Environmental impacts and production performances of organic agriculture in China: a monetary valuation

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ABSTRACT: Organic agriculture has developed rapidly in China since the 1990s, driven by the increasing domestic and international demand for organic products. Quantification of the environmental benefits and production performances of organic agriculture on a national scale helps to develop sustainable high yielding agricultural production systems with minimum impacts on the environment. Data of organic production for 2013 were obtained from a national survey organized by the Certification and Accreditation Administration of China. Farming performance and environmental impact indicators were screened and indicator values were defined based on an intensive literature review and were validated by national statistics. The economic (monetary) values of farming inputs, crop production and individual environmental benefits were then quantified and integrated to compare the overall performances of organic vs. conventional agriculture. In 2013, organically managed farmland accounted for approximately 0.97% of national arable land, covering 1.158 million ha. If organic crop yields were assumed to be 10% to 15% lower than conventional yields, the environmental benefits of organic agriculture (i.e., a decrease in nitrate leaching, an increase in farmland biodiversity, an increase in carbon sequestration and a decrease in greenhouse gas emissions) were valued at 1921 million RMB (320.2 million USD), or 1659 RMB (276.5 USD) per ha. By reducing the farming inputs, the costs saved was 3110 million RMB (518.3 million USD), or 2686 RMB (447.7 USD) per ha. The economic loss associated with the decrease in crop yields from organic agriculture was valued at 6115 million RMB (1019.2 million USD), or 5280 RMB (880 USD) per ha. Although they were likely underestimated because of the complex relationships among farming operations, ecosystems and humans, the production costs saved and environmental benefits of organic agriculture that were quantified in our study compensated substantially for the economic losses associated with the decrease in crop production. This suggests that payment for the environmental benefits of organic agriculture should be incorporated into public policies. Most of the environmental impacts of organic farming were related to N fluxes within agroecosystems, which is a call for the better management of N fertilizer in regions or countries with low levels of N-use efficiency. Issues such as higher external inputs and lack of integration cropping with animal husbandry should be addressed during the quantification of change of conventional to organic agriculture, and the quantification of this change is challenging.

Keywords: organic agriculture; environmental benefits; crop yield; nitrogen fertilizer; economic value

1. Introduction

Chinese farmers have achieved harmonious coordination with nature over the past several millennia using traditional farming technologies (King, 1927; Ellis and Wang, 1997). From the 1970s to the 2000s, agriculture was intensified through farming practices of high-yield crop varieties and increasing reliance on irrigation and agro-chemicals. With the introduction of relevant laws, regulations and standards in 2005, organic agriculture in China has developed rapidly, driven by an increasing domestic demand (Guo and Zheng, 2011) and exportation to developed countries (CNCA, 2014). By the end of 2013, China became one of the largest organic producers worldwide (Willer and Lernoud, 2014) and is expected to see a rapid growth in organic agriculture in the future (CNCA, 2014).

Organic agriculture is a production system that sustains the health of the ecosystem and human beings by relying on processes and cycles of ecological biodiversity adapted to local conditions. External (synthetic) inputs are dramatically reduced in organic agriculture because of the prohibition of synthetic fertilizers, pesticides, and additives (IFOAM, 2014). Organic agriculture has been promoted as an environmentally friendly alternative to conventional agriculture (Giovannucci, 2006; De Schuter, 2010; The National Academies, 2010). Within the past decades, a multitude of studies have been undertaken to compare the performances of organic agriculture with that of conventional agriculture, in various dimensions. Generally, these studies have shown that organic agriculture performs better than conventional agriculture in most environmental aspects (Gomiero et al., 2008; Schader et al., 2012; Tuomisto et al., 2012; Meier et al., 2015), social well-being (Reganold and Wachter, 2016) and economic viability (Crowder and Reganold, 2015), although the crop yields are lower (Badgley and Perfecto, 2007; Kirchmann et al., 2008; De Ponti et al., 2012; Seufert et al., 2012). As the key function of agriculture is the production of food and fiber, one critical important question to be answered is: can the environmental benefits and production performances of organic agriculture compensate for its lower crop yields?

