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A comprehensive review of constraints to improved management of fertilizers in China and mitigation of diffuse water pollution from agriculture

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ABSTRACT

Complex and inter-related factors explain the excessive use of fertilizer observed in many intensive farming systems in China, and hence act as barriers to development of a comprehensive policy and intervention framework for mitigation of diffuse water pollution from agriculture (DWPA). This review provides an original and contemporary synthesis of these factors that is broader, deeper and more inter-related than existing assessments. The analysis confirms that DWPA cannot be addressed by single regulatory or policy measures. There is a need to develop a mitigation framework that encompasses central policy directives, reform in governance at local level, an enabling regulatory environment, horizontal and vertical coordination in food supply chains, unbiased incentives for efficient fertilizer use and protection of water resources, enhanced agricultural, food safety and environmental education for farmers and consumers, and engagement of multiple actors beyond government.

1. Introduction

Nutrient losses from agriculture are a major constituent of diffuse water pollution (Norse, 2005). The costs to society of diffuse water pollution from agriculture (DWPA) can include environmental and ecosystem damage, lost aquaculture and fisheries income, and increased treatment costs for drinking water (Norse et al., 2001; Norse, 2005). In China environmental impacts of DWPA are manifest in the widespread eutrophication of lakes, elevated nutrient concentrations in groundwater and soil acidification (Cui et al., 2014), while approximately 300 million rural residents lack access to safe drinking water (Liu and Yang, 2012). In 2009, 57% of the nitrogen (N) and 69% of the phosphorus (P) entering watercourses were from agriculture (MEP, 2010). A decrease in soil pH of 0.5 units in the major crop production regions over two decades has been attributed mainly to excessive application of N fertilizers (Guo et al., 2010). Excessive use of fertilizers also contributes to greenhouse gas emissions (Liu et al., 2011).

China uses more fertilizer than any other country (FAOSTAT, 2014). Increased use of chemical fertilizers and other inputs has contributed to increased grain productivity since 1978 (Table 1; also Carter et al., 2012; FORHEAD, 2014) but much evidence now indicates that fertilizer use could be reduced in many cropping situations with minimal or zero impact on crop yields (see for example: Ju et al., 2009; Rahn, 2010; Zhang and Powlson, 2010). Over application for cereals varies by region but can average one third in excess of crops needs, and be even higher for high value horticultural crops (Zhang and Powlson, 2010; Rahn, 2010).[1] Table 1 shows that use of chemical fertilizer in China increased fourfold from 1978 to 2012. Other countries shown for comparison largely reduced fertilizer use over the same period, whilst also demonstrating increased cereal yields.

In many intensively farmed areas an accumulation of surplus N and P in soils now constitutes both a resource to be exploited by farmers and a source of DWPA. Returns to increasing fertilizer use are diminishing (Carter et al., 2012) and reductions in use would support national priorities to reduce water pollution and greenhouse gas emissions, and could reduce farm costs (Garnet and Wilkes, 2014). However, overuse of fertilizer continues for reasons not yet fully understood and explained (Norse, 2005; FORHEAD, 2014; Holdaway, 2014).

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[1] Although excessive use of fertilizers is common regional variation remains important. For phosphorus, for example, approximately one third of soils by area are above the optimum level, one third about optimal, and one third still deficient in this nutrient (Zhang and Powlson, 2012).

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Table 1
A comparison of fertilizer consumption and cereal yields in China and selected countries post 1978.

Country			1978	2012	Change
China	Fertilizer consumption (total NPK, million tonnes nutrients)[a]		10.6	53.4	404%
	Fertilizer consumption (total NPK, kg per ha of arable land and permanent crops)[b]		106	436	311%
	Major cereal yields, kg/ha[c]	Wheat	1845	4987	170%
		paddy rice	3981	6775	70%
		maize	2803	5870	109%
Republic of Korea	Fertilizer consumption (total NPK, million tonnes nutrients)[a]		0.82	0.48	−41%
	Fertilizer consumption (total NPK, kg per ha of arable land and permanent crops)[b]		369	277	−25%
	Major cereal yields, kg/ha[c]	Wheat	2089	3910	87%
		paddy rice	6938	6988	1%
		maize	3246	4894	51%
United Kingdom	Fertilizer consumption (total NPK, million tonnes nutrients)[a]		2.13	1.46	−31%
	Fertilizer consumption (total NPK, kg per ha of arable land and permanent crops)[b]		303	233	−23%
	Major cereal yields, kg/ha[c]	Wheat	5253	6657	27%
United States	Fertilizer consumption (total NPK, million tonnes nutrients)[a]		20.36	20.12	−1%
	Fertilizer consumption (total NPK, kg per ha of arable land and permanent crops)[b]		106	127	20%
	Major cereal yields, kg/ha[c]	Wheat	2114	3115	47%
		paddy rice	5026	8349	66%
		maize	6342	7744	22%

[a] Source: total NPK for chemical fertilizer products (not including organic manures) International Fertilizer Industry Association, IFADATA, electronic database, at www.fertilizer.org/Statistics, downloaded 5 January 2015.
[b] Source: area of arable land and permanent crops from FAOSTAT, Food and Agriculture Organization of The United Nations, Statistics Division, at www.faostat3.fao.org/home/E, downloaded 5 January 2015.
[c] Source: FAOSTAT, Food and Agriculture Organization of The United Nations, Statistics Division, at www.faostatfao.org/home/E, downloaded 5 January 2015.

This paper addresses this issue through a comprehensive review of the inter-related factors that contribute to excessive use of fertilizer in China. 'Political', 'policy', 'structural' and 'behavioural' barriers to improved fertilizer management and mitigation of DWPA are identified, along with priority agendas for policy and further research. The review is broad and multi-disciplinary to provide an original synthesis of factors inadequately inter-related by existing literature. Critical analysis of the literature has been enhanced by insights from purposive semi-structured interviews with expert informants, field visits to intensive farming areas, three exploratory focus group meetings with farmers and township level agricultural extension agents, and workshop discussions with higher level agricultural officials and researchers.

2. Technical and institutional constraints to improved management of fertilizer in China

2.1. Political and policy barriers

2.1.1. Policy commitment and effectiveness for environmental improvement

Many authors and commentators cite that there is growing environmental awareness and public demand for improvements in environmental quality in China; though little research has been published on public awareness of, and demand for improvement in, environmental quality and ecosystem services. It can, however, be observed that many people want better controls as protests over environmental issues have become commonplace (Economist, 2014b). Urban air pollution is often foremost amongst public concerns, but soil and water pollution and food contamination also receive attention in public protests and the media.

