UK-China Sustainable Agriculture Innovation Network

low carbon agriculture

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Policies and technologies to overcome excessive and inefficient use of nitrogen fertilizer: delivering multiple benefits[1]

Executive Summary

China's position as one of the most food secure countries in the world could not have been achieved without the tripling of synthetic nitrogen (N) fertilizer use since 1980. Nitrogen fertilizer will continue to make a key contribution to future food security. But there is unequivocal evidence that average rates of N use as synthetic fertilizer and manure now exceed what is required for high crop yields and 95% food grain self-sufficiency. One estimate is that approximately one-third of the cropland suffers from N overuse, about another third receives the correct amount (though often applied in wasteful ways leading to inefficient use) and the rest suffers from either insufficient or badly managed N. Other estimates are that the over-use situation is worse. All agree that over-use and inefficient use of N from both fertilizer and manure in the rapidly expanding horticulture sector is especially severe.

The excessive and inefficient use of N has a range of negative impacts. A major issue is that it contributes to unnecessarily large greenhouse gas (GHG) emissions from agriculture – this aspect is often overlooked. It is also a cause of water pollution including the increasing incidence of algal blooms or "red tides". It reduces national energy use efficiency by distorting N fertilizer production. Net farm incomes are lowered by unnecessary expenditure on fertilizer, and this is proportionately greater for the poorest farmers. Other environmental damage includes decreased air quality and widespread soil acidification, which can lower crop yields and threaten food security. Improving N use

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efficiency will provide multiple benefits including reducing agricultural GHG emissions by up to 30%, improving farm incomes and helping to lower food price inflation. Hence it will help meet the GHG reduction and other targets of the 12th Five Year Plan.

Consequently this Policy Brief has two main objectives. First, it considers what type of strategic framework might be most appropriate for overcoming the multiple challenges posed by the excessive and inefficient use of N fertilizers. Second, it outlines the most promising policy and technological options that could form the main components of an action plan. At the centre of the strategic framework must be policies to give farmers:

(a) the economic incentive to raise nitrogen use efficiency (NUE) and
(b) make it possible for them to adopt the most efficient technologies.

Actions on (a) must include the removal of perverse subsidies for N fertilizer production. These once played an important role in developing China's fertilizer industry but are now an unacceptable and unnecessary distortion. It is now time to re-allocate these economic resources to more positive measures such as the introduction of payments to farmers for environmental services, for example, the use of less polluting N fertilizers. Actions on (b) should include measures to overcome the labour constraints that currently prevent farmers from improving NUE, for example, the mechanisation of fertilizer and manure application.

The proposed action plan is consistent with this strategic framework. It is centred on a range of cost-effective technological and institutional innovations that are currently or will shortly be available. These will often lead to farmers using less N fertilizer, and thus save them money, whilst maintaining or even increasing production. However, the Plan acknowledges that the benefit of these innovations may not be readily apparent to individual farmers or there may be barriers to their uptake. So the whole enabling and incentive environment needs to be addressed through policy interventions. The approaches include:

- **More effective delivery of information to farmers**. Farmer Field Schools and the "farmer trains farmer" approach have proved more effective than "expert tells farmer". Policies and incentives for actions through Farmer Professional Associations is one means of promoting the approach. It essential to ensure that those involved in training are equipped with up to date information that is relevant to farmers real situations.
- Policies and incentives to **promote the development of a contractor sector for fertilizer application.** This would facilitate the use of new machinery, especially for sub-surface placement of N fertilizer that greatly decreases gaseous losses but requires specific application equipment. It would also overcome problems of labour shortage at key times in the cropping season; this is a major cause of excessive and inefficient N use through inappropriate practices for N application.
- Use of **modified forms of N fertilizer, especially inclusion of inhibitors** to slow the release of N into crop-available forms and decrease gaseous losses. This requires adjustment of subsidies to cover the (usually small) additional cost of incorporating inhibitors and as an incentive for farmers to adopt new techniques.
- **Policies to further promote production of organic fertilizers** from animal manure. But this needs to be combined with improved labelling (to inform farmers and advisors of the crop-available nutrient content – not only total content), training of advisors and farmers, and measures to reduce N losses during production of organic fertilizers.