Instead of focusing on individual aspects, many comparative studies emphasized the importance of a comprehensive assessment, i.e., integrating the research from various related categories (Gomiero et al., 2008; Schader et al., 2012; Tuomisto et al., 2012; Reganold and Wachter, 2016). In 2005, the International Fund for Agriculture Development (IFAD) conducted a survey in China and India and concluded that organic agriculture could ensure long-term soil fertility, reduce external resource consumption and promote regional food security and poverty alleviation (Giovannucci, 2006). In UK, organic production mostly utilizes less energy than conventional production (except poultry and eggs), but organic production often results in increased burdens in greenhouse warming potential (GWP), acidification and eutrophication (Williams et al., 2006). In the studies mainly for European countries, Schader et al. (2012) concluded that organic agriculture has positive impacts on biodiversity, nutrients and energy efficiency, greenhouse gas (GHG) emissions, eutrophication, ammonia volatilization and soil biological activity. Reganold and Wachter (2016) found that the performances of organic agriculture were better than that of conventional agriculture in many ecological, social and economic dimensions, though not in crop yields. However, few of these studies were undertaken at a relatively larger spatial-temporal scale, such as by targeting a region or nation as the study context, and this has lowered the efficacy of transferring the research conclusions to policy making. In addition, the assessment impacts can be expressed either in physical (e.g., carbon (C) sequestrated) or monetary terms. In the communication of the assessment results to farmers, consumers and policy makers, the monetary approach is particularly useful because the environmental impacts can then be easily understood, aggregated and compared (Schader et al., 2012). Hence, as proposed and used in farming systems research (Pretty, 2000; Pizzol et al., 2015), a simple language, such as monetary value, can better quantify and compare the performances of organic and conventional agriculture.

Given China's rapidly growing economy and the need to protect the environment and enhance ecosystem services, development of sustainable agriculture, including organic agriculture, has become one of the nation's priority strategies (Ministry of Finance, 2015). According to the Organic Agriculture Development Report (CNCA, 2014), the area of organically managed farmland in China was 1.158 million ha in 2013. An integrated comparative study for organic production at this scale could provide support for sound decision making on agriculture development in China. The aims of this study are to 1) analyze the individual environmental impacts and production of organic agriculture across China as a whole in 2013 and 2) to quantify the environmental impacts and saved production costs in monetary terms and compare them with the economic losses due to crop yield decreases. In the discussion section, we analyze the methodological difficulties and uncertainties of the current study, while examining those implications from this assessment that should be incorporated into future agricultural research and development.

2. Materials and Methods

2.1 Theoretical framework and assessment indicator, boundary and unit

This study targeted the total certified organic farmland (arable land), including that in conversion, in China in 2013. As the relationship between an agricultural system and the environment is complex, we chose the Driver-State-Response (DSR) framework (van Huylenbroek et al., 2009), in which a social activity, agriculture in our study, is the "driving force" disturbing the environment. Agricultural functions can be categorized into four key metrics: productivity, environmental impact, social well-being and economic viability (Reganold and Wachter, 2016). Although evidence indicates that a greater social well-being is also delivered by organic agriculture than by conventional agriculture, this was not covered in our study because of lack of appropriate quantification methodologies considering the complexities between farming activities and social well-being, e.g., the social benefits of soil C sequestration (Pretty et al., 2000; Forman et al., 2012; Schader et al., 2012). For the economic viability category, as Crowder and Reganold (2015) highlighted in a global meta-analysis, the total and variable costs are not significantly different, except the higher costs of labor in organic agriculture, and higher use of synthetic fertilizers and pesticides in conventional agriculture. Based on a state-of-the-art literature screening, we selected the following assessment indicators for use in our comparison (Table 1): 1) inputs of synthetic fertilizers, pesticides, labor and energy; 2) agricultural production; and 3) environmental impacts of soil C sequestration, GHG emissions, biodiversity and nitrate leaching.

The use of various methodologies to assess farming systems make comparison among systems difficult. This is particularly true for determining farming system boundaries (Gomiero et al., 2011; Schader et al., 2012). For the system boundary, we analyzed only the production of organic crops because the organic livestock production is in the very early stages of development and total production quantity is low in China (CNCA, 2014). Although organic food/product processing is important throughout the entire food chain, particularly in life cycle assessment (LCA) studies (Ziesemer, 2007), the processing does not differ significantly from conventional processing in causing environmental impacts, except for the use of fewer additives and processing aids. Therefore, processing is not analyzed in most studies and nor was it in our study (Schader et al., 2012; IFOAM, 2014; Reganold and Wachter, 2016). Transportation stage was not included in the assessment because both organically and conventionally produced foods need to be transported from the farm gate to consumers, although transportation may account for a substantial proportion of the environmental impacts (Luo et al., 2011).

