

Greater food security and a better environment through improved nitrogen fertilizer management¹

The maintenance of high levels of food security for all of its people has been a central objective of the Chinese Government for many decades. It has achieved this with great success but the farming practices used to increase food production have resulted in serious environmental damage at the local, national and regional scale. These practices also had unintended negative impacts on some aspects of food security and are now causing economic losses to farmers and the nation.

Grain output has increased faster than population growth since the 1970s. Per capita grain production increased by 30% between 1978 and 2008 and basic food prices were kept relatively stable and low enough for poor people to meet most of their needs. Moreover,

Improved nitrogen management (INM) aims to maximize resource efficiency and agricultural sustainability by a combination of 5 main actions:

- Preventing the overuse of synthetic N fertilizers by ensuring that application rates allow for the N already in the soil, in manure and in irrigation water, and do not exceed the amount needed for high crop yields.
- Ensuring that N fertilizer is applied at the right (optimum) time.
- Using the most efficient technologies for the application of fertilizers.
- Minimising the non-point pollution, GHG emissions and other environmental impacts of N fertilizers using slow release fertilizers and “inhibitors” where they are cost effective, and by expanding the availability and use of organic fertilizers.
- Getting the balance right between the amount of nitrogen, phosphate and potassium given to crops.

¹ This briefing note is based on the findings of the China-UK Project “Improved Nutrient Management in Agriculture—a Key Contribution to the Low Carbon Economy”. The project is funded by the UK’s Foreign and Commonwealth Office and by China’s Ministry of Agriculture. It is led by Prof Zhang Fusuo, China Agricultural University, Beijing and Prof David Powlson, Rothamsted Research, UK. The project forms part of the China-UK Sustainable Agriculture Network – SAIN (see www.sainonline.org).



people were able to increase both their total intake of food and the nutritional quality of their diets with, for example, total protein and animal protein consumption increasing by about 50% and >100% respectively over the past 20 years².

But this food security success has resulted in serious and ever increasing environmental damage that threatens the long-term sustainability of Chinese agriculture. Much of this damage can be avoided by improvements in nitrogen (N) management and particularly by the reduction of the widespread overuse of nitrogen fertilizer³. These improvements will also raise farmer's incomes, decrease non-point water and air pollution and contribute to China's transition to a low carbon economy and to global climate change mitigation as outlined in Policy Brief 1. When taken at face value it may seem to be a contradiction to state that food security can be maintained or improved by *reducing* synthetic N fertilizer use. Hence this policy brief focuses on providing evidence that there is no contradiction and that the current trade-off between food security and environmental quality can be overcome to present China with a true win-win achievement. It does so by:

(a) outlining the role of N fertilizer in food security;

(b) presenting evidence from across China that there is widespread N overuse (mainly of synthetic N fertilizer but also of manure on some vegetable crops) which can be reduced without lowering grain yields and national food security; and

(c) substantiating the case for greater action on improving N management and nitrogen use efficiency (NUE) because such measures will also reduce non-point pollution and some of the unforeseen negative impacts of overuse on the environment and food security.

The role of nitrogen fertilizer in food security

China's food security success could not have been achieved without N fertilizer – and this will continue to be the case. Given China's limited opportunities for expanding the area under cultivation, the increase in food production during the past 30 years came largely from land use intensification based on greater irrigation, the development of improved crop varieties and a substantial increase in farmer's use of synthetic N fertilizer (Figure 1). For example, rice and wheat production increased by > 100 Mt between 1978 and 2007 and initially about 30% of this increase came from the use of synthetic nitrogen fertilizer but then fell to as little as 10% by 1999-2003.

Unfortunately since about 1990 the increase in grain production was associated with a major decline in nitrogen use efficiency (NUE) and with widespread environmental damage. During the initial expansion of synthetic N fertilizer use the application rates were approximately in balance with crop needs for N, and consequently the average NUE was satisfactory although below the global average. Since then there has been a major decline in NUE from 30-35% to 20-30% for the whole of China and below 20% in some major grain producing provinces (Figure 2), compared with a global average of 40-60%^{4 5}

² FAO Food Balance Sheets

³ Peng, S., Buresh, R.J., Huang, J., Zhong, X., Zou, Y., Yang, J., Wang, G., Liu, Y., Hu, R., Tang, Q., Cui, K., Zhang, F., Dobermann, A. Improving nitrogen fertilization in rice by site-specific N management. A review. *Agron.Sustain.Dev.* 30 (2010) 649-656. doi: [10.1051/agro/2010002](https://doi.org/10.1051/agro/2010002).