Clear policies are required to ensure that manure management is taken fully into account at the planning stage for the rapidly growing number of large animal units.

- **Promotion of integrated water and nutrient management including "fertigation"** in situations where irrigation is practiced – especially in the greenhouse horticulture sector but in some cases for field grown crops. This can greatly increase the efficiency of N use. Subsidies for initial cost of equipment are needed and policies to ensure that training is provided by equipment or fertilizer suppliers. Increasing efficiency of use of water is a key issue in the face of decreased water availability due to climate change, as highlighted in a recent MoA report.

The challenges

Increased inputs of nitrogen (N) fertilizer have played a major part in China becoming one of the most food secure countries in world. Factors in this success include government policies to ensure a ready supply of synthetic fertilizers, pesticides and new crop varieties to farmers at affordable prices, and infrastructure for irrigation. But now the amounts of N fertilizer being applied are considerably in excess of the requirement to deliver food security, and have a range of negative social, economic and environmental impacts (Ju et al PNAS).

Earlier policy briefs from this China-UK project have examined this issue. SAIN Policy Brief No. 1 presented estimates of the greenhouse gas emissions associated with the manufacture and use of N fertilizer – and, importantly, the opportunity for decreasing emissions and the energy intensity of food production by moving to more rational use of fertilizer and by fostering a shift to low carbon agriculture. It was estimated that, over time, this measure could decrease total national GHG emissions by about 3%. SAIN Policy Brief No. 2 summarised the evidence that N fertilizer application rates can be reduced in many regions and cropping systems without reducing grain production or endangering food security. This change would also control non-point pollution, soil acidification and other environmental problems and increase incomes of farm households and boost spending power in the rural economy.

What can be done?

This Policy Brief builds on these analyses by outlining some of the promising approaches for overcoming N overuse and mismanagement and the environmental problems associated with them. Some of these approached are simple changes in fertilizer management by farmers; others require technological innovation. Most of them need changes in government policies to provide the improved incentives and supporting services that are essential for farmer uptake of new technologies and practices. All of them are consistent with (a) the objectives of the 12th Five Year Plan and NDRC proposals regarding low carbon development, and (b) with specific programmes of MOA, MOST and other ministries to increase fertilizer and energy use efficiency, reduce ammonia emissions and other agricultural problems including the MoA "Ten Technologies for Agricultural and Rural Energy Saving and Emission Reduction" and MoA "Guidelines on promoting more appropriate fertilizer technologies" published in 2012.

In some cases the proposed changes would increase farmers' costs, e.g., if additives included in fertilizers to control the rate of release and reduce losses increase fertilizer costs, or if new application machinery is purchased, or contractors are used to spread

fertiliser. In these cases it is clearly essential to reorganise subsidies to offset this increase because some of the benefit will be national rather than directly seen by the farmer – an example of paying for environmental services. In other cases the changes would save the farmer money – e.g. by decreasing the amount of N fertilizer purchased because efficiency of use is increased. But even in these cases, some form of incentive payment may be required to promote the change as there may well be other barriers to uptake such as labour shortage at critical times or inconvenience. Such barriers are often associated with the fact that many farmers have off-farm activities that are more important to household income than farming. In time, as new approaches become widely accepted, such incentives could probably be gradually removed. Delivery of information to farmers has to take account of the impact of off-farm actovities.

The Table below summarises the measures recommended as a result of this project.