The farming performances and environmental impacts of agricultural activities can be expressed on the basis of different functional units: per unit of product or per unit of field area (Schader et al., 2012; Tuomisto et al., 2012). In our study, the performances and impacts were evaluated on a per ha of land area basis. Food production is the most important function of agriculture, and most of the environmental consequences are also from farmland use (Reganold and Wachter, 2016). This was particularly the case in our study (CNCA, 2014). It poses a daunting challenge to both feed a growing global population that is expected to reach 9 to 10 billion people by 2050 and provide long-term protection for the environment (Pimentel and Wilson, 2004). With land resources finite and scarce, agriculture and food production must compete with other land uses (e.g., housing and industry). When performances and environmental impacts are expressed per unit area, policy-makers can account for differences in land use efficiency (Gomiero et al., 2008, 2011; Schader et al., 2012).

2.2 Data collection for organic production in China

Data were obtained from a 2014 survey organized by the Certification and Accreditation Administration of China (CNCA) for all certified organic farms and enterprises, which is accessible in the Food and Agro-product Certification Information of China System (FACICS, http://food.cnca.cn). The data were current as of Dec 31, 2013, and included the certified (organic and in conversion) acreage of farmland, production quantity and marketing price of the products. Hong Kong, Macao and Taiwan were not included in the survey. The organic products were grouped into categories of vegetables, fruits, tea, soya and other beans, cereals and others, according to the CNCA survey (CNCA, 2014).

2.3 Quantification of economic value of farming performance and environmental impact

Indicator values of farming performance and environmental impact (the differences between organic and conventional agriculture per ha of farmland area) were collected from the global literature, governmental data sets and our own studies (detailed in the following parts and Table 1). For the impact/performance pricing, we used commonly accepted methods in ecosystem service studies (D'Amato et al., 2016), i.e., the market price and avoided cost method, to produce a general approximation of the monetary value of provisioning services, production and inputs for organic agriculture and then compared these approximations with those for conventional agriculture. The market price method is applicable to crop products, synthetic fertilizer and pesticide inputs, labor, energy and reduced GHG emissions. The cost-based (or avoided costs) method is based on the costs avoided from environmental impacts or those required to restore certain ecological services; for example, the cost of nitrate treatment is the “monetary value” for nitrate pollution. Similarly, we determined the price for farmland biodiversity (Pretty et al., 2000; Sandhu et al., 2010).

For the economic (monetary) values of the farming performances and environmental impacts between organic and conventional agriculture at the national level, the area of organic arable land was multiplied by the price for each performance or impact indicator. Then, we summed the economic values of each individual performance or impact to quantify 1) the input costs, which included synthetic fertilizers, pesticides and energy, 2) the economic value losses due to crop yield decreases, and 3) the environmental impacts, which included C sequestration and GHG emissions, nitrate pollution and farmland biodiversity. In our study, the quantified economic values were for December, 2013 and were not adjusted for purchasing power parity or inflation.

2.3.1 Farming inputs I: Synthetic fertilizers and pesticides

In organic agriculture, the use of synthetic fertilizers and pesticides is prohibited and the costs are thereby saved compared with conventional agriculture. For the conventional production of vegetables, fruits and tea, we collected the average fertilizer and pesticide input rates from published studies (Ma et al., 2000; Hao and Jiang, 2001; Guo, 2007; Huang et al., 2009; Guo and Guo, 2010; Zhang, et al., 2011; Zhu et al., 2013; Ruan and Wu, 2001), which were validated based on national datasets (http://data.stats.gov.cn, accessed on Nov 18, 2014; National Bureau of Statistics of China, 2014; Tables 2 and 3). For the conventional production of cereal, soya, beans and other crops, we obtained the national average input rate and the price of fertilizers and pesticides in 2013 from governmental data sets (http://data.stats.gov.cn/easyquery.htm?cn=C01, accessed on Nov 18, 2014; National Bureau of Statistics of China, 2014).

2.3.2 Farming inputs II: Energy

For organic and conventional production, the input of direct energy (oil, electricity, etc.) on an area-unit basis is similar because most of the energy-consuming field operations are the same (Halberg, 2008). The energy consumed in synthetic fertilizer manufacturing is the largest energy difference between organic and conventional agriculture (Halberg, 2008; Tuomisto et al., 2012) and included in the study. The energy parameters for synthetic fertilizer use were obtained from Brentrup and Pallière (2008).

