Journal of Environmental Management 163 (2015) 146–154

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

The effect of simple nitrogen fertilizer recommendation strategies on product carbon footprint and gross margin of wheat and maize production in the North China Plain

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ARTICLE INFO

Article history:
Received 17 February 2015
Received in revised form
11 August 2015
Accepted 13 August 2015
Available online 28 August 2015

Keywords:
Nitrogen fertilizer recommendation strategies
Product carbon footprint
Gross margin
North China Plain

ABSTRACT

Overuse of nitrogen (N) fertilizer constitutes the major issue of current crop production in China, exerting a substantial effect on global warming through massive emission of greenhouse gas (GHG). Despite the ongoing effort, which includes the promotion of technologically sophisticated N management schemes, farmers' N rates maintain at excessive rates. Therefore the current study tests three simple and easily to apply N fertilizer recommendation strategies, which could be implemented on large scale through the existing agricultural advisory system of China, at comparatively low cost. Building on a detailed crop production dataset of 65 winter wheat (WW) and summer maize (SM) producing farm households of the North China Plain, scenario analysis is applied. The effects of the three N strategies under constant and changing yield levels on product carbon footprint (PCF) and gross margin (GM) are determined for the production condition of every individual farm household. The N fixed rate strategy realized the highest improvement potential in PCF and GM in WW; while the N coefficient strategy performed best in SM. The analysis furthermore revealed that improved N management has a significant positive effect on PCF, but only a marginal and insignificant effect on GM. On the other side, a potential 10% yield loss would have only a marginal effect on PCF, but a detrimental effect on farmers' income. With farmers currently applying excessive N rates as "cheap insurance" against potential N limitation, it will be of vital importance to avoid any yield reductions (caused by N limitation) and respective severe financial losses, when promoting and implementing advanced fertilization strategies. To achieve this, it is furthermore recommended to increase the price of fertilizer, improve the agricultural extensions system, and recognize farmers' fertilizer related decision-making processes as key research areas.

1. Introduction

Before the development and worldwide application of the Haber–Bosch process in the 1950s, nitrogen (N) was the major limiting nutrient in agricultural systems (Ma et al., 2008; Robertson and Vitousek, 2009). In China, which currently needs to feed 22% of the world's population on only 9% of the world's arable land, the widespread availability of N fertilizer has played a premising role for agricultural development and food security (Ma et al., 2014). However, in recent years N application rates in crop production have gone far beyond the agronomic and economic optimum, exerting a severe negative environmental impact (Huang and Tang, 2010; Chen et al., 2011). Apart from contamination of ground- and surface water, the N related massive emission of greenhouse gas (GHG) and consecutive contribution to global warming constitute a serious threat to sustainability in crop production. Zhang et al. (2013) estimated that about 7% of GHG emissions from the entire Chinese economy is N fertilizer related emission, while the contribution of synthetic fertilizer use to total GHG emission in EU-15 countries is only about 2% (European Environment Agency, 2014). Agricultural production, on one side a major contributor to global warming, is on the other side negatively affected by the consequences of climate change (Parry et al., 2004; IPCC, 2007a), with large areas of China being especially endangered (Wang and Watson, 2010).

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http://dx.doi.org/10.1016/j.jenvman.2015.08.014
0301-4797/

As China's granary, the North China Plain (NCP), dominated by the winter wheat (WW) and summer maize (SM) double-cropping system, is experiencing the overapplication of N fertilizers at an alarming rate (e.g. Chen et al., 2006b; Cui et al., 2008; Ma et al., 2008); e.g. Ju et al. (2009) reported a huge discrepancy between farmers' current N application rate (588 kg N ha^{-1}) and actually required N rate under good agricultural practice (286 kg N ha^{-1}). The mean N recovery rate, which indicates the share of applied N taken up by the crop, is rather low in the NCP with 33% in WW and 30% in SM Huang and Tang (2010) compared to global N recovery rates of 30–50% reported by Smil (1999) and Cassman et al. (2002).

As such, considerable research efforts are ongoing that aim at identifying potentials to reduce N application rates in the NCP. In field experiments a range of research groups successfully proved that significant reductions in N fertilization rates and related environmental impacts are possible without significant yield reductions (e.g. Chen et al., 2006b; Jia et al., 2014; Meng et al., 2012). In some first attempts of transferring those theoretical findings into crop production practice in the NCP, Huang et al. (2012) and Jia et al. (2013) reported limited success of training farmers in improved nitrogen management. Also Pan et al. (2014) identified only a marginally (1–4%) higher fertilizer use efficiency of Chinese farmers participating in fertilizer management training programs compared with non-participating farmers.