Proposed changes in nitrogen fertilizer management and the necessary policy changes – immediate action

	Change in practice by farmers or agricultural support industry	Policy interventions to facilitate changes
1	**Decrease N fertilizer applications to rational rate** for specific regions and cropping systems – to increase efficiency of use, decrease losses to environment, increase farm incomes, improve food security.	• Adopt more effective methods of delivering information to farmers, including Farmer Field Schools and working with Farmer Associations. • Promote role of contractors for fertilizer application. • Policies to ensure that fertilizer suppliers provide appropriate technical information and training to farmers, advisors and contractors. • Investigate regulatory approaches to control excessive N use (from both fertilizers and manures) – for example when planning new greenhouse vegetable developments in peri-urban regions (analogous to Nitrate Vulnerable Zones in the EU).
2	**Change timing N fertilizer applications** – less at sowing, more during growth season. To increase N use efficiency.	• Promote role of contractors for fertilizer application – to overcome labour shortage at key times.
3	**Sub-surface placement of N fertilizer** using appropriate machinery – to decrease ammonia loss and increase use efficiency.	• Use existing mechanisation grants. • Promote role of contractors or co-operative purchase of machines. • Support training of machine operators. • Ensure fertilizers are available in correct forms for machines.
4	**Incorporate urease inhibitors (UI) in urea fertilizer** – to decrease ammonia loss, increase use efficiency and provide a degree of controlled release.	• Change subsidy structure for farmers to cover additional cost of (estimated as about 5% above urea – but the details of costs requires clarification).
5	**Incorporate nitrification inhibitors (NI) in certain fertilizers** – to decrease nitrous oxide emissions and nitrate leaching, and in some cases, provide a degree of slow release.	• Change subsidies for farmers as for UIs in appropriate situations.
6	**More effective recycling of nutrients from manures** and other organic sources.	• Continue policies to promote organic fertilizers. • Strengthen regulations on labelling.

		• Promote training on utilisation of different organic fertilizers and integrated use with fertilisers. • Undertake studies to decrease N losses during production of organic fertilizers. • Ensure manure management is included in planning of large animal units.
7	**Integrate advice and practices to improve both water and nutrient use efficiency**. Where practicable, practice **"fertigation**– to increase use efficiency by matching timing of supply to crop uptake.	• Policies to ensure integrated water and nutrient expertise by advisers. • Subsidies for initial cost of equipment. • Policies to ensure training and provision of information by suppliers of equipment and fertilizers.

Proposals for further consideration or use in specific situations

	Change in practice by farmers or agricultural support industry	Policy interventions to facilitate changes
8	**Use slow release and coated fertilizers in appropriate situations** – to overcome labour constraints to rational timing of applications. But potentially limited by high cost.	• Policies for subsidies in specific situations where cost is justified.
9	**Use compound fertilizers with higher nitrate content than standard** – to decrease nitrous oxide emissions and provide a fast release component to complement slow release from other components. This approach is only applicable in dry regions; in regions with high rainfall (or with certain irrigation practices) there is a risk that it would increase nitrous oxide emissions. So this approach would need to be carefully focussed on appropriate regions and cropping systems.	• Policies for changes to fertilizer manufacture. • Policies to ensure safety of nitrate-based materials in view of the risk of fire or explosion if stored or handled incorrectly.

The way forward

In this Policy Brief we summarise a range of practical actions and technologies that can assist in increasing the efficiency of use of N fertilizer, thus significantly decreasing GHG emissions associated with N fertilizer over-use and misuse. These actions will also deliver a wide range of benefits for food security, environmental quality and economic development (for farmers and nationally). The main technological innovations that we recommend to increase N use efficiency are sub-surface placement of fertilizers using appropriate machinery, inclusion of urease inhibitors (UIs) or nitrification inhibitors (NIs) in selected forms of N fertilizer in certain situations, measures to use N and other nutrients from manures more effectively and reduce fertilizer rates accordingly, and the use of "fertigation" where this is appropriate and practical. Other technologies such as coated or slow release fertilizers and the greater use of nitrate-based fertilizers may have a role but also have distinct limitations.