2.3.3 Crop production

Globally, the yields of organic crops are 15% to 50% lower than the conventional yields (Badgley and Perfecto, 2007; Kirchmann et al., 2008; Gomiero et al., 2011; Seufert et al., 2012); however, the context is very important in interpreting yield differences. For vegetables and fruits, the yield differences between organic and conventional farms were lower than those for other crops because vegetables and fruits are more sensitive to the balanced nutrient supply that results from the higher soil organic matter content in organic fields than in conventional fields (Tuomisto et al., 2012), although Seufert et al. (2012) found the opposite result. In China, certified organic farms rely heavily on organic fertilizer inputs, so there was a smaller yield difference between organic and conventional agriculture (Oelofse et al., 2010). Based on the literature analysis above, we set the yield decrease between organic and conventional agriculture at 10% for vegetables, fruits and tea and at 15% for all other crops (Table 4). The market prices for organic and conventional products were collected from the FACICS system (http://food.cnca.cn).

2.3.4 Environmental impact I: Soil C sequestration and GHG emissions

Compared with conventional agriculture, organic agriculture exhibits soil C sequestration and reduces GHG emissions. As indicated in the energy section, the energy use is similar in organic and conventional farming systems; hence, we only considered the increase in soil organic carbon (SOC) and the decreases in N_2O and CH_4 emissions. The SOM (or SOC) is higher in organic than in conventional farming systems by 3% to 23% (Tuomisto et al., 2012), or 0.45 ± 0.21 t C ha^{-1} yr^{-1} (Gattinger et al., 2012). From a meta-analysis of long-term experimental studies in China (Wang et *al.*, 2010), organic and chemical fertilizers increase the SOC compared with pre-experiment levels at rates of 0.24 and 0.11 t C ha^{-1} yr^{-1}, respectively, indicating that approximately 0.13 t C ha^{-1} yr^{-1} is sequestered in soils via organic farming operations. Because the organic manure input and crop residue incorporation are much higher in vegetables, orchards and tea gardens than those in croplands, we estimated that the increases in the SOC stock were 0.6, 0.5 and 0.5 t C ha^{-1} yr^{-1}, respectively (Jin, 2008). The SOC also increases in conventional agriculture when organic manures and crop residues are recycled. However, due to the lower proportion of recycled organic materials within farming systems (including organic farm) in China (Liu et al., 2008), we assumed that 1/3 of the organic materials in organic agriculture were recycled, whereas no recycling occurred in conventional agriculture.

Consequently, the above SOC sequestration rates for organic farming were multiplied by 1/3. The emissions of GHGs (N_2O and CH_4) are similar or higher (Tuomisto et al., 2012; Skinner et al., 2014) in organic farming, compared with those in conventional farming. Considering the high external nitrogen (N) input in organic agriculture in China (Oelofse et al., 2010) and the high heterogeneity and uncertainty in GHG measurements (Skinner et al., 2014), we considered only the reductions in GHG emissions caused by the non-use of chemical fertilizers in organic farming (Zhang et al., 2013) (Table 5). We set the price of C sequestered or reduced CO_2 emissions at 75 RMB t^{-1} CO_2-eq (or 12.5 USD according to the exchange rate (1 USD=6 RMB) in Dec, 2013) according to the average price from Nov 1 to Dec 31, 2013 (http://www.tanjiaoyi.com, accessed on March 1, 2016), on the Shenzhen Carbon Trading Market, the first national carbon market in China.

2.3.5 Environmental impact II: Farmland biodiversity

Biodiversity is the number, variety and variability of living organisms in an environment (Gomiero et al., 2011), which is commonly higher under organic farming than in conventional farming systems (Du et al., 2004; Wang et al., 2007; Lynch, 2009; Mondelaers et al., 2009; Wang et al., 2012; Schader et al., 2012; Reganold and Wachter, 2016). A high biodiversity improves ecosystem services, including the biological control of pests, the formation of soils and the mineralization of nutrients. Cobb et al. (1999) attached a price of £23 to £130 ha^{-1} yr^{-1} to the value of the additional biodiversity and countryside amenity of organic agriculture under the UK agri-environmental policy inducement. Using the market price and avoided cost methods, Sandhu et al. (2010) quantified the economic value of these ecosystem services in organic farming at 37 USD ha^{-1} yr^{-1} higher than conventional farming. We adopted this value for croplands (240 RMB, or 40 USD ha^{-1} yr^{-1}), with the vegetable and fruit and tea farm values set at 325 RMB (54.2 USD) and 260 RMB (43.3 USD) ha^{-1} yr^{-1}, respectively (Table 6).