According to Cao et al. (2012) the failure of existing fertilizer recommendation schemes may for the major part be caused by an insufficient consideration of spatial and temporal variability in N demand and availability. Therefore the application of advanced technology, such as chlorophyll meter and GreenSeeker active crop canopy sensor to determine the crops' in-season N requirements are recommended to optimize N management of small scale farmers (Cao et al., 2012). Cui et al. (2008) proved the success of enhanced nitrogen management by in-season soil testing. Those two studies show that with the help of sophisticated N management schemes it is possible to accurately address the site-specific crop production conditions, at least when conducted and closely guided by researchers. However, under the given conditions of practical crop production in China such technology driven approaches may be inappropriate to successfully cope with the overfertilization issue within the next few years. Firstly, implementing N management schemes for more than 200 million small scale Chinese farmers is very costly (Huang et al., 2012). Considering the existing land fragmentation and soil quality disparity in Chinese crop production (Li et al., 2012), the required funds to implement frequent soil and plant N sampling on farm scale or even plot scale would exceed the existing extension budgets many times (Xu et al., 2014; Zhang et al., 2014). Furthermore, the N management schemes to be promoted need to build on the existing extension structure. With agricultural extension agents generally having a relatively low education level and limited training skills (Ma et al., 2014), the transfer of technologically sophisticated approaches to farmers constitutes a great challenge to the existing agricultural extension system (Hu et al., 2009).

There is an urgent need to identify approaches, which improve farmers' N management in an efficient and cost-effective way through the existing top-down oriented agricultural advisory system of China. Therefore the present study aims at testing the effect of three simple fertilizer recommendation strategies on WW and SM production in the NCP. The alternative N recommendation strategies are evaluated with regard to their environmental effect, represented by the product carbon footprint (PCF), as well as their economic effect, represented by the gross margin (GM), on farmers' WW and SM production. Scenario analysis is applied testing the effects of the three strategies under constant, as well as decreasing and increasing yield levels. Finally the relative advantages of the tested N fertilizer recommendation strategies are discussed and specific policy recommendations developed.

2. Materials and methods

2.1. Farm household survey

The present study builds on a primary survey dataset of 65 farm households from Quzhou county in Hebei province. Quzhou, located in the center of the NCP, is considered a typical county of the NCP with regard to its natural and socio-economic conditions; it has been frequently used to evaluate the prevailing WW–SM cropping system of the NCP (e.g. Chen et al., 2006a; Hu et al., 2013; Pan et al., 2014). The randomly selected households were interrogated on their WW and SM crop production using face-to-face interviews. Detailed crop management data, i.e. the individual farmer's input- and output-information as well as fertilization management practice during the 2009–2010 WW–SM growing season was collected, as shown in Table 1. To assess PCF and GM of grain production of the surveyed households, GHG emission factor[1] (EF) and market price of the respective inputs and outputs were obtained from peer-reviewed literature, the IPCC national inventory, the database of the life cycle assessment (LCA) software GaBi 5, national and provincial level statistical yearbooks, and other relevant reports provided by government agencies as summarized in Table 1.

2.2. Product carbon footprint and gross margin

The amount of GHGs emitted to produce one unit of a particular product is described by its PCF (BSI, 2008). In the present study, PCF was determined according to ISO 14040 (ISO, 2006) methodology by dividing the individual farm's calculated amount of GHG emission per hectare by its actual grain yield per hectare. The applied system boundary of GHG emission from the WW–SM production system in the NCP spans from resource extraction to farm gate as shown in Fig. 1. The functional unit was set as one kilogram WW/SM grain. Global warming potentials (GWP) assigned to carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions were taken from the IPCC guideline for national GHG inventories (IPCC, 2006).

The calculation of the household-specific total PCF entailed the pre-farm embedded and on-farm GHG emissions. Pre-farm embedded emissions are all GHG emissions released during the production process of farm inputs. On-farm GHG emissions include two parts; firstly all GHG emissions from soil related to fertilizer input and crop residue handling, and secondly all GHG emissions caused by agricultural machinery use and water management. The GHG emissions from soil related to fertilizer and crop residues comprise direct and indirect emissions from applied mineral and organic fertilizers as well as crop residues. CO_2 in the present study was considered as background emission, because the net emission of CO_2 caused by decomposition of organic matter and photosynthesis is negligible compared to its total cycling amount in agricultural cropping system (Snyder et al., 2009). Arable soils of the NCP are generally considered a light though insignificant sink of CH_4 (e.g. Hu et al., 2013; Liu et al., 2013; Tian et al., 2013). CH_4 was therefore excluded from the calculation of GHG emissions in this study. For the calculation of N_2O emissions, all N_2O related EFs, namely EF of N_2O emissions per unit of nitrogen input (EF_1), EF of N_2O emissions from atmospheric deposition (EF_4), leaching and

[1] EF is defined as the rate of emission per unit of activity, output or input (IPCC, 2007b).