However it must be emphasised that making technologies available will not, in itself, overcome the current problem in China of inefficient use and over-use of N fertilizer. In

some situations technologies are only a minor part of the solution; in others they are vital but can only be taken up by farmers and used effectively if the appropriate facilitating policies are in place. Another key requirement is that information is delivered to farmers in more effective ways than is currently the case.

Some key policy related issues are:

- Development of more effective methods for delivering information, both technical and economic, to farmers. These must take account of the current situation in which many farmers are involved in off-farm activities that impose a constraint on labour and make "best practice" for farm operations impracticable. Working through Farmer Professional Associations and using Farmer Field Schools are obvious ways forward. In some situations the development of technicians or service providers from the private sector (or public-private partnerships) for delivering advice would be a positive development. These innovations require new policies and practices by government agencies that enable multiple approaches.
- In view of the impacts of profitable off-farm work by many farmers, the development of a contractor sector to undertake some farm operations is highly desirable. This has become very successful for grain harvesting – we recommend that it be encouraged for fertilizer application, and probably other operations such as pesticide sparaying. It will lead to improved timing of applications and overcome labour constraints that are currently a major barrier to practices that would deliver more efficient use of N. We also recommend a similar role for contractors to improve manure management. To promote this development, current mechanisation grants can be utilised for initial purchase of machinery but policies are required to make them better focussed to promote the desired outcome.The combination of machinery for applying fertilizers, and the more accurate and timely application, has the potential to greatly increase the efficiency with which N from fertilizer and manures are used. This directly addresses the issue of excessive use and decreasing GHG emissions and will assist in delivering a range of benefits for food security and environmental quality. In practice many emerging contractors will be skilled farmers who use the opportunity to become more professional. This represents a significant contribution to rural economic development and sustainability.
- Some of the technological innovations such as inclusion of inhibitors in fertilizers, or use of coated or slow release fertilizers, incur an increase in the cost of fertilizer manufacture – in the case of UIs and NIs some industry sources indicate a 5% increase above standard urea, though this requires clarification. Clearly these products will not be used widely by farmers without an incentive. We propose that the subsidy structure for fertilizers is altered in order to meet farmers additional costs This is an example of "payment for environmental services" in addition to increasing N use efficiency. Over time, as farmers see the benefits of increased N efficiency, such subsidies could probably be gradually withdrawn.
- Current developments in the production or organic fertilizers are positive, providing an opportunity to use manures more efficiently especially where produced in very large quantities in the new large animal enterprises. But policies are required to improve the labelling of these products, and the technical advice for efficient nutrient use to

accompany their sale. At present, information provided is limited to the total quantity of nutrients in the manure, with no guidance on the proportion of nutrients available to crops from such products. As the development of large animal units is now very rapid, it essential that policies and regulations are in place to ensure that manure utilization is fully planned into each new development.

Annex:

Additional information on technology and policy options

1. Decreasing N fertilizer applications to a rational level

It is never easy to accurately predict the optimum rate of N fertilizer for a specific crop in a specific field and communicate this to farmers – it is challenge in all countries. Approximate rates can be determined using a range of different approaches and these form the basis for farmer advice in many countries. In China Tables of recommendations are available nationally and locally but there is abundant evidence that these recommendations are widely ignored by farmers and excessive rates are extremely common. For example, one study showed that rates applied to grain crops in some major production areas can be decreased by 30-60% without reducing crop yields (Ju et al PNAS); in fact yields are often *increased* slightly. The situation with vegetables and fruit crops is even more extreme. Rates of N fertilizer applied to crops in China are among the highest in the world, yet yields are generally not the highest, strongly indicating inefficient use of N fertilizer in China.

Factors contributing to farmers' ignoring recommendations include:

- A general belief by farmers (and sometimes extension staff) that "more is better"; this is fuelled by the past (and necessary) policy to increase production at all costs.
- Lack of understanding by farmers and advisors that substantial amounts of N are supplied by soil, manure and irrigation water – so the whole of a crops requirement does not need to be supplied as fertilizer.
- Deficiencies in the delivery of information through the extension system. Includes the failure to take account of the social and economic situations regarding part- time farming in the grain crop sector.
- The major importance of off-farm work for household incomes means that logical arguments about saving money by using less fertilizer exert little influence.

