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Original Articles

Agricultural subsidies assessment of cropping system from environmental and economic perspectives in North China based on LCA

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ABSTRACT

In China, government subsidies in the agricultural sector have played an important role in increasing grain production and supporting farming incomes. However, agricultural intensification has also led to concerns about environmental harm, especially on the North China Plain. In this study, life cycle assessment (LCA) was used to assess environmental impacts relating to the winter wheat-summer maize rotation system in the high-yielding and intensively cultivated Huantai County. Over the period 1996–2012, energy depletion potential, global warming potential, acidification potential and eutrophication potential all decreased both per t grain produced and per ha production area. However, water resource consumption, human toxicity potential, aquatic ecotoxicity potential and terrestrial ecotoxicity potential increased. The weighted environmental index, integrating all eight indicators into a single score, suggested that overall environmental impact had decreased by 15.2% per t of grain produced and 11% per ha cropped, largely as a result of improved management of N fertilizers as EP was identified as the most important environmental impact category. When human health impacts of emissions (assessed in DALYs) were monetarized, the life cycle environmental costs of both winter wheat and summer maize were also found to have decreased over time. Taking both the increased grain production and the reduction in life cycle impacts, the total life cycle environmental costs of grain production in Huantai County were found to have fallen from 16.6 million RMB.yr^{-1} to 12.8 million RMB.yr^{-1}, a decrease of 23.2%. These results suggest that production and welfare-oriented subsidies in the agricultural sector in China have generally brought about environmental co-benefits. Nevertheless, there is scope for ongoing environmental improvement, particularly in relation to pesticide use. With agricultural subsidies increasingly viewed as a means of achieving environmental goals, there is an ongoing role for LCA to evaluate the different types of environmental impacts. The coupling of LCA with monetarization tools also has potential for use in informing the design of environmental policy instruments in the agricultural sector.

1. Introduction

Cereal production and food security are important concerns across the world (Anderson and Strutt, 2014; Xue et al., 2014; Takeshima and Liverpool-Tasie, 2015). In China, the area of cereals harvested has remained relatively stable over recent decades, increasing only from 92.65 Mha (million hectare) in 1981 to now 95.92 Mha. However, in contrast, yields have almost doubled over this period from 3.09 t ha^{-1} to 5.98 t ha^{-1}. As a consequence, total cereal production has increased greatly from 286 Mt (million t) to 573 Mt (FAO, 2016), accompanied also by changes in farming systems and the consumption of fertilizers and other inputs. For example, chemical fertilizer consumption in China (including N, K_2O and P_2O_5) increased 3.35 times from 15.27 Mt in 1981 to 51.12 Mt in 2015 (IFA, 2016).

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In China, these long-term changes in agricultural production have taken place within the context of a wide range of government policies designed to promote agricultural development (Anderson and Strutt, 2014; Zhou and Zhang, 2013; Lopez et al., 2017). Support for new technology has included research, development and extension related to plant breeding, water-use-efficient irrigation and fertilizer management. For example, since 2005, soil testing has been emphasized with the goal of achieving both high grain yields and high nutrient use efficiency (Shen et al., 2013). In addition, in order to improve farming incomes and enthusiasm for grain production, the Chinese government has also abolished most agricultural taxes and introduced a range of subsidies. These subsidies have targeted grain producers both directly and indirectly. Indirect subsidies have been applied to purchases of agricultural inputs, new crop varieties, as well as agricultural machinery (Huang et al., 2013; Lopez et al., 2017).

The North China Plain (NCP) is a major grain producing region in China, accounting for 60–80% and 35–40% of the nation's wheat (*Triticum aestivum*) and maize (*Zea mays*) production, respectively (Liao et al., 2015). As such, the region makes a critical contribution to China's food security. Huantai County, in the central Shandong Province, is a typical agricultural region on the NCP, where the high-yielding and intensified winter wheat-summer maize rotation system (WMRS) is implemented on > 80% of cultivated lands. Towards the end of the 20th century, the local government in Huantai County began to promote conservation agricultural practices including crop residue retention to improve soil properties. The policy was supported by subsidies to farmers implementing these practices and rapid rates of adoption followed to the extent that ~90% of wheat and maize straw has been incorporated to farmland (S1). This occurred about 10 years earlier than in other parts of China. In the 1990s, the grain (wheat + maize) yields exceeded 15 t ha^{-1} yr^{-1} for all of its cropland, and the region came to be known as the "Granary of North Lu" (Zhang et al., 2017). Based on the statistical yearbooks of Huantai County, from 1981 to 2015, the total cropland area was relatively stable. However, the N input changed greatly, at first increasing from ~300 kg ha^{-1} yr^{-1} in 1981 to ~600 kg ha^{-1} yr^{-1} in 1994, and then gradually decreasing to 418 kg ha^{-1} yr^{-1} in 2015 (ZBSY, 2017). Apart from some irregular individual years, the yield per unit area and total yield has increased continually over the last thirty-five years (S2). In addition, the local government and China Agricultural University have also operated an experimental farm in the region which has been used to identify and promote improved fertilizer management (Wang et al., 2007; Liu et al., 2007; Chen et al., 2010; Liao et al., 2015, 2016; Zhang et al., 2017). Thus, Huantai County is highly representative of modern, high-yielding, intensive agricultural production in China.