Public demand has been matched by high level policy announcements. For example, the Law on Water Pollution Prevention and Control revised in 2008 made provisions for control of pollution of drinking-water sources, industrial pollution, agricultural non-point source pollution and ecological damage. The Five-Year Plan (2011–2016) articulated energy-saving goals and targets for increased forest coverage. In 2014 the national Environmental Protection Law of 1989 was amended and more punitive penalties set for polluting companies and negligent executives or officials failing to meet environmental regulations (Marquis et al., 2011; Economist, 2014b). Since 1979, significant legislation for environmental protection has made up about ten percent of laws passed by the Congress (Wang and Wang, 2011), though legislation to protect agricultural lands, wetlands and river basins is still inadequate (Marquis et al., 2011).

Despite public demand and this evident policy intent effective implementation of environmental protection is often lacking. Marquis et al., 2011, identify a 'decoupling' of regulation and enforcement in China; i.e. stringent regulations responding to public demand are weakly enforced. Explanations given are that, although the central government issues strict regulations, monitoring and enforcement of these are undertaken by local governments that tend to give greater priority to economic growth. At both national and local levels the supporting and advocacy roles of civil society are underdeveloped given the political restrictions placed on the activities of non-governmental actors including lawyers, the judiciary, journalists, and NGOs. Finally, at all levels of government there is a fragmentation of authority in relation to the environment, and a lack of monitoring and transparency.

Environmental legislation in China is also criticised for "*an outdated underlying philosophy, inadequate scope, lack of substantive content and poor functionality*" (Wang and Wang, 2011, p. 162); there is inadequate support for the objective of sustainable development, whilst a preference for generality over specificity compromises practical application and enforceability. Thus responsibilities may not be clearly assigned by level and agency, enforcement agencies have considerable discretionary power despite shortcomings in technical capacity, and there is weak coordination with partner agencies. Guidance issued and enforcement tend to be inconsistent and less than comprehensive, while penalties are typically insufficiently severe to ensure compliance. "*A growth-first mentality, flaws within the judiciary system itself, poverty, and inadequate environmental laws, mean that China's judicial system is still incapable of providing robust protection of environmental rights against abuses*" (Wang and Wang, 2011; p. 169).

2.1.2. Prioritisation of food security and economic growth

China has over 20% of the world's population but only 7% of global cultivated land (Sun et al., 2012), and it is notable that 'Policy Document Number 1' from central government addresses agriculture and rural development first each year (Maidor and Ma, 2014). Food production and food security remain the primary objectives

of the Ministry of Agriculture. These objectives are translated into targets and production incentives (subsidies) administered by regional Bureaus of Agriculture (Ma et al., 2013). Self-sufficiency in the key protein and energy providing foods – wheat, rice, maize, livestock and aquaculture products – has been seen as a prerequisite for food security (Garnet and Wilkes, 2014), although the official goal is now 95% self-sufficiency in essential grains given acceptance that complete self-sufficiency is impractical (Information Office of the State Council of the PRC, 1996).

In Chinese '*liangshi anquan*' translates as either food security or grain security, but for official policy is mainly about boosting grain production (Hongzhou, 2011). This emphasis has dominated agricultural policy in China and intersects with fertilizer use and DWPA in several ways. Prior to the reforms of the household responsibility system in the late 1970s collective farms were expected to increase production to meet local and national food self-sufficiency targets, and most of them responded by increasing fertilizer use (Sun et al., 2012). Agricultural production has since expanded rapidly over 30 years (Carter et al., 2012), and much of the increase results from increased use of chemical fertilizers. For example, a significant correlation is observable between the annual use of synthetic N fertilizer and grain production (Sun et al., 2012). Rapid development of vegetable production has also greatly increased use of fertilizers and pesticides. Even today the 'psychology' of many farmers and officials remains one of seeking to maximise production. This is particularly evident in rural areas most dependent on their agricultural economy, where significant trade-offs may be perceived to exist between local economic development and environmental protection (CCICED, 2012).

The preoccupation with 'grain security' has also led to regulation to protect the area of land under cultivation. Arable land has declined to 121.7 million hectares in 2012 from a peak in 1991 of 132.4 million.[2] Urban and industrial development is most rapid in eastern and coastal provinces where the most fertile land is disproportionately located (Ho and Lin, 2004; World Bank, 2014; Daquan et al., 2015). Urban infrastructure and property development contribute strongly to local government revenue and economic growth is an overriding goal for local officials (FORHEAD, 2014)[3], whilst environmental legislation is weak. Both conversion of arable land to non-agricultural uses and mandated targets for cultivated area inevitably push at least some farming onto marginal land where the pressure to maintain high yields can result in high application rates for fertilizers and pesticides.

2.1.3. Food safety and consumer-led drivers of environmental improvement

Popular food safety concerns are fuelled, at least in part, by media stories of acute instances of food-related illness and by fear of diseases such as cancer. Some international comparative surveys are also cited as evidence that the environmental motivations of Chinese consumers can be high (Garnet and Wilkes, 2014). Anxiety is heightened by a lack of reliable public information and communication of risks, and by some evidence of corruption of officials associated with food safety issues (FORHEAD, 2014). With the exception of heavy metals and other toxic chemicals in pesticides, DWPA is primarily a threat to drinking water safety, agricultural sustainability and ecosystems rather than food safety. However, overly-intensive farming can contribute to degradation of soil in ways that increase the risk that heavy metals will affect food crops and animal feeds.

Thus food and drinking water safety could be drivers for mitigation of DWPA in China, but although the need for greater public oversight is recognized other mechanisms to enable this are lacking. Regulatory systems and safety standards need to be developed, but models from other countries are often context dependent in terms of institutions, governance, capacity needs and diet, and not readily transferable to China. Consumer associations are lacking, and policies and institutions developed in China, such as its new Food and Drug Administration, need to build capacity in monitoring and enforcement to become effective (Garnet and Wilkes, 2014).

Certification of food production processes based on environmental criteria does exist as 'green food', 'organic' and 'hazard-free' certifications. The first – 'green food' – requires standards to be met for the use of pesticides, production methods and residue testing, and may achieve a price premium of approximately 12% compared to conventional produce (Garnet and Wilkes, 2014). 'Green' certification is estimated to apply to about 10 million hectares of agricultural land (Paull, 2008). Organic certification began in the late 1980s (Garnet and Wilkes, 2014) and 1.9 million hectares were certified by 2011. 'Hazard-free' certification, introduced in 2001 in response to contaminated food incidents (Garnet and Wilkes, 2014), aims to prevent illegal use of toxic agricultural chemicals, and pesticide residues in excess of standards (Taylor, 2008). It is estimated to apply to some 21 million hectares of agricultural land (Paull, 2008). Thus in total, eco-certification across all three schemes, applies to at most some 6–7% of China's agricultural production by area (Paull, 2008; Willer and Lernoud, 2014), while trust in certifications may also be weak, as evidenced by frequent media reports of incorrect labelling and poor enforcement of standards (Garnet and Wilkes, 2014).