With vegetable crops, especially those grown in plastic greenhouses (a sector that has expanded extremely rapidly) and fruit trees excessive use of N fertilizer is especially severe. It has been clearly demonstrated that the economic losses to farmers from this are large and the impacts on water quality through non-point pollution are great – affecting drinking water quality in urban areas. Avoidable GHG emissions will also be very large, though few direct measurements yet exist. The scope for reducing N rates is very large. In the longer term, consumer pressure and the need for labelling to demonstrate the growing practices may have an impact.

Proposed action
Use more effective means of communication with farmers. The Farmer Field School (FFS) approach in which "farmer trains farmer" has been demonstrated to be effective. The approach is relatively low cost. Ensure information is presented in such a way as to develop farmers understanding.

Barriers and required policy interventions
The FFS approach requires appropriate training of the trainers and facilitators. Surveys of the impact of farmer training in China by CCAP have clearly demonstrated that concerted

efforts are required for training over extended periods: one-off training, especially if given by extension staff with little confidence in new methods, are ineffective. Policies to promote training in modern approaches to delivery information are essential. With high value crops as in the horticulture sector, development of private advisors or public-private partnerships is a possibility for improving quality of advice and its delivery. Policies need to be formulated to encourage multiple means of delivering information, different approaches being suitable for different sectors. Policies to promote contractors for fertilizer application would facilitate better focussed training. In certain situations (e.g. intensive animal or greenhouse vegetable production) regulatory approaches may be required to promote good practice.

2. Changing timing of N application

For many crops, especially the grains (maize, rice, wheat) it is customary for farmers to apply some N at the time of sowing seeds or planting (with transplanted rice) – the basal dressing. Then apply more later when the crop is growing rapidly (top-dressing). There is considerable evidence that N applied during periods of rapid growth is used more efficiently than that applied at sowing or planting time – in fact, where soil contains much nitrate (as in most cases in China) it may be unnecessary to apply any fertilizer N as basal. But the common practice in China is to apply a large proportion of the total as basal, leading to inefficient use. A move to applying the majority of N later in the growing season would increase efficiency.

Proposed action

Apply a larger proportion of N as top-dressing; details will vary according to crops and rainfall patterns in different regions. This change is low cost and requires no new technologies.

Barriers and required policy interventions

Labour shortage at critical times for top-dressing and lack of suitable application machines for later application. Policies to promote contractors to provide a fertilizer application service could be very effective in changing management practices leading to increased N use efficiency. The design and manufacture of robust small-scale machines for use by contractors, or groups of co-operating famers, is essential. This may require a government subsidy or facilitating policies to start the process – this is reasonable as it is promoting environmental services through more timely (and efficient) N application. The use of inhibitors or slow release N fertilizers permits N to be applied at sowing time but used with increased efficiency – discussed below.

3. Sub-surface placement of N fertilizer

With surface application of urea or ABC, large losses of N as ammonia gas occur. This can be reduced by at least 40% by sub-surface application using appropriate application machinery. In addition to greatly increasing N use efficiency, the cutting of ammonia emission has numerous environmental benefits for the quality of air, water and soil. It also leads to more precise application, again improving N use efficiency.

Proposed action

Use sub-surface application in all possible situations. Promotion of new machines for this mode of application is consistent with the government goal of increasing mechanisation on farms and can be assisted through existing mechanisation grants. Manufacture and use of such machines represents an improvement in rural enterprise.