2.3.6 Environmental impact III: Nitrate leaching

Because the N input is lower in organic form, the N surplus and therefore nitrate leaching is lower in organic farms than in conventional farms (Hansen et al., 2000; Xi et al., 2010; Ning et al., 2011; Meier et al. 2015). Globally, the average nitrate leached from organic farmlands is approximately 10-30 kg N ha^{-1} yr^{-1} lower than that leached from conventional farmlands

(Torstensson et al., 2006; Bergström et al., 2008; Meng et al., 2014). In China, conventional farming is being intensively operated with high rates of fertilizer and irrigation, which leads to high levels of N leaching, e.g., 24 (wheat season) and 65 kg N ha^{-1} (maize season) reported (Chen et al., 2014). For similar intensive organic production in China, less nitrate may be leached because of lower rates of N input and the increase in cropping rotations. Therefore, based on the above intensive analysis, we set the difference in nitrate leaching between organic and conventional farming at ca. 10 (crop), 15 (tea and fruits) and 20 kg N ha^{-1} yr^{-1} (vegetables) (Table 7). Based on studies in China (Zhang et al., 2013; Ma et al., 2015), the pollution control costs for nitrate-polluted water are from 0.6 to 7 RMB m^{-3} yr^{-1}, with a reduction in total nitrate from 40 to 60 to < 10 mg N L^{-1} that is equivalent to 20 to 210 RMB kg^{-1} N yr^{-1}. For the treatment of water polluted with leached nitrate in this study, we set the price at 100 RMB (16.6 USD) kg^{-1} N yr^{-1}.

3. Results

By the end of 2013 in China, 1.158 million ha were devoted to organic farmland, including 0.588 million ha of cereals, 0.236 million ha of soya and other bean crops, 0.211 million ha of fruits, 0.048 million ha of vegetables, 0.053 million ha of tea and 0.022 million ha of other plants (Table 2). Organically managed farmland accounted for 0.97% of the total farmland in China.

3.1 Farming inputs and economic values

- Pesticides saved: In organic agricultural production, the pesticide saved was approximately 3 million tons in 2013 (Table 2), and the associated economic value was 899 million RMB, or 149.8 million USD.
- Synthetic fertilizer saved: In organic farming, synthetic fertilizers are not used. The amounts of urea, diammonium phosphate and potassium chloride saved were $467*10^3$, $353*10^3$ and $260*10^3$ t, respectively. The total costs saved was 2211 million RMB, or 368.5 million USD (Table 3).
- Reduction in energy consumption: The reduction in fertilizer use in 2013 in organic farming was $467*10^3$ t of urea, $353*10^3$ t of diammonium phosphate and $260*10^3$ t of potassium chloride, which were equivalent to energy savings of 12,000, 2000 and 1200 TJ, respectively. The total direct energy saved was estimated at approximately $508*10^3$ t of standard coal equivalent. We used the conversion of 1 t of raw coal = 0.7143 t of standard coal and a raw coal price of 500

RMB t^{-1}; consequently, the cost saved was 356 million RMB, or 59.3 million USD. However, because the cost saved of synthetic fertilizer was already quantified above, it was not included in the calculation of total farming input cost savings.

3.2 Economic value of crop production decreases

Compared with conventional farming, the decrease in the total economic value caused by the lower levels of production in organic farming was 6115 million RMB (1019.2 USD), which included 1296 million RMB for vegetables, 2114 million RMB for fruit, 198 million RMB for tea, 485 million RMB for soya and other bean crops, 1725 million RMB for cereals and 297 million RMB for other crops (Table 4).