⁴ Zhang, F. S., Wang, J.Q., Zhang, W. F., Cui, Z. L., Ma, W. Q., Chen, X.P., Jiang. R.F. 2008. Nutrient use efficiencies of major cereal crops in china and measures for improvement. *Acta*

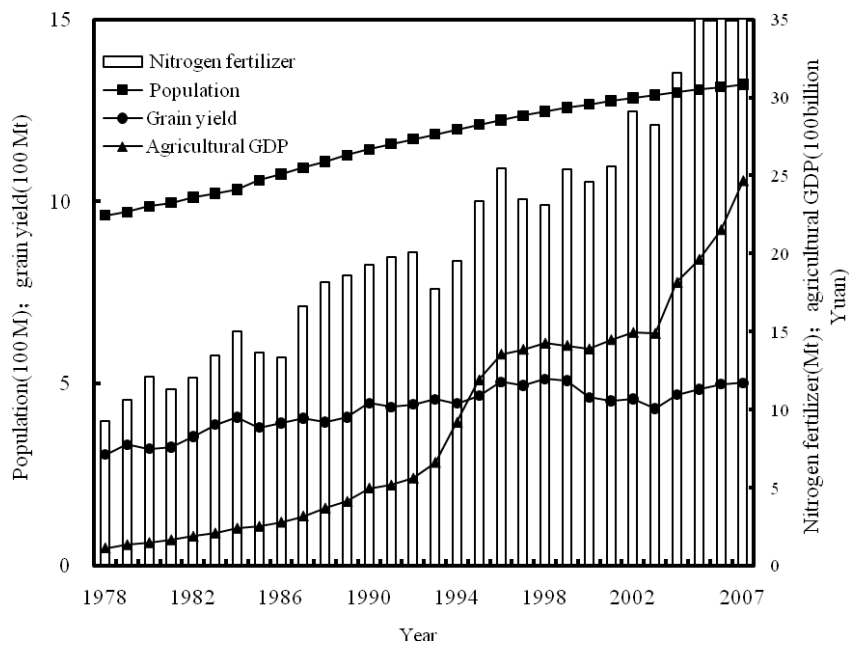


Figure 1 Increase in N use on crops since 1978 (source: NBSC⁶)

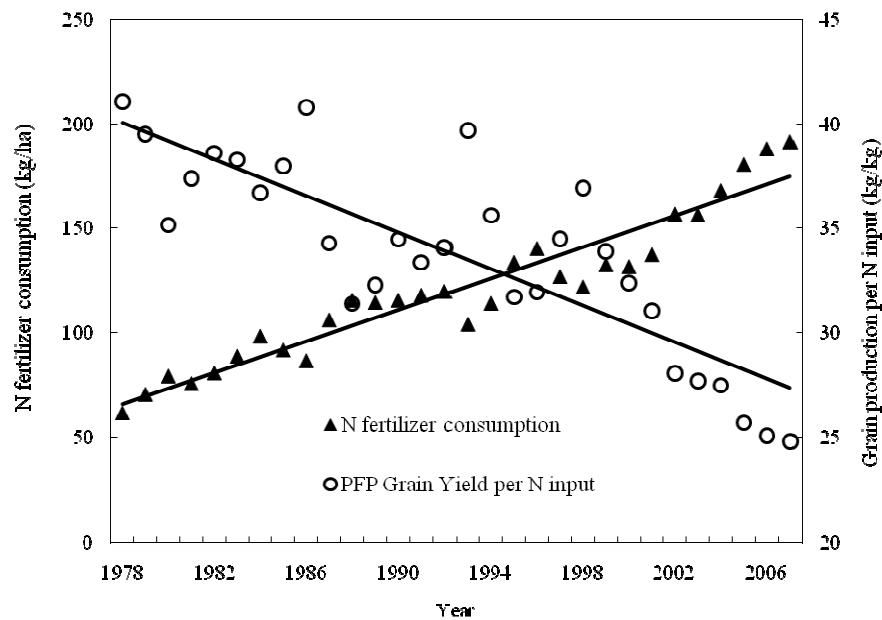


Figure 2 Decline in NUE with increased rate of N fertilization

Pedologica Sinica 45, 915-924. (In Chinese with English abstract).