Some affluent middle class consumers turn to 'short food supply chains'. Community supported agriculture schemes more directly link producers and consumers; for example, farmers' markets, direct internet selling, farm visits, farm-restaurants and farm-to-school supply chains can build trust without third party certification (Garnet and Wilkes, 2014). Beyond these, improving vertical coordination for product safety in supply chains depends on ability to enforce farm production and processing standards. Long-term supply contracts and modern supply chains are indicators for this, but testing of produce, provision of extension services by buyers and reach into rural areas are all limited (Huang et al., 2008).

Given the number of people for whom food expenditure is a high proportion of income, trade-offs between food safety and cost need to be balanced whilst seeking to ensure universal access to safe and affordable food (FORHEAD, 2014). Consumer willingness and ability to pay a premium for improved food safety will determine the feasibility of upgrading production methods and supply chains in ways that could influence farmer behaviour. Research on this issue to date is mainly limited to surveys of urban consumers and demand for organic products, with less knowledge available for rural populations, lesser cities and consumers purchasing from traditional vendors and wet markets rather than supermarkets (FORHEAD, 2014). The demography of consumption patterns in China is also complex and rapidly changing. Age income, education and lifestyle all affect preferences for improvements in food safety and environmental quality, and similarly await more systematic research (Garnet and Wilkes, 2014).

2.1.4. Limitations in governance and central-local relations

The central government communicates its priorities to lower levels of government through national development strategies, the five-year plans and targets such as 'grain security'. These indicate which economic activities are appropriate and become manifest in the incentives that guide local government. Over three decades the

[2] Area of arable land and permanent crops, source: FAOSTAT, Food and Agriculture Organization of The United Nations, Statistics Division, at www.faostat3.fao.org/home/E, downloaded 8 January 2015.

[3] See Section 2.1.4 below.

intense growth orientation of national policy has been the primary influence and criterion for local government decision making and career progression of local officials (Marquis et al., 2011).

China's civil service became more oriented towards merit and performance management with the formalisation of the objective responsibility system (ORS) from 1995 (Burns and Zhou, 2010). Naturally, officials tend to focus on goals that directly influence their career opportunities while giving less priority to others. Birney, 2014, has described this as a "*rule of mandates*" (p. 55) under which the officials are accountable to relative rather than fixed standards. In contrast to regulations mandates are directives, or performance targets and indicators (Burns and Zhou, 2010), that are hierarchically ranked. The continuing emphasis on targets such as GDP growth and 'grain security' has meant that secondary 'mandates' such as environmental protection become conditional on their compatibility with the higher priority mandate. High economic growth rates, regardless of environmental and social implications, bring promotions and political opportunities; whilst environmental improvements become at best an optional consideration in terms of both local priorities and the performance evaluation of local leaders (Wang and Wang, 2011).

For example, Burns and Zhou, 2010, list the performance targets of a township government in 2005. The priority and "*functional*" (p. 15) targets included the value of agricultural production, income targets for township enterprises, and revenue targets; secondary to these was a vague target to protect farm land. As the ORS has developed it has increasingly focused on measurable targets for inputs and outputs, but little on outcomes such as improving efficiency, equity or sustainability (Burns and Zhou, 2010).

The influence of the ORS on the behaviour of officials should not though be overstated. Structural constraints also impede alignment of incentives for officers with official policy goals (Burns and Zhou, 2010). Almost 60% of civil servants are employed at county and township level where promotion opportunities are few and pay differentials narrow, thus limiting these as a motivating factor. As a performance management system the ORS is also undermined by the compressed and relatively egalitarian structure of the local civil service, by supervisors who empathise with subordinates based on personal relationships rather than performance, and by practices such as selling of positions and other forms of corruption (Burns and Zhou, 2010). Thus in terms of 'decoupling' of environmental policy from implementation the ORS may have a dual effect. Where it works it emphasizes economic growth over sustainability (as compounded by other factors discussed below), and where it is ineffective it simply fails to translate official environmental goals into action.

Local politics may compound these failings, as officials can hold joint appointments in both the Communist Party and administrative bodies at local level, and functional decision making invariably becomes subject to political influence. For example, a local agency with responsibility for environmental protection that fully sought to discharge its obligations and duties for pollution control could adversely affect local economic growth rates and with this performance evaluations for local cadres. Under such circumstance, both the state's role in environmental monitoring and supervision and the environmental rule of law may become dysfunctional (Wang and Wang, 2011).

Fiscal and tax systems make local government revenue highly dependent on GDP growth and thus combine with the ORS in influencing behaviour by officials (Keting, 2011). County level government is required to implement central policy but funding for this must often be found locally (Ellis and Turner, 2008). Differences in local resources lead to variation in capacity for service provision and policy implementation. In general, rural areas have less capacity than urban areas, but across both there is a continuum from poor and low-capacity to relatively rich and high-capacity (FORHEAD, 2014). Local government dependence on local industry for tax revenue and employment can make it difficult to close down or impose the costs of regulation on polluting enterprises (FORHEAD 2014). This tends to exacerbate local protectionism, government-business collusion, and competition between localities to attract outside investments. Not only are environmental protection 'mandates' treated as secondary, but it may be in a local government's best interests to ignore or violate national environmental regulations in a "*race to the bottom*" with its neighbours (Marquis et al., 2011, p. 43). Under these conditions, despite the decentralised political system and local autonomy to develop local policy solutions, it is unrealistic to expect local governments to pursue fiscal discipline and take the initiative in limiting economic expansion (Keting, 2011; FORHEAD 2014). Whilst these observations are more relevant to urban and industrial expansion than smallholder farming, they are important features of the political and policy environment in which approaches to mitigate DWPA must be developed and implemented. They also become increasingly relevant to the larger scale farming operations and agri-businesses that are rapidly emerging in China (as discussed further below).

Inter-locality competition for investment and economic growth can also under-value and limit cooperation across administrative boundaries (Marquis et al., 2011). Managing shared resources and the environment requires coordinated action by the varied agencies with relevant responsibilities and budgets, yet ORS targets do little to encourage collaborative arrangements and shared outcomes such as clean water. Protecting rivers and lakes from pollution cuts across the functional and spatial responsibilities of government, and cross-boundary partnership working is an obvious but largely unmet need.

