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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

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