to be more fertilizer intensive than grain crops. Continued increases in fruit and vegetable acreage will increase total nitrogen fertilizer use even if application rates for individual crops remain constant.

The relatively small contribution of declines in nitrogen use efficiency to growth in nitrogen fertilizer consumption does not suggest that current levels of nitrogen application in China are agronomically efficient. Nitrogen use efficiency in China is generally thought to be much lower than in the U.S., and a growing number of field trials suggest that application rates for grain crops in China could be reduced by 20–30% while either maintaining or increasing yields.

Even so, current nitrogen application levels in China may be economically efficient, given the conditions and constraints that farmers face. If this is true, incentivizing farmers toward more socially optimal levels of nitrogen fertilizer use will require identifying and overcoming barriers to efficiency improvements.

Food Security and the Environment

Improving nitrogen fertilizer use efficiency is crucial to balancing food production goals and environmental sustainability in China. Improvements of this kind will require policy initiative along two parallel tracks. First, subsidies for fertilizer producers need to be scaled back, allowing retail fertilizer prices to better reflect resource and environmental costs. Reducing energy price subsidies and relaxing retail price constraints can also facilitate a restructuring of China's nitrogen fertilizer industry that would likely reduce its environmental footprint.

Second, extension and other agricultural services will need to be improved to ensure that farmers, and the agricultural system more broadly, have the ability to adapt to higher input prices. The required price adjustment is considerable. If, for example, urea farm prices in China were allowed to rise to U.S. levels (from US$0.14 per pound to $0.20 per pound, based on 2010 prices), farmers would need to reduce urea application rates by more than 30% to maintain fertilizer expenditures at current levels.

Enhancing agricultural services to support fertilizer efficiency improvements will pose a non-trivial challenge for China. China's agricultural sector is huge, diverse, decentralized, and unorganized, with limited extension support and little regulation. Additionally, a number of studies, including work that we have done in Yunnan Province, indicate that nitrogen application rates vary significantly across households and regions. Barriers to higher use efficiency, therefore, are also likely to be household and region specific.

Tackling fertilizer and other sustainability challenges in China's agricultural sector will require a rethinking and reorienting of public service support to agriculture, as well as an exploration of funding mechanisms to support those services. China's agricultural extension system, which has historically been an arm of central government policy and has never had an explicit environmental mandate, will need to improve its capacity to identify local environmental problems and design local solutions—in particular through stronger linkages with research institutes. Funding mechanisms to support sustainability programs might include payments for environmental services or the creation of a domestic or participation in an international GHG offset program.

Suggested Citation:

Kahrl, F., L. Yunju, D. Roland-Holst, X. Jianchu, and D. Zilberman. 2010. "Toward Sustainable Use of Nitrogen Fertilizers in China." *ARE Update* 14(2):5-7. University of California Giannini Foundation of Agricultural Economics.

Fredrich Kahrl is a Ph.D. candidate in the Energy and Resources Group at UC Berkeley. Li Yunju is a Ph.D. candidate at the College of Resources and Environment at Nanjing Agricultural University. David Roland-Holst is an adjunct professor in the Department of Agricultural and Resource Economics and the Department of Economics at UC Berkeley (dwrh@berkeley.edu). Xu Jianchu is a professor at the Kunming Institute of Botany, Chinese Academy of Science, and senior scientist with the World Agroforestry Centre's China Program. David Zilberman is a professor in the Department of Agricultural and Resource Economics at UC Berkeley (zilber1@berkeley.edu).

For additional information, the authors recommend:

Galloway, J.N., Townsend, A.R., Erisman, J.W., Bekunda, M., Cai, Z., Freney, J.R., Martinelli, L.A., Seitzinger, S.P., Sutton, M.A., 2008. Transformation of the Nitrogen Cycle: Recent Trends, Questions, and Potential Solutions. *Science* 320(5878): 889-892.

Gao, C., Sun, B., Zhang, T., 2006. Sustainable Nutrient Management in Chinese Agriculture. *Pedosphere* 16(2), 253-264.

Ju, X., Xing G., Chen X., Zhang S., Zhang L., Liu X., Zhen C., Yin B., Christie P., Zhu Z., Zhang F., 2009. Reducing Environmental Risk by Improving N Management in Intensive Chinese Agricultural Systems. *Proceedings of the National Academy of Sciences* 106 (9), 3041-3046.

Kahrl, F., Li, Y., Su, Y., Tennigkeit, T., Wilkes, A., Xu, J., 2010. Greenhouse Gas Emissions from Nitrogen Fertilizer Use in China. *Environmental Science and Policy*. In Press.