⁵ Fan Mingsheng, Zhang, Fusuo & Jiang Rongfeng, Integrated nutrient management for sustainable agriculture in China, Proceedings of the International Plant Nutrition Colloquium XVI UC Davis 2009 <http://escholarship.org/uc/item/5hc5k91x>

⁶ National Bureau of Statistics of China, 1949-2007. China Agriculture Yearbook. China Agricultural Press:Beijing

The reasons for this decline are complex but one factor dominates namely the overuse of synthetic N fertilizer, which in some provinces has been an issue since the 1980s and now is a concern for almost all provinces and crops. None the less it is important not to over-generalise – even in provinces and counties where the average application rate is greater than the amount recommended by MOA and local agricultural bureau, some farmers apply too little N.

The overuse of N fertilizer

Numerous agronomic and economic studies under both experimental conditions and on farmer’s fields provide conclusive proof that (a) overuse of N fertiliser is very serious and (b) it can be overcome with considerable benefits for food security, farm incomes and the environment. The overuse of N fertilizer has been a growing problem for 10-30 years with grain crops and during the past 10-15 years with intensive vegetable and fruit production, even in provinces or counties where the average N application rate is low. Table 1 gives examples of the level of overuse which is commonly 30% but can be >50%.

Table 1 Levels of overuse in different parts of China

Province	Crop	Farmers rate kg.N/ha	Recommended rate kg.N/ha*	% overuse	Yield with reduced rate
Jiangsu ⁷	rice	300	200	50	+3 %
6 Provinces ⁸	rice	195	133	47	+6%
NCP**	wheat	325	128	150	+4%
NCP	maize	263	158	66	+5%
Shaanxi	wheat	249	125-225	~100	same
Shaanxi	maize	405	165-255	>60	>8%
Shandong	tomatoes	Upto 630	150-300	80-200	+10% n.s.

*based on soil tests and field trials

**NCP = North China Plain

The reasons for the overuse are complex and include lack of awareness by farmers and extension workers of the amount of N available in the soil from previous crops, the N content of manure, irrigation water, dust and rain. These sources can often provide at least 50%, sometimes more, of the N required to give maximum crop yield⁹. Farmers may also be unaware of the best available technologies or, not have access to them. Fortunately, there are many opportunities for stopping much of the overuse that are easy to implement, though most need to form part of an integrated plan of action in order to gain the maximum benefit. Many of the agronomic and economic studies in China that provided the evidence in Table 1 have focused on working with farmers to develop improved N management systems involving a range of changes in farmer’s practices including soil testing, the timing and method of N application, and taking account of N supplied from manure and irrigation water.

⁷ Ju et al, 2009. op cit

⁸ Guangdong, Heilongjiang, Hubei, Huan, Jiangsu & Zhejiang, Peng et al, 2010 op cit

⁹ Cui Z.L., X.P. Chen, and F.S. Zhang. 2010. Current nitrogen management status and measures to improve the intensive wheat–maize system in China. *Ambio*. 39:376–384

The unforeseen environmental and economic impacts of the overuse of nitrogen fertilizer

The environmental impacts take 4 main forms:

- upstream environmental damage (especially greenhouse gas emissions) associated with the mining of coal and other raw materials for N fertilizer production and CO₂ emissions from the energy used in fertilizer manufacture;
- loss of N from the soil by leaching and runoff leading to contamination of ground and surface waters and widespread eutrophication;
- breakdown of the N fertilizer to release ammonia gas that increases acid rain which in turn adds to acidification of soil and water, and to nitrous oxide emissions;
- emissions of nitrous oxide from the processes of nitrification and denitrification in soil. Nitrous oxide is particularly important because each molecule is 298 times more powerful as a greenhouse gas than CO₂, thus even small emissions can make a large contribution to climate change.

All of these impacts are intensified when farmers use more N fertilizer than that required for achieving the large crop yields required for national food security (Table 2).

Table 2 Nitrogen losses to the environment with farmer's practice & improved management (kg.N/ha/year)

	Jiangsu/Hubei		Beijing/Hebei/Shandong	
	Farmer's practice	Improved management	Farmer's practice	Improved management
N application	550	353	588	286
Leaching	12	8	56	23
Ammonia	38	24	135	46

Source: Ju Xiao-Tang et al, op cit Supporting information.

The main economic impacts are twofold. First, the waste of economic resources on subsidies for N fertilizer production. Secondly, the loss of farm income when farmers use so much N fertilizer that they lower crop yields and spend more money on fertilizer than they gain by higher yields. As Table 3 shows, these losses are large even in Shaanxi where average N use is not high.

