Environmental Development 21 (2017) 52–65

Contents lists available at ScienceDirect

Environmental Development

journal homepage: www.elsevier.com/locate/envdev

Strategies for sustainable nutrient management: insights from a mixed natural and social science analysis of Chinese crop production systems

J. Bellarby[a], G. Siciliano[b], L.E.D. Smith[b,*], L. Xin[c], J. Zhou[e], K. Liu[d], L. Jie[c], F. Meng[d], A. Inman[b], C. Rahn[f], B. Surridge[a], P.M. Haygarth[a]

[a] Lancaster Environment Centre, Lancaster University, Bailrigg, Lancaster, UK
[b] Centre for Development, Environment and Policy, SOAS, University of London, London, UK
[c] Agro-Environmental Protection Institute, Ministry of Agriculture, Tianjin, China
[d] College of Resources and Environmental Sciences, China Agricultural University, Beijing, China
[e] College of Natural Resources and Environment, Northwest A & F University, Yangling, China
[f] Warwick Crop Centre, University of Warwick, Wellesbourne, Warwick, UK

ARTICLE INFO

Keywords:
Diffuse pollution
Nutrients
Systemic approaches
Extension
China

ABSTRACT

In China intensification of agriculture has been achieved at a cost to the environment. The extension service is the leading public resource to address this but remains focused by a historic national ethos for food security, production and economic growth, whilst its administrative structure is hierarchical, slow to change and lacking in relevant functional integration. Investigation of three case study farming systems identifies how to rebalance productivity with stewardship of farm inputs and natural resources. Substance flow analyses for each case demonstrate that crop nutrient management can potentially be improved to reduce environmental risk without yield loss. Complementary stakeholder surveys and social network analyses identify barriers to change relating to the knowledge, attitudes, practices and operational constraints of farmers and extension agents, and to the structure and performance of agricultural knowledge and innovation systems. This combination of analyses offers an original synthesis of needs, planning priorities and strategies.

1. Introduction

Losses of the primary macronutrients nitrogen (N) and phosphorus (P) from food production systems degrade water resources globally (Vorosmarty et al., 2010). Nutrient export from soils contributes to diffuse water pollution (Norse, 2005), and gaseous losses from inorganic fertilisers and manures also contribute to atmospheric pollution (Liu et al., 2011). For China there is accumulating evidence at plot scale (or aggregated for large areas) that inorganic fertiliser application is excessive and nutrient use efficiency is low in many farming systems (Foley et al., 2011; Ma et al., 2013a). Nationally, fertiliser use grew fourfold from 1978 to 2012 (FAOSTAT, 2015) and diffuse water pollution from agriculture (DWPA) has grown rapidly (Zhang et al., 2013; Ju et al., 2009); as evidenced by indicators of eutrophication in 80% of lakes and at least 40% of rivers (Liu and Yang, 2012), increased nutrient concentrations in groundwater and widespread soil acidification (Cui et al., 2014). In 2009, agriculture was estimated to be the source of 57% of the N and 69% of the P entering watercourses within China (MEP, 2010). Recently, Strokal et al. (2016) confirmed that inorganic fertiliser

* Correspondence to: Centre for Development, Environment and Policy, SOAS, University of London, 36 Gordon Square, London WC1H0PD, UK.
E-mail address: ls34@soas.ac.uk (L.E.D. Smith).

http://dx.doi.org/10.1016/j.envdev.2016.10.008
Received 25 August 2016; Received in revised form 24 October 2016; Accepted 25 October 2016
2211-4645/

use contributes significantly to river nutrient loads. The environmental costs of all this are difficult to quantify and disaggregate from non-agricultural causes, but indicatively the aggregate costs of all water pollution may approach two percent of national GDP (Sepa and Nsb, 2006; Guo, 2011).

Addressing sub-optimal management of inorganic fertilisers and manures would reduce these negative externalities and farm costs, and accord with national priorities (Garnet and Wilkes, 2014). For example, in 2015 the Ministry of Agriculture declared that annual growth in the use of inorganic fertilisers should be capped below one percent from 2015 to 2019, with zero growth from 2020 (Xu, 2015; SCMP, 2015). However, there is little evidence to date that improvements to nutrient management are being realised on a wide scale, and hence that high level policy pronouncements can be translated into action by many millions of farmers (Ma et al., 2013b). Policy needs to be informed by quantitative analyses of nutrient management within farming systems, particularly systemic analyses in which all significant nutrient flows and stocks within a system are considered (e.g. Senthilkumar et al., 2012). However, such quantification alone will not be sufficient to change the apparent inertia and economic non-rationality of excessive nutrient use on farms (Norse, 2005; Forhead, 2014; Holdaway, 2014).