3.3 Economic value of environmental impacts

- C sequestration and GHG emissions reduction: In organic farming, the C sequestration and the direct plus indirect reductions in N_2O emissions were calculated to be $314*10^3$ and $3.63*10^6$ t CO_2-eq yr^{-1}, respectively. The total economic value was 296 million RMB, or 49.3 million USD (Table 5).
- Increase in ecosystem services due to improved farmland biodiversity: the economic value was estimated at approximately 287 million RMB, or 47.8 million USD (Table 6).
- Reduction in nitrate leaching: in 2013, the reduction in nitrate leaching was approximately 13,380 t as a result of organic agriculture, and the associated economic value was estimated at 1338 million RMB, or 223 million USD (Table 7).

The economic costs saved in farming inputs because of the adoption of organic agriculture in 2013 was 3110 million RMB (518.3 million USD), of which pesticides and synthetic fertilizers accounted for 28.9% and 71.1%, respectively (Tables 2 and 3). The monetary value of the environmental benefits of organic agriculture in 2013 was estimated at 1921 million RMB (320.2 million USD), of which the reduction in nitrate leaching, carbon sequestration and GHG emission and farmland biodiversity enhancement accounted for 69.7%, 15.4% and 14.9%, respectively (Tables 5, 6 and 7). The total economic value due to the implementation of organic agriculture, i.e., cost saved in farming inputs and environmental benefits, amounted at 5031 million RMB (838.5 million USD), or accounted for 82.3% of the total economic losses due to crop yield decrease (6115 million RMB, or 1019.2 USD; Table 4).

4. Discussion

4.1 Methodological difficulty and uncertainty analysis

Finding appropriate methods for comparing agricultural systems is more difficult than for many other goods and services due to the high variations in the study goal and natural and social contexts (Schader et al. 2012). For our study, we tried to quantify the production performances and environmental impacts on the basis of a unit of area, i.e., for the 1.158 million ha of organic farmland in China. The different performances and impacts that occurred in these organic farmlands, compared with the scenario of conventional agriculture, were mostly identified and determined (Table 1). Our quantification results sensitively identified the magnitudes of individual elements and their performances and the impacts between organic and conventional agriculture (see Results section), indicating that our valuation was appropriate.

There are several sources of error and uncertainty in our study. First, the unavailability or high variations of data: this occurred mainly for the indicator values that were adopted. For each indicator, we undertook a global literature study, identified the range of indicator values and set an appropriate value within the Chinese agricultural context. The soil C sequestration rate, for example, was corrected by the low proportion of organic materials cycling in organic and conventional agriculture in China (multiplied by 1/3). Second, some indicators were not included in the current study, e.g., higher labor costs in organic agriculture (Crowder and Reganold, 2012). We assumed that these higher labor costs are largely equalized by the higher incomes within an organic farm, hence there is no need to consider this indicator in the study. Some of the health benefits of organic farming, including the lower contamination of drinking water by pesticides and safer foods because of the prohibited use of chemicals, were not considered because of the complicated relationship between health and pesticide applications and the lack of appropriate methods for quantification (Tuomisto et al., 2012). This is in line with the findings of Pretty et al. (2000), that the total positive externalities leading to the environmental benefits were likely underestimated in most comparative studies, and they asked for more observations and studies in the future (Schader et al., 2012). The other uncertainty is the crop yield decrease of organic agriculture. In organic agriculture, the use of chemo-synthetic fertilizer (e.g., N) is not allowed (IFOAM, 2014). On a large scale, for instance, in the entire country of China, some farmland must be used for biological N fixation to provide the essential N for crop production

(De Ponti et al., 2012). Then, the decrease in crop yield for organic farming was likely much higher than the 10-15% scenario set in our study. If the crop yield decrease was doubled from 10-15% to 20-30%, this total economic loss would increase from 6115 million RMB (1019.2 million USD) to 14,237 million RMB (2372.8 million USD), or from 5280 RMB (880 USD) to 12294 RMB (2049 USD) ha^{-1}. This means that organic agriculture has the pressure of increasing crop yield, or we should shift the allocation of crops from animal feed and biofuels toward more direct means of feed the human population (Emily et al., 2013).

4.2 Provision of environmental benefits by organic agriculture

In our study, total environmental benefits and production costs saved of organic agriculture accounted for 82.3% of the total economic losses due to crop yield decrease. The environmental benefits of organic agriculture were quantified at 1659 RMB (276.5 USD) ha^{-1}, approximately 31% of the total economic value of the crop yield decrease (5280 RMB, or 880 USD ha^{-1}). This indicates that organic agriculture could substantially compensate for the economic value loss caused by the crop yield decrease.