Barriers and required policy interventions
Machines are only likely to be purchased by contractors servicing a number of farms or by a group of farmers working together due to their cost, even with a mechanisation subsidy – so policies and actions to promote this development are essential to achieve the many benefits from the technology. In some situations engineering developments are required to ensure that machines are reliable. For some fertilizer types it will be necessary to produce them in a different physical form suitable for machine instead of hand application, so there are implications for fertilizer manufacture subsidies. There will also need to be provision of training for machine operators. The approach is limited to certain cropping situations such as basal applications to wheat and maize due to physical constraints of the crop – but is still suitable for use in many situations It is at present not applicable to rice.

4. Urease inhibitors (UIs)

Several chemicals are commercially available that slow the release of N into crop-available forms by inhibiting the enzyme urease, which promotes the conversion of urea to ammonium in soil. This leads to a slower release, more in line with the temporal pattern of N requirement and uptake by crops, thus permitting N application at sowing time, with increased efficiency of use, but avoiding the need for top-dressing and the labour required for this. UIs decrease gaseous loss of N as ammonia from urea fertilizer, again contributing to increased efficiency and decreased environmental impact. UIs have been tested in many regions of China so their suitability in different situations can be documented. The chemicals are safe and break down in soil to simple non-toxic materials. UIs could also be useful at improving poultry manure N utilisation (as could incorporation of poultry manures into soil).

Proposed action
Include UIs in urea fertilizer on a large scale according to data on benefits in specific situations.

Barriers and required policy interventions
UIs increase the cost of urea fertilizer –some industry sources indicate by about 5%, but this requires detailed clarification. To promote widespread adoption by farmers it will be necessary to subside the extra cost, at least initially until the benefits are seen in practice – i.e. farmers finding that efficiency gains outweigh the additional cost. This could be achieved by replacing general subsidies with one specifically for UIs in line with the environmental benefits they deliver. To gain the maximum benefit they should only be sold in regions and situations where they have been demonstrated to be effective. It is also

necessary that fertilizer manufacturers provide appropriate information and training. Their use allows reduced rates of N fertilizer; the economic gain to farmers through reduced N purchases would normally be expected to outweigh the small extra cost. But as the use of UIs is a new innovation, covering the slightly increased fertilizer cost is probably necessary to promote uptake. Also, by using UIs, farmers are delivering environmental benefits to society – so payment for environmental services is appropriate.

5. Nitrification inhibitors (NIs)

Nitrous oxide is a greenhouse gas almost 300 times as powerful as CO_2. When N fertilizer, or manure, is applied to soil a small quantity is released to the atmosphere through the biological transformations occurring in soil. In the drier regions in northern China, such as the North China Plain, it has been demonstrated that this emission can be significantly decreased in two ways. One way is to inhibit the process of nitrification through which nitrate is formed from ammonium – NIs do this. The other way is to apply N in the form of nitrate – this option is considered later. The quantity of nitrous oxide emitted is small in agronomic terms, so inhibiting the process will not deliver a measureable benefit to the farmer, but rather an environmental benefit. But in addition, in some situations, NIs lead to slower release of N into crop available forms, thus giving a benefit to farmers in term of saving labour. In regions of high rainfall, NIs can also reduce nitrate leaching leading to agronomic benefits in addition to decreased GHG emissions and water pollution.

Proposed action
Include NIs in selected forms of N fertilizers for use in appropriate regions and cropping systems as a direct means of reducing nitrous oxide emission from agricultural soils and, in some situations, increasing N use efficiency for the farmer.

Barriers and required policy interventions
As with UIs, inclusion of NIs in fertilizers increases cost. As the farmer will often not see a measurable benefit, but the national benefit will be significant, it is appropriate for government subsidy to meet the additional cost

6. More effective recycling of nutrients from manures

It was recently estimated that manures in China contain about 8 Mt of N – about one quarter of the amount of N used in the form of chemical fertilizers (China-UK SAIN review of manure utilization in China). Manures represent a major resource but at present are utilized very inefficiently and are a source of water and air pollution. The review concluded that the main barriers to more effective utilization were labour availability for transport and spreading. This was combined with poor financial returns from improved manure management in comparison with income from off-farm sources. There was also poor understanding by farmers of the nutrient value of manures, such that farmers are not reducing fertilizer applications to take account of nutrients from manures.