Marquis et al., 2011, define bureaucratic alignment as "*the extent to which the structure of the government allows national development strategies and policies to be consistently and effectively implemented*" (pg. 41). Another obstacle to improved environmental protection can be overlap in responsibilities and competition for authority (or 'turf wars') within the regulatory structure (Ellis and Turner, 2008). For example, responsibilities for environmental issues are primarily divided in two. At provincial and county levels, Environment Protection Bureaus are responsible for industry-associated pollution and Agricultural Bureaus are responsible for pollution caused by agriculture and for rural environment conservation. However, in practice matters become more complex. For example, for pesticides "*the Ministry of Agriculture monitors field use, the state planner and the Commerce Ministry grant production licenses, the Ministry of Health is responsible for setting maximum residue levels, and the State Environmental Protection Administration monitors environmental impacts*" (Reuters, 2007, cited in Ellis and Turner, 2008, p. 26). Similarly, responsibility for regulating soil and water quality is spread across the Ministry of Environmental Protection, the Ministry of Land Resources, the Ministry of Water Resources and the Ministry of Agriculture; each having varied and overlapping responsibilities (World Bank, 2006; FORHEAD, 2014). Policies and measures relating to land-use planning and zoning similarly emanate from different agencies and are not well integrated (Yeh et al., 2011). Deficiencies in communication, coordination and data sharing amongst agencies can result in poor implementation and enforcement of policy. Constraints to publication and sharing of data are a significant barrier to improved agency cooperation and environmental management. Meta-data and sampling methods are rarely made accessible to other users, whilst internally awareness is lacking of other data available (FORHEAD, 2014).

Frequently the goals of rival agencies are contradictory. Notionally there should be a balance of power between those

concerned with environmental protection and those focused on economic development, but with the compliance of local and central government the authority of the latter typically wins over that of the former (Tao, 2011). For example, provincial governments, the Ministry of Environment Protection, and economic development agencies such as the Ministry of Industry and Information Technology and the Ministry of Commerce are at the same bureaucratic level without power over their counterpart agencies (Marquis et al., 2011). It can similarly be the case for economic development agencies and environmental protection agencies within local governments.

Another dimension of 'decoupling' is inadequacy in governmental and societal mechanisms for monitoring government agencies and private enterprises with respect to policy and regulatory compliance (Marquis et al., 2011). Information disclosure and transparency standards should allow both higher government and civil society to monitor actions. For example, the ORS provides no formal mechanism for citizen participation. Although some local governments have begun surveying public satisfaction with government performance as part of the performance management process, public participation generally remains limited to a passive role of 'information provider' with little influence on performance evaluation and decision making (Burns and Zhou, 2010). The lack of transparency and varied instances of corruption at local level has led processors and farmers to distrust local oversight or regulation (Ellis and Turner, 2008). Lack of transparency also applies to private and government enterprises. Without established standards for reporting, many firms can be accused of 'greenwashing' their outcomes (Marquis et al., 2011).

Compared with most other policy areas, environmental protection does demonstrate a positive role played by civil society. Environmental NGOs have remained acceptable to government by deliberately and strategically acting in a non-confrontational and politically neutral manner, and like other NGOs are subject to restrictions on taking collective action or acting on behalf of interested groups. Despite these limitations they have gained influence which cannot be ignored completely by decision makers. NGOs that specialize in organic agriculture, rural development, and sustainable development exist, but similarly are pragmatic in their focus on non-political roles of information provision and producer advice. Political tensions do remain, particularly where environmental issues relate to the rights of citizens, and the government remains wary of environmental activism (Tao, 2011). A multilateral and open system of environmental regulation and management has certainly yet to form (Wang and Wang, 2011). As a consequence economic incentive instruments, market mechanisms and action by civil society remain weak alternatives to direct administrative control.

2.2. Agricultural sector policy barriers

China's agricultural support policy is in a transitional stage. In a developing economy agriculture typically contributes a large share of GDP and employment, and purchase of food accounts for a high proportion of household expenditure. Thus agricultural support policy aims to ensure food security, rising farm incomes and farm employment through increasing productivity of land. Once growth has been achieved in the non-farm sector (at least in some regions) transition in policy becomes necessary to support increase in farm labour productivity (e.g. through increasing farm size and mechanisation) as labour leaves the agricultural sector for employment in industry and urban areas. Greater priority then also tends to be given to environmental protection. Policy needs in China are complicated by the geographic scale and spatial diversity of its economy. Nearly 97% of poor people live in rural areas (Ni, 2013), and agricultural support policy retains the objective of reducing poverty by supporting small farmer livelihoods. This is said to be reinforced by a sense of a 'national debt' to farmers as it was the household responsibility system and growth in the agricultural sector that led to China's unprecedented growth since 1980 (Ma, 2014). Support to agriculture primarily aims to meet domestic needs, but accession to the WTO and international trade commitments will hasten further reform in agricultural policy.

2.2.1. Agricultural support policies

Agricultural support policies primarily consist of direct payments for grain production, a general subsidy for agricultural inputs, a subsidy for adoption of improved crop varieties, a farm machinery purchase subsidy, minimum grain purchasing prices, temporary storage options and some environmental protection measures (Ni, 2013). Direct payments for grain production were introduced in 2004 in response to production declines, signalling a switch from sector taxation via price controls to subsidy (Gale et al., 2005). There are differences by province and grain type, but most payments are based on taxable land area certified in the agricultural tax reform which tends to remain constant, rather than actual area planted to grain (Ni, 2013). Since 2006 a general subsidy for agricultural inputs has been provided to reduce production costs and relieve the effects of price fluctuations for grain production inputs such as diesel fuel, fertilizer, pesticides, plastic sheeting and other materials. The amount is based on past production practice and prevailing input prices. In most provinces the subsidy is received as a direct annual payment via the same channel (usually credited to bank accounts) as the payment for grain production. Huang et al., 2009, state that this subsidy amounted to less that 1% of output value in 2005 and was insignificant in terms of market distortion and production decisions. The subsidy amounted to about USD 14.5 per farm household in 2007 (Beckman et al., 2009), but had increased by a factor of three by 2010 (Li et al., 2013). However, it is said to be 'barely noticed' by farmers when credited to their bank accounts (Huang, 2014).