These environmental benefits gained by organic farming, or rather interpreted as the environmental costs caused by conventional farming, could be covered with payments, from the buyer/consumer, i.e., price premiums, or by fines issued to the producer/farmer (Zhang, 2011). European countries have pioneered compensation for organic farmers since the 1990s (Schwarz et al., 2010; Directorate-General for Agriculture and Rural Development, 2010; Xie and Zhou, 2013). Subsidy policies, introduced in European Council regulation (ECC) 797/8520, have been fully operational in the Common Agricultural Policy of the EC since 1992. From 2000 to 2007, the subsidy for organic farms was 72 euros per hectare. The subsidy facilitated the expansion of organically managed land in EU countries and improvement of agri-environmental quality (Schwarz et al., 2010). Although there are some subsidies for organic certification (Scott et al., 2014) and some proposed payments for C sequestration and GHG emission reductions in China (Ministry of Finance, 2015), a systematic financial package for the environmental benefits of organic agriculture has not been enacted.

Paying for the environmental benefits through price premiums or other feasible approaches, will benefit the whole of society and humans in the long term (Lu et al., 2015). The investigation conducted by CNCA (2014) found that 51% of the organic farms interviewed were profitable.

Given the overall lower crop yields (10% to 15%) in organic agriculture, at least a similar level of price premiums is needed for organic farmers to achieve similar financial rewards for those of conventional farmers, assuming that the costs per unit product are similar for organic and conventional farms. In practice, however, the direct production cost of organic products is higher than that of conventional products (CNCA, 2014) because of the increased labor costs due to the rapid industrialization process in China in recent years (Li et al., 2012). We, therefore, suggest that payment for the environmental benefits of organic agriculture should be incorporated into public policies, to encourage agriculture to move towards truly sustainable production systems.

4.3 Implications for conventional agriculture

As highlighted in section 3.3, the environmental cost of conventional agriculture in China may be significantly reduced if the 1.158 million ha of arable land was organically farmed. This can be also interpreted that conventional agriculture requires an improvement, e.g., ecological intensification (Bommarco et al., 2013). Although organic agriculture has an untapped role in the establishment of sustainable farming systems, a blend of organic and other innovative systems or the ecological intensification of conventional farming provides a good option (Matson et al., 1997; Cassman, 1999; Bommarco et al., 2013; Lu et al., 2015; Regaold and Wachter, 2016). In China, the improvement of agriculture practices has been accepted and implemented in recent decades (Chen et al., 2014; Liao et al., 2015) and will be further promoted (Political Bureau of the Central Committee of the CPC, 2015). The quantitative assessment in our study would work as an illustration of the potential that may be expected from a change conventional to organic agriculture or optimization of conventional agriculture. As most organic operations certified in China (CNCA, 2014) are stockless and fertilized with high levels of external nutrients (Oelofse et al., 2014), it is essential to integrate cropping with animal husbandry for both organic and conventional agriculture, to increase the nutrients and energy efficiency. This means that these issues should be addressed during the quantification of change of conventional to organic agriculture, and the quantification of this change is particularly challenging.

Among the environmental performances analyzed in this study, the reduced use of N fertilizers, leading to reductions in N_2O emissions and NO_3 pollution, produced more than 84% of the total environmental benefits. This finding is consistent with most studies (Tuomisto et al., 2012), which concludes that the most critical agricultural environmental impacts are related to N fluxes. Thus, although N fertilizers have contributed greatly to the increases in the world grain supply (Erisman et al., 2008), its negative impacts can no longer be neglected. Increases in N-use efficiency and decreases in N losses, particularly with the recycling of agricultural wastes within agroecosystems, must be the priorities for conventional agriculture in China (Chen et al., 2014). Recent studies by Steffen et al. (2015) also noted that in China, some agricultural regions need to decrease the very high N application rates to simultaneously boost crop production and reduce the negative environmental impacts.

5. Conclusions

In our understanding, this is the largest and the first national-level study to economically quantify the farming performances and environmental impacts of organic agriculture. The saved farming input costs and the environmental benefits of organic agriculture, when quantified as monetary values per unit of land area, substantially compensated for the economic losses associated with the decrease in crop yield. Most of the environmental impacts were related to the N flux within agroecosystem, which is a call for the better management of N fertilizer in regions or countries with low levels of N-use efficiency. This study likely underestimated the total positive environmental impacts