Proposed action
In small farm situations, develop policies and financial incentives for development of manure management contractor businesses. Ensure that this is combined with effective delivery of technical information to farmers and contractors on the nutrient value of manures so that fertilizer applications can be decreased accordingly. There is a particular

need for these actions in the rapidly expanding horticulture sector where a combination of over-use of manure and of chemical fertilizer is causing nitrate pollution of drinking water in urban areas with potential impacts on human health, in addition to decreased profits for farmers. Where manure is used for biogas production (already encouraged by government policies), ensure that the residue is fully utilized as a source of crop nutrients. Again, development of a specialist contractor sector would increase the possibility of effective management.

With very large animal units (another rapidly expanding agricultural activity in China) ensure that manure management is fully taken into account at the planning stage. Large scale aerobic composting to produce organic fertilizers (already encouraged through government subsidies) is an effective means of adding value and converting manures into a more transportable form. But there is currently poor knowledge of the nutrient value of the products

Barriers and required policy interventions
Development of a manure management contracting sector at a local scale would overcome the labour and economic constraints that are currently a barrier to improved utilization by individual farmers. Government policies for financial incentives are necessary to initiate such action, for example to assist with start-up costs of equipment for handling, transport to fields, and spreading.
A major benefit, in addition to decreased GHG emissions and pollution and wasted or inefficiently used fertilizers, is increased rural enterprise and employment. It is very likely that such activity would be developed by an existing farmer in a village who would add this enterprise to his/her existing enterprise, thus increasing professionalism within the agricultural sector.

To ensure more efficient utilisation of commercially produced organic manures, there is an urgent need for simple trials in different localities to measure the crop availability of nutrients in the products. Policies to mandate improved labelling are required so that farmers are informed of this, not just total contents as at present. There is also considerable scope to improve design and practices at the processing plants to reduce gaseous emissions of ammonia and losses to local water courses – both causing wastage of N and avoidable pollution. Policies are needed to achieve this, perhaps involving adjustment of subsidies to pay for more expensive, and less polluting, equipment or practices.

7. Combined improvements in water and nutrient management including "fertigation"

Poor management of water and nutrients often go together. In view of the likely worsening of water availability due to climate change, it is especially important to include measures that increase water use efficiency. A specific management practice is inclusion of fertilizer N in irrigation water – termed "fertigation". This has been demonstrated to greatly increase efficiency of use compared to surface application of solids at a single time because N is delivered throughout the growing season, more closely matching the time course of crop uptake. The practice also saves labour as it avoids the need for numerous fertilizer

applications manually. In situations where irrigation is routinely used it is highly beneficial to adopt the practice. It is easily applicable to greenhouse vegetables, and is already widely practiced in simple forms. It can also be used effectively with large scale growing of vegetables in open fields.

Proposed action
Through advisory approaches promote practices to promote combined efficient management of water and nutrients. Encourage fertilgation wherever practicable.

Barriers and required policy interventions
For small farmers it is reasonable to have policies permitting start-up subsidies to assist with the initial cost of equipment, whether for improved management general irrigation or specifically for fertigation, because the potential environmental benefit from reduced N applications is considerable. To gain the maximum benefit for GHG emissions and water quality it is necessary to ensure that suitable soluble forms of fertilizer are available at reasonable cost and that farmers receive appropriate training and technical back-up. This technical support can be provided by the companies supplying equipment or fertilizers, or through public-private partnerships. Government policy development is essential to ensure that this occurs, thus minimising the considerable environmental burden of the rapidly growing greenhouse vegetable sector. In the greenhouse vegetable situation where large initial manure applications are common, technical information on rates and timings of fertilizer through fertigation must be combined with information on nutrients becoming available from manures (see point 6 above). Without this information, excessive rates will still be applied. Information on water use is also required to counteract a strong tendency to over-irrigate, causing leaching of nutrients below crop rooting depth and excessive use of valuable water resources.