Farmers can receive the subsidy for improved varieties either as a direct payment based on growing area or via discounted retail seed prices. For the farm machinery subsidy, farmers pay a discounted price with the price difference settled between the government and suppliers (Ni, 2013). Minimum grain purchasing prices were introduced in 2005 and 2006 for rice and wheat respectively in major grain producing areas. When the unregulated market price is lower than the minimum purchase price, government authorities purchase grain at the minimum purchase price (which was set before sowing). When the market price is higher the programme is dormant. Grain purchased is stored until market prices rise, providing modest intervention against fluctuations in farm-gate prices and farm incomes.

Although in aggregate the level, number and scope of agricultural support policies has risen in recent years, because of the large rural population the value of support per capita and per farming household remains relatively low. There are regional differences in the implementation and outcomes of policies, but estimates are that government support and subsidies typically provide Chinese farmers with around 5–6% of their income, a far lower proportion than in most developed economies (OECD, 2011; Ni, 2013). Most farmers are said not to know the exact amount of farmland being subsidized or the standard for calculating it, and simply accept changes to the subsidy amount received (Ni, 2013; Huang, 2014). In addition it is common that farmers in many areas may sublease their land to others but still receive the subsidies (Chen, 2011; Ni, 2013). Minimum price and temporary storage programmes have marginal impact on output prices given the volumes purchased and stored compared to total domestic

production, and are implemented primarily in the interests of farm income and food security. Together with the level of aggregate support described above, all of these factors indicate that agricultural support, and most specifically payments for grain production and input subsidies, act as direct income subsidies de-coupled from crop production decisions including fertilizer use (Gale et al., 2005; Chen, 2011; Ni, 2013; Huang, 2014). This cannot be stated absolutely as all farm income support is fungible, and the extent to which these policies reduce income and output price risk may encourage more intensive use of inputs. Also, while the subsidies may have little direct influence on farmers' production decisions they nevertheless contribute to farm incomes and may make farming structures and traditional spatial patterns and production practices profitable enough to inhibit a more rapid transition to more efficient and higher value production systems. This supports aims of self-sufficiency in grains and rural poverty reduction, but may contribute to persistence of excessive use of fertilizer in intensively farmed areas.

2.2.2. Fertilizer industry subsidies

Since 2009 the fertilizer sector in China has become largely de-regulated and market-oriented in so far as all price controls have been removed with the exception of tariffs for managing trade to prevent domestic shortages. However, four significant subsidy programmes remain in place, most taking effect since the mid-2000s (Li et al., 2013). These are: exemption from electricity price increases for fertilizer manufacturing plants; exemptions from price increases and certain charges for rail transport costs; exemption from value added tax (VAT); and a credit subsidy for enterprises providing six months storage of fertilizer as a reserve to stabilize supply and minimize peak shortage.

Together with the general farm input subsidy described in Section 2.2.1 above these programmes provided the fertilizer industry with a total subsidy of USD 0.95 billion in 2003, rising to 18.76 billion in 2010 (Li et al., 2013). This level of subsidy has had a number of impacts. Rapid growth in the fertilizer industry, and a proliferation of producers and distributors, has created employment but led to low levels of manufacturing efficiency compared to international standards and variability in the quality of output. Scarcities existed prior to the 1990s, but since then availability and affordability of fertilizers has not been an issue for farmers. Despite the removal of price caps in 2009 the subsidies to the sector have ensured that fertilizer prices have remained relatively low and stable. For example, since the 1970s, farmers have paid 50–75% less for urea fertilizer than the world market price (Li et al., 2013). Some authors assert that this has contributed to excessive fertilizer use and thus to DWPA (Sun et al., 2012; Li et al., 2013). Others cite estimates of highly price inelastic demand for fertilizer (e.g. Liu and Sheng, 2012; Huang et al., 2012b), and the issue merits further rigorous research.

2.2.3. A lack of adequate environmental regulation

Water quality standards for each major reach of river exist, defined on the basis 23 parameters and five categories of chemical quality related to the designated use of the water. With the addition of total nitrogen and phosphorus the same parameters and grades apply to lakes (OECD, 2007). However, for DWPA there is a lack of well-defined and matching regulations for agricultural nutrient management. Provinces produce guidelines but these remain advisory and non-enforceable. Another deficiency is a lack of regulation of quality control in the manufacture of chemical fertilizers. Several government agencies have relevant responsibilities but there are no consistent well defined standards for product registration, labelling, monitoring and quality. Distribution of poor quality and mis-labelled products is a continual problem (Li et al., 2013). There is similarly a lack of sufficiently tight controls on the discharge of organic waste from livestock and poultry farms. Environmental protection regulations for livestock production need to be established relative to potential to increase waste treatment and utilization of manures, the livestock carrying capacity of the land, waste storage and disposal requirements, and the need for riparian buffer zones (Sun et al., 2012). A national policy is needed to establish the infrastructure necessary to collect, store, treat, distribute and apply organic wastes from concentrated livestock feeding operations to smallholder farms, thus assisting farmers to reduce chemical fertilizer use and improve soil organic matter content (Li et al., 2013).

2.2.4. Deficiencies in agricultural research and extension services

The Department of Extension of the Ministry of Agriculture is responsible for both agricultural education management and environment protection education (Chen and Huang, 2001). The solutions to excessive fertilizer use most commonly advocated in the literature are improvements to the structure and performance of extension services (e.g. Sun et al., 2012; Li et al., 2013; Garnet and Wilkes, 2014). Recent studies are critical of the current state of public agricultural extension following successive reforms since the 1980s. Huan et al., 2010, describe a crisis in extension as despite new technologies being demanded by farmers, state research and advice provision has become less responsive to need, whilst other important factors such as market access and information receive insufficient attention. Typically at provincial and municipal levels, and in some counties, functional specialisation and sub-sector divisions remain in place, even though at township level, a single station usually now implements all extension activities. According to Ma et al., 2013, the extension system is still responding to the reforms and has become fragmented. It has many different stakeholders, each with varying roles, knowledge, objectives and policy instruments relevant to nutrient management. The Ministry of Agriculture and its Bureaus of Agriculture still exert a dominant influence through the extension system and provision of subsidies, whilst the private sector, universities and research institutes also engage in in technology development and transfer, but without much coordination and scientific consensus (Ma et al., 2013). Regardless of paymaster, extension agents tend to have a relatively low education level and limited training in modern communication techniques. Resource use efficiency and environmental protection tend to remain low on the political agenda in rural areas (for reasons considered in Section 2.1.4 above), which hinders any coordinated efforts to develop a coherent nutrient management strategy and policies to improve nutrient use efficiency by farmers.