Table 3 Overuse of N and losses in farm income in Shaanxi

Crop	Recommended N rate, non-irrigated, (kg/ha) *	Farmer's practice (kg/ha)	% households applying too much	Average loss in income from overuse (¥/ha/yr)
Wheat	150-225	287	25	266
Maize	165-255	405	77	331

Source: unpublished project results

*by local extension bureau

Reduced food security from N overuse

This reduction is primarily a secondary consequence of the environmental and economic impacts described above. The economic impact leads to reduced food purchasing power in two ways. First, because of lost income as illustrated in Table 3. Second, because of

higher food prices, for example, when eutrophication and algal blooms lowers fish production and increases fish prices, as well as damaging the livelihoods of fish farmers. The environmental impacts reduce food security in a number of ways, for example, by:

- (a) damage to crop roots from N overuse which lowers plant growth and yields(Fig.3);
- (b) soil acidification that has doubled in the past 30 years and to which N fertilizer has contributed about 60¹⁰
- (c) increased attacks by pests and diseases and greater vulnerability to lodging.

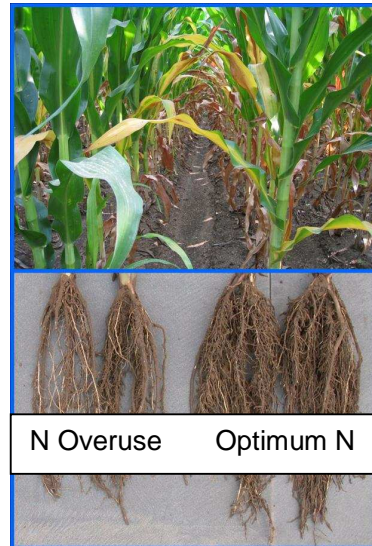


Figure 3 N overuse causes root damage

Limiting N overuse and long-term food security

Most of the studies on improved management practices to limit N overuse took place over 3-5 years so its necessary to determine if it is possible to maintain the gains in NUE and crop yields in the longer-term in spite of the lower inputs of synthetic N fertilizer. The short answer is yes. Long term fertilizer experiments (co-ordinated by CAAS) for cropping systems that occupy some two-thirds of China's cropland show that N rates can be reduced appreciably for at least 15 years without any decline in yields, providing further evidence that GOC and farmer actions to limit overuse of synthetic N fertilizers need not endanger national food security¹¹

The way forward

There is now overwhelming evidence that too much N fertilizer is currently used in the majority of cropping situations in China. Quantities applied could be reduced with no impact on crop yields or food security. For grain crops the extent of over-use often averages about 30%, though specific data is available for different regions showing both larger and smaller values. With high value horticultural crops the extent of over-application is frequently far higher. As outlined above, and in many publications based on work by Chinese researchers, there are numerous ways to reduce N overuse and raise fertilizer use efficiency – these involve a combination of technological and institutional initiatives and policy changes to improve the delivery of information to farmers, promote the uptake of science based advances in fertilizer use and accelerate agricultural modernisation. They include:

- strengthening the soil testing and fertilization (*Cetu Peifang Shifei*) programme
- promoting better methods of applying fertilizers e.g. through pilot programmes on appropriate mechanisation

¹⁰ Guo, J.H., Liu, X.J., Zhang, Y., Shen, J.L., Han, W.X., Zhang, W.F., Christie, P., Goulding, K., Vitousek, P. & Zhang, F.S. (2010) Significant Acidification in Major Chinese Croplands *Science* 327, 1008-1010 (2010). <http://dx.doi.org/10.1126/science.1182570>

¹¹ Zhao, B., Li, X., Shi, X., Huang, S., Wang, B., Zhu, P., Yang, X., Chen, Y., Poulton, P., Powlson, D., Todd, A. & Payne, R. Long-Term Fertilizer Experiment Network in China: Crop Yields and Soil Nutrient Trends *Agronomy* Vol. 102 No. 1, p. 216-230, (2010) . doi:10.2134/agronj2009.018

- speeding up the development and uptake of specially made N fertilizers that reduce GHG emissions and non-point pollution e.g. a network of demonstration sites
- providing farmers and extension workers with better access to fertilizer use information through mobile phone networks and geographic information systems
- supporting the role of cooperatives and farmers associations in information transfer and technology development.

All of these initiatives will help to:

- increase or maintain crop yields with lower N fertilizer inputs
- improve food security and agricultural sustainability
- lower national GHG emissions, non-point pollution, lake and river eutrophication and the frequency and size of red tides
- raise energy use efficiency by lowering the fossil fuel needs of the fertilizer industry
- increase the incomes of many poor farmers by up to 10%, increase the economic efficiency of crop production and help to lower food price inflation.

As further outputs of this China-UK collaborative project it is planned to produce other Policy Briefs on the technologies and management practices available for increasing the efficiency of use of nitrogen fertilizer and the issues of policy and practice required to encourage their uptake.