8. Slow release and coated fertilizers

Numerous such products are available in China. Much research has been conducted but uptake by farmers is extremely low. As with inhibitors (UIs and NIs) they have potential to increase the degree to which N from a single application (often at the time of sowing, or transplanting in the case of rice) becomes available during the growing season and avoid the need for labour to be expended on additional applications later. A major constraint is cost which can be at least 40% higher than standard urea, and for some products far higher. It is therefore difficult to justify these products for general use, but they may be appropriate for some specific situations. In practice manufacturers often mix a coated product with uncoated, thus reducing the price. This also overcomes a problem than can arise as the rate of release from a slow release product may be too slow for early crop growth.

Proposed action
No general action is proposed at present. These products should be considered amongst the range of options to increase the efficiency of use of N fertilizer, especially taking account of their labour-saving benefit by removing the need for multiple times of fertilizer application. Their role in specific situation can be considered where sufficient experimental evidence is available. Use with flooded rice is one possibility.

Barriers and required policy interventions
Cost is a very significant barrier. In many cases UIs or NIs are likely to be a more cost-effective alternative. However, there may be specific situations where such products (probably mixed with standard fertilizer) offer realistic opportunities for improved fertilizer

management in cases where labour constraint is severe; policies for subsidies could be considered in these cases.

9. Use fertilizers with a greater content of nitrate

In China and many regions of the world, urea is the dominant form of N fertilizer; in China a significant amount of ammonium bicarbonate (ABC) is also used. Both forms are subject to considerable losses of N to the atmosphere through volatilization of ammonia gas, especially if the fertilizer is surface applied – losses of 30% or more are not uncommon. In Europe, mainly for historical reasons affecting the fertilizer industry, ammonium nitrate is the dominant form. For dryland crops there are some benefits from applying N in the form of nitrate instead of urea or ammonium-based forms. These include: (a) eliminates ammonia loss; (b) avoids emission of nitrous oxide during conversion of ammonium to nitrate, as discussed above in relation to NIs; (c) readily soluble in water so suitable for use in "fertigation" using drip irrigation which is an extremely efficient delivery mechanism for N fertilizer as discussed separately below. With some crops (including leaf vegetables, cotton, tobacco) nitrate gives improved crop quality. A potentially useful approach is to include nitrate within compound fertilizers to deliver the benefits outlined above. In addition, the nitrate component provides a rapidly available form of N that can complement N in slow release forms – providing a season-long supply.

Limitations include increased risk of N loss through the process of denitrification which occurs in wet soil – thus nitrate is unsuitable for paddy rice. This process can occur in dryland situations after rainfall or irrigation but evidence from China suggests that it is less prevalent that in some other regions. A major drawback is that ammonium nitrate is explosive if stored under inappropriate conditions and can be used as an explosive in bomb making. This problem can be reduced by producing calcium ammonium nitrate, as is done in Northern Ireland.

Proposed action
Consider the use of ammonium nitrate or calcium ammonium nitrate in selected situations as a means of reducing ammonia losses and increasing efficiency of use of N fertilizer.

Barriers and required policy interventions
It is thought that the benefits due to reduced ammonia loss could be substantial in drier regions, including the North China Plain. To achieve this saving of N would require changes to the fertilizer manufacturing process. If it was decided to increase use of nitrate-based fertilizers for reasons of increased efficiency of N use and decreased environmental impacts, it would be necessary to introduce policies to facilitate construction of modified fertilizer plants. A widely recognised problem with the manufacture of nitrate-based fertilizers is emission of nitrous oxide at the manufacturing stage. However, technologies have been developed and are now in use in European plants to greatly decrease emissions. Because of the explosion risk with nitrate, policies would be required to ensure safe handling and storage.