However, with the success of policies aimed at increasing grain production in China, the environmental implications of agricultural intensification have now become a major cause of concern. This has resulted in a shift in focus toward subsidies that encourage farmers to reduce the negative externalities of agricultural production (Meng, 2012; Xue et al., 2014). However, compared to point source emissions in the industrial sector, non-point source emissions in the agricultural sector can be difficult to characterize in terms of environmental impact and it can be challenging to establish appropriate financial mechanisms to achieve environmental outcomes. Experts are divided about the environmental implications of past policies which have been designed to secure grain productivity. Meng (2012), Yu and Jensen (2010, 2014) and others have identified positive impacts. However, Yu et al. (2017), and Wu and Miao (2017) estimated that agricultural input subsidies have aggravated non-point source pollution.

Life cycle assessment (LCA) is a technique that can be used to systematically document resource use and emissions associated with a production system and to evaluate potential environmental impacts (ISO, 2006). Application of LCA in the agricultural sector has increased greatly over recent years (Noya et al., 2015; Wang, et al., 2015a; Bacenetti et al., 2016; Boone et al., 2016; Liang et al., 2018a,b). As for intensive crop production, at the global level Bennetzen et al. (2016) assessed greenhouse gas emissions over the period 1970–2007 and estimated a reduction of 39% per unit crop product but an increase of 15% per unit cultivated area. As for China, the LCA methodology has been used to assess the carbon footprints of rice, wheat and maize (Huang et al., 2017; Xu and Lan, 2017). Wang et al. (2015b) used the LCA methodology to assess the benefits of improving nitrogen and water management in cropland. In China, applications of LCA in the agricultural sector have tended to focus at the national scale and include only one or a few environmental indicators. Thus, in this research, LCA was used to assess the environmental impact of a long-term intensive cropping system on the NCP. The objectives were 1) to evaluate the change in impacts over time, and 2) to inform the design of an agricultural subsidy scheme designed to mitigate environmental harm from agricultural intensification.

2. Study area and method

2.1. Study area

The study was conducted in Huantai County of Shandong Province, which covers an area of almost 510 km^2. Huantai County is located in the NCP (N36.54° ~ N37.04°, E117.50° ~ E118.10°). The region has a typical continental monsoon climate, with an annual average temperature of 12.5 °C and an annual precipitation of around 540 mm. The predominant farming system involves cultivation of winter wheat and summer maize in an annual rotation (WMRS). For two decades, Huantai has exemplified the high-yielding WMRS which reflects intensified grain production practices in the NCP.

2.2. Life cycle assessment method

2.2.1. Data sources

Assessment of the impacts of intensive grain production in Huantai was undertaken by obtaining official records and survey documents of farming practices across the county over the period from 1996 to 2012. Some additional information, such as cropland area, annual nitrogen input and grain output from 1981 to 2015, came from governmental statistical data. In 1997 and 2013, China Agricultural University experimental station in Huantai County made twice-yearly investigations, and the surveys were conducted in the same three towns (Tangshan, Chenzhuang and Guoli) These towns represented a cross-section of higher and lower levels of economic performance across the County. Two villages were chosen randomly for each town and twenty households were chosen for each village to ensure that the results would be well balanced. The investigators used the same questionnaire which collected information about material and economic flows such as planting area, cultivar, use of fertilizers, irrigation, chemicals, electricity, and machinery, the cost of human labor, transportation, agricultural material inputs, selling prices for produce, subsidies received, etc. A description of the annual cycle of farming activities is shown in S3.

2.2.2. System boundary and functional unit

The goal and scope definition of an LCA includes a description of the product system in terms of the system boundary and functional unit (FU). In this study, one FU of analysis was the production of 1 t of wheat and maize under the WMRS, and the other FU was a hectare cropped for one year. The system boundary was cradle to farm gate (Fig. 1) and included two main subsystems: the agricultural materials production system (AMPS) and the arable farming system (AFS). The former included the production systems for fertilizers, pesticides, fuels and electricity, as well as the transportation to farm. The latter included sowing, irrigation, fertilizer application, plant protection, harvesting and drying processes. The inputs and outputs per ha of winter wheat and summer maize cultivation are presented in Table 1.