The 'crisis' in extension includes the cost to the public purse. While past reforms have favoured a focus on individual production units (i.e. households and farms, not 'production brigades'), there remains a strongly hierarchical structure, with authority and prioritisation linked to the production and growth ethos in both the extension service and local government. Until corrected, reforms to extension from the late 1980s reinforced this production ethos by enhancing commercial incentives for many public as well as private extension agents to promote intensive use of agricultural inputs. Overall the functional divisions and failures suggested by the literature indicate that current provision for agricultural extension is poorly equipped to meet the needs for horizontal coordination, integrated assessment, and integrated design and implementation of management measures for mitigation of DWPA. However, at village level functions and approaches may be more integrated, and despite technical capacity limitations, there may be some scope for the emergence of a more holistic approach. Provision of education and advice must address the whole farm as a business, taking account of the objectives of the farming family. Advice to increase production alone is no longer

sufficient, and greater account must be taken of managing costs, labour use and environmental impacts. Finally it can be noted that both a lack of relevant regulation and publicly available monitoring data for ground and surface water quality, means that there are no 'baselines' against which to set advice and training for good farming practice in relation to control of DWPA.

A specific lacuna for improved nutrient management is widespread farmer adoption of fertilizer use recommendations based on adequate soil testing. The Ministry of Agriculture's National Soil Testing and Fertilizer Program involves testing soil properties and crop nutrition needs to make location and crop specific fertilizer use recommendations (Garnet and Wilkes, 2014). Appropriate compound fertilizer formulations are then produced by participating fertilizer manufacturers and supplied with guidance to farmers. To date improved monitoring is needed to fully evaluate the impact of this programme. Some research suggests that in regions where participation rates are high, significant reductions in N fertilizer use have been achieved (Sun and Huang, 2012; Garnet and Wilkes, 2014). From field visits and expert opinion it is clear, however, that in most regions of China a soil testing regime of adequate frequency and spatial resolution is lacking. Correspondingly, unbalanced nutrient ratios in compound fertilizers can cause acidification, secondary salinization and reduction of microbial activity in soils, reducing yields and possibly inducing farmers to apply even more fertilizers to try and compensate for the reduced soil productivity (Sun et al., 2012; Shen et al., 2005).

2.3. Structural barriers

China's economy exhibits a dualistic economic structure in which an increasingly modern urban and industrial economy co-exists with a relatively traditional rural economy comprised mainly of small-scale agricultural production units. Infrastructure and services in urban areas are generally well-developed while those of the rural areas lag behind, and the average income and consumption levels of urban residents are significantly higher than that of most rural residents (Ni, 2013). From this situation emerges a number of structural barriers to improved nutrient management in agriculture and mitigation of DWPA.

2.3.1. Small-scale farming, land fragmentation and constraints to consolidation and coordination

Farming in China is dominated by smallholder farmers, with on average only around 0.7 hectares of farmland (Lowder et al., 2014). There is variation, but even in the most land-abundant province (Heilongjiang) the average is only 3 hectares per household. Agriculture remains the main source of livelihood for a rural population of approximately 185 million households and 670 million people although its importance as a share of total and net household income has declined during the last decade as the share of income from off-farm employment has increased. Farmers in the thirteen major grain producing provinces remain those amongst the farming population most dependent upon agriculture as a source of income. The average annual net income per head of farmers in 2010 was RMB 5919 (USD 874) compared to the national poverty line of RMB 2300 (Ni, 2013). Thus many farming households have an income below this average, and make up a high proportion of the 128 million people who exist below the poverty line nationally. Small farm scale and low levels of farm income have implications for farmer behaviour and measures to mitigate DWPA.

Land use rights were given to rural households in the late 1970s with the dissolution of collective farming and introduction of the household responsibility system. This stimulated growth in productivity but also resulted in fragmentation of land holdings. Resulting operational inefficiencies contribute to low farm income and low capital investment, and can preclude adoption of more advanced management of inputs and impede bulk application of organic manures. Small and fragmented holdings (and transfer of farm labour to non-farm employment) have been associated in some areas with higher rates of nutrient application (Tan et al., 2008).

Fragmentation of holdings persists because of continuing prohibition of the sale of farmland, although consolidation can increasingly be achieved through a range of rental and transfer arrangements (Huang et al., 2012a). In relation to food safety, Waldron et al., 2006, argue that the pace of farm consolidation is also limited by government commitment to maintaining small farmers' access to markets for reasons of livelihood and rural social security. This limits the compliance-related costs of higher food safety (or environmental protection) that can be imposed on smallholders before they are forced out of markets (FORHEAD, 2014).

Horizontal coordination is another potential strategy for overcoming problems associated with a small-scale, low income and fragmented agrarian structure. However, marketing and processing of agricultural produce also tends to be fragmented in China. Marketing and processing of many agricultural commodities is dominated by small scale and mobile traders or companies who purchase products from villages and transport these to market or processing plant (Gale and Hu, 2012; Thompson and Hu, 2007). Farmer cooperatives could help to overcome such constraints but are generally still at an early stage of development, although supported by government policy.

An alternative strategy for coordination and consolidation in farming are so-called 'dragon-head enterprises' (FORHEAD, 2014). These are scale producers supported by government to encourage vertical integration. Such companies may provide inputs, technical advice, processing and better access to markets. Typically they engage in contract farming with households and invest in infrastructure for input supply, processing, storage and marketing. Such companies and cooperatives are not mutually exclusive, and could beneficially contract with each other (FORHEAD, 2014), but modalities for such coordination are not well understood and developed across commodities and farming sub-sectors. Other forms of contracting to achieve scale in farming operations are also emerging. Examples include: firms contracting with villages to consolidate land holdings which can then be directly farmed and managed by the agribusiness; farmers working on their own land contracted to produce the same crop for a given company; or a company renting village land and then employing farmers to produce for them using specified inputs and methods (Calvin et al., 2006).

2.3.2. Other structural trends in the agricultural economy

As productivity has risen, agricultural specialization and spatial concentration exhibits a shift from mixed crop and livestock farming to monocultural agriculture in many regions (Garnet and Wilkes, 2014; FORHEAD, 2014). For example, rice and maize production in eastern and northeast regions, pork and poultry close to the more urbanised southeast and dairy production in the grasslands of northern regions (Garnet and Wilkes, 2014). There also tends to be concentration of vegetable production and confined livestock feeding operations in peri-urban areas. Such spatial specialisation in commodities has environmental implications as the decline in mixed crop-livestock systems means that livestock farming becomes 'disconnected' from arable farming. There is then insufficient surrounding crop production to absorb and benefit from nutrient surpluses from livestock (Garnet and Wilkes, 2014). As well as being a major source of polluting wastes, the livestock sector accounts for an increasing proportion of crop

use, and thus with increasing meat and dairy consumption drives an increasing proportion of crop-related environmental impacts (Garnet and Wilkes, 2014).