The public agricultural extension system and farmer training are frequently recommended as means to change farmer behaviour in China (e.g. Guo et al., 2015; Huang et al., 2015). Yet, a combination of policies including regulation and incentives is likely to out-perform a single approach such as a fertiliser tax or farmer training alone (Weersink and Livernois, 1996; OECD, 2012). Farm advice provision is, however, important as it can facilitate compliance with regulation and adoption of improved technologies/practices and incentivised actions. Hence the functions of agricultural knowledge and innovation systems (AKIS)[1] are 'cross-cutting' and complementary and synergistic with other policy instruments.

To address this agenda this paper advances understanding of farmer behaviour in China through in-depth empirical investigation of selected farming systems representative of farming methods across large areas. For each case, systemic, quantitative analysis of nutrient management is combined with investigation of determinants of farmer attitudes and practices. The actions of, and information flows between AKIS actors need to be consistent and well-coordinated in order to delivery change and hence the structure and performance of the AKIS for each case are also holistically examined. Finally, comparative lessons are drawn from the case studies which suggest future directions for public policy for more sustainable nutrient management in Chinese agriculture.

2. Materials and methods

2.1. Case studies

Three case studies were selected to represent important crop production systems in China. With respect to their location (Fig. 1) these are referred to below as "Lake Tai", "Huantai" and "Yangling". They encompass arable and protected horticultural production systems of different spatial scales, and both groundwater- and surface water-dominated systems. They also span a spectrum in terms of agrarian structure and progress of land transfer.[2] This is important because in comparison to small farms, farm management decisions in consolidated units are usually made by fewer, more professional farm managers, with relative uniformity across a cultivated area.

The Lake Tai case study relates to a sub-catchment of the Li river and the village of Sandongqiao. The large and nearby Lake Tai is used for urban water supply and has suffered from well-publicised eutrophication, including algal blooms (e.g. Economist, 2008, 2010). This case is representative of the rice-wheat rotation that is common in southern and eastern China (Zou et al., 2005) and the major pathway for DWPA is through surface runoff. The case is also representative of medium to large scale village-based consolidated farming enterprises post land transfer.

The Huantai case study refers to a county in Shandong province. Rotational double cropping of maize and wheat is representative of farming across the North China Plain (Ha et al., 2015), and the major pathway for DWPA is pollutant leaching to groundwater. The case is also representative of small plot farming by individual farm households before land transfer.[3]

The Yangling case study relates to 36 solar greenhouses in Zaixi village near the city of Yangling. Solar greenhouses are widely used[4] for the production of vegetables in central and northern China (Bomford, 2010). A variety of crops are grown over two seasons, although tomato is the most common. The major pathway for DWPA is leaching to groundwater. A farmer usually cultivates one greenhouse with a standardised area of 672 m^2 (~1 mu). This is typical for this farming sector (Gao et al., 2012), although large-scale protected horticulture also exists in some locations.

2.2. Substance flow analysis

Substance flow analyses (SFAs) were constructed to quantify the stocks and flows of N and P at an annual time step for each case study. The SFA approach uses mass balance principles to systemically identify and quantify an element from source (here entry into the case study agroecosystem), through internal stocks and flows within a defined system boundary (each case study), to the final

[1] Defined as the set of organisations, institutions and actors that, through services to farmers, will exchange information and enhance farmer knowledge and skills, with the aim of enabling them to co-produce new knowledge and solutions (EU SCAR, 2012).

[2] Consolidation of small and fragmented land holdings, encouraged by government, and achieved through a range of rental and transfer arrangements (Huang et al., 2012; Smith and Siciliano, 2015).

[3] An average of 0.4 ha was recorded by our survey (details below).

[4] An area of 4.67 million hectares in 2010 (Gao et al., 2012); 4% of arable land in China (FAOSTAT, 2015).