2.3.3. Demographic constraints and farmer characteristics

Demographic changes in China are affecting the organization of agricultural production in ways that impact on the potential for improved environmental protection. Rural-urban migration for employment, particularly by male able-bodied workers, and ageing of the rural (and general) population is reducing the labour force available for farming. Even if they remain in the countryside fewer people of working age now work in agriculture, and where alternative employment is available the opportunity cost of working on one's own farm or as an agricultural labourer has risen. The result is that farming is now often the responsibility of women with young children and/or the elderly, or is managed in short periods of farm labour, when workers return for peak periods such as sowing and harvesting. In some areas women make up 70–80% of agricultural labour, and are often middle-aged with limited education and lower wage rates than men (Cao and Birchenall, 2013; Song and Vernooy, 2010). Agricultural support policies, research, technology development and extension may rarely consider the specific needs, objectives and expertise of women (Vernooy, 2012). A feminised and ageing workforce may require increased mechanisation and training to substitute for manual labour, and land policies that take account of the current transition whilst evolving towards a consolidated and modernised structure for agricultural production.

Shortages of adult farm labour thus contribute to the adoption of chemical fertilizer and pesticides as labour-saving technologies. One of the main barriers to effective utilisation of organic manures as a source of nutrients is the shortage of labour for their transport and application in bulk (Chadwick et al., 2012). There is increasing diversity in labour availability and use in agriculture, for example, from still relatively labour intensive small-scale protected horticulture, through a paid labour force for large agri-businesses, to displacement of labour by mechanisation.

These changing patterns of rural demography and employment affect the use of farm inputs and incentives to engage in sustainable farming practices in complex ways which merit further research (Holdaway, 2014; FORHEAD, 2014). For example, farmers are likely to apply fertilizer in a single application rather than using split applications which need more labour (Sun et al., 2012). Such single applications are likely to be made in excess and will be vulnerable to losses through leaching and surface runoff before uptake by the crop, whereas split (or possibly slow-release) applications will usually result in higher nutrient use efficiency (particularly where also well matched with irrigation regimes).

2.4. Behavioural barriers

The excessive use of fertilizers on many Chinese farms appears to be economically irrational, both from a private farm income perspective, and from a social perspective when account is taken of the costs of DWPA. The sections above have identified a wide range of factors beyond the control of farmers that influence or constrain their behaviour in relation to fertilizer use. This section considers the objectives of rural households and how this may influence farmer decision making.

2.4.1. Farm household objectives and risk aversion

As noted above, extensive fertilizer trials in China have provided estimates of the yield maximizing, or agronomic optimum application rate for fertilizer under a wide range of conditions. However, as also noted, data available are not necessarily comprehensive and up to date. In particular, crop varieties developed in recent years may require more nutrients and higher management levels, justifying higher rates of fertilizer to reach the optimum agronomic efficiency (Sun et al., 2012). The economic optimum (profit maximising) fertilizer application rate will be less than the agronomic optimum, as determined by the point at which diminishing marginal returns to increased fertilizer use match the incremental costs of that additional use. Farmers can be expected to aim to approximate this economic optimum, unless their behaviour is dominated by extension advice based on the agronomic optimum application rate.

Complicating this assumption are the other objectives that may influence a farmer's decision making. Considered foremost in the literature is risk, and the assumption that small-scale farmers with low incomes dependent on farming in particular, will be risk averse. In relation to risk and nutrient use in agriculture, two main categories of risks can be identified: environmental and economic risks. Economic risk is mainly related to the risk that reducing the amount of fertilizers could result in yield loss and therefore profit reduction. Therefore, the over application of fertilizers can be perceived by farmers as a risk reducing activity, in other words an insurance mechanism to guarantee at least average yield (SriRamaratnam et al., 1987; Babcock, 1992; Yang et al., 2012; Stuart et al., 2014). Environmental risk should have the opposite effect, i.e. excessive use of fertilizers could result in negative environmental impacts including soil degradation, climate change impacts, and water pollution (Han and Zhao, 2009; Wauters et al., 2010; Stuart et al., 2014). Given the wide incidence of environmental costs across society (compared to private costs for the farmer) and probable weak knowledge of these costs, economic risk linked to nutrient use and yield loss (as well as associated with adoption of new conservation practices and technologies) can be expected to dominate farmers' decisions over environmental risk. Economic risk aversion can thus be a cause of excessive use of nutrients, and an influence for farmers' decisions on adoption of environmental mitigation strategies (Pannell, 1991; Morris and Potter, 1995; Aimin, 2010; Bowman and Zilberman, 2013; Stuart et al., 2014).

Farmers' attitude towards risk and the degree to which their decision making is risk averse will depend on a range of factors. These include: the level, security and degree of diversification of farm household income; the quality of a farmer's information and knowledge about output risk (as affected by weather, pests, disease, irrigation shortage etc.), agricultural input use and effectiveness, and environmental risk; the degree of trust in extension agents or other sources of advice; and the farmer's level of education. For instance, Han and Zhao, 2009, demonstrate that there is a negative relationship between fertilizer application and farmers' education level and knowledge of environmental impact. Babcock, 1992, shows that increasing uncertainty about soil nitrogen concentration and weather conditions usually increases nitrogen applications beyond the rates that would occur under certainty. Sheriff, 2005, argues that trust and a farmer's perceptions of agronomic advice will influence the rate of fertilizer application. If farmers perceive that the suggested rate of fertilization is too conservative, or that the recommendations of extension advisors under-estimate crop response in their fields, they may over-apply relative to the recommendation. Evidence is cited that farmers systematically over-estimate the impact of additional nitrogen relative to agronomists' recommendations (Sherrif, 2005). Chadwick et al., 2012, note that farmers lack knowledge of the nutrient content of organic manures such as composted manure products, and animal manures are often applied to land, either as fertilizer or as a means of disposal, without adequate accounting for nutrient content applied or risks incurred. Farmers' perceptions and knowledge of fertilizer use, its profitability and associated environmental risk are obviously key factors influencing excessive use of crop nutrients in China.

2.4.2. Farm household objectives, rural social security and urbanisation in China

As identified above, the agricultural sector performs a range of social and cultural functions in the dualistic Chinese economy, providing important positive externalities for society, but often at the cost of efficiency and negative externalities for the environment. The absorption capacity of the cities for rural-urban migrants may be declining (Ni, 2013) and certainly when the economy fluctuates agriculture can help buffer the impact by providing at least basic food security and income to returning migrant workers. For example, many migrant workers went back to farming after the financial crisis in 2008 (Ni, 2013), taking advantage of the alternative social security mechanism provided by access to land and/or casual agricultural employment. The need for rural areas to provide at least minimum social security arrangements for migrant workers is reinforced by their living and working conditions in cities, and by their legal status. Migrants are a vulnerable population in urban areas because of low incomes (further reduced by remittances to family remaining in the home village), long working hours and poor housing conditions, often all provided by the informal sector (FORHEAD, 2014). Poor urban residents in neighbourhoods with limited social infrastructure are similarly vulnerable but migrant workers are particularly so, and also less likely to have access to medical and other social services, frequently living in more densely concentrated conditions in old or peripheral areas of cities with more limited access to drinking water, heating, waste disposal and other services (Holdaway, 2014).

Although the policy is undergoing progressive liberalisation (Economist, 2014a), rights to settlement, and access to public services and certain types of employment are often still tied to a person's residence registration (*hukou*), which specifies both an administrative jurisdiction and rural/urban status (FORHEAD, 2014). Full access to schools and hospitals in the cities at subsidised rates requires an urban *hukou*, but birth in a rural area provides a rural *hukou* (for parents and their children); a status which has been difficult and costly to change (Economist, 2014a). Only 36% of China's total population are urban *hukou* holders (Economist, 2014a). The system is a hangover from a centrally planned system under which the key differentiation was the source of a person's grain supply (FORHEAD, 2014). People could not live in cities without state provided resources, whereas rural residents were assumed to be at least self-sufficient in basic food supply. In pre and post reform periods the system has been partially effective as a means of controlling rural-urban migration (Yeh et al., 2011), but discrimination against migrants without an urban *hukou* remains a barrier in terms of access to social protection (Chan and Buckingham, 2008).

Although whole family migration is becoming more common, access to education in urban areas remains in doubt, and many migrants maintain two households, sending remittances home to support children, wives or elderly parents in the countryside (FORHEAD, 2014). Migrants from rural areas may dislike the discrimination in cities, but many may doubt the social security of an urban *hukou* even if offered (Economist, 2014a). These doubts include whether new, rapidly expanding and still imperfect urban welfare systems will provide unemployment benefits or a promised pension to often still transient workers. Dependents of migrants who remain in rural areas also clearly retain needs for care in that location, as may retiring migrants returning to rural life carrying the health impacts of life in urban areas (Holdaway, 2014). Thus migrants tend to "*keep one foot in the countryside, holding onto their tiny patch of land and never making the break*" (Economist, 2014a). Farming and traditional ways of living provide a more reliable source of unemployment and pension security, and at least some access to education and healthcare in rural areas. A small parcel of land provides a 'buffer' for migrant workers of more than just employment and food security. This is relevant to concerns about nutrient management and DWPA because anecdotal evidence suggests this as an explanation for minimisation of farm management input. Fertilizer and other agro-chemical inputs are utilised as conveniently as possible, to minimise labour input and/or the expertise needed from elderly 'caretakers' of the land. Where urban work is well paid, both farm input costs and farm profit generated may be increasingly insignificant compared to the labour opportunity cost of the migrant head of household (or other migrant family members), but an interest in farming is sustained for the reasons explored here. Secondly as a barrier to DWPA, even if migrants did wish to sell their land they are not able to do so. Although alternative mechanisms for land consolidation are emerging, this may hinder development of modern farms of sufficient scale to be well managed for both production and environmental protection.

3. Conclusions and ways forward

Through its comprehensive approach this review has identified many factors that constrain improved fertilizer management and mitigation of DWPA in China. These include drivers of poor nutrient management that derive from deficiencies in policy approaches, as well as from economic and social structural characteristics and dynamics of the rural economy. The resulting synthesis is broader and deeper than other assessments of the nutrient management challenge in China to date.

The analysis confirms that DWPA cannot be addressed by single regulatory or policy measures alone. There is a need to develop a mitigation framework that encompasses clear policy directives from central government, facilitating governance arrangements at local level, an enabling regulatory environment, horizontal and vertical coordination in food supply chains, incentives for protection of water resources by farmers (unbiased by other sector policies), and enhanced agricultural, food safety and environmental education for both farmers and consumers. Lack of adequate, reliable and universally accessible urban and rural social security systems comes at a cost in terms of agricultural efficiency and environmental impact. Effectively managing the environmental impacts of changes in the farming sector will require not only integrated policy measures but also the engagement of multiple actors beyond government. Thus NGOs, the media, water suppliers, industry and consumers can all play important roles in developing a comprehensive mitigation framework for DWPA. At the centre of the mitigation framework must be policies to give farmers economic incentives to raise fertilizer use efficiency and make it possible for them to adopt the most efficient technologies (Zhang and Powlson, 2012). In turn this must be supported by an adequate scientific knowledge base.

Positive trends are identifiable in a number of relevant respects. For example, the 12th five year plan (2011–2016) emphasizes the need for environmental quality improvement in rural areas (Li et al., 2013). The gap between environmental regulation and enforcement may also be closing ('re-coupling') through shifts in government priorities and leader incentives, governmental reorganization, and increasing pressure for transparency and monitoring (Burns and Zhou, 2010; Marquis et al., 2011; Economist, 2014b). Improvement will inevitably take time and be uneven, and will require capacity building at county and township levels (FORHEAD, 2014).

There is also a strong consensus emerging that increasing the scale of production can help in addressing environmental impacts (Shen et al., 2013; Garnet and Wilkes, 2014). The 2013 'Number One Document' envisaged strengthening of land rights as a means of supporting development of large-scale family farms and agricultural

cooperatives and other recent policy announcements indicate that further reforms of land rights may enable farmers to transfer or mortgage contracted land and to convert land use rights into shares in large-scale farming operations (FORHEAD, 2014). Concentrating nutrient management in larger-scale farm operations will facilitate application of precision management techniques, investment in waste facilities (e.g., manure management systems), and will facilitate both provision of extension advice and monitoring of guidelines and regulations. Mechanisation associated with large holdings can address scarcities of agricultural labour that contribute to deficiencies in management of farm inputs. Furthermore, farmers are becoming ever-more self-organising, creating the potential for new institutions for agricultural and rural development (Huan et al., 2010). However, more research is required to understand the environmental impacts of production at different scales and in different management systems, with and without integration of crop and livestock production. More research is also needed into how supply chain coordination strategies can develop for different commodities in ways which can benefit farm incomes, consumer standards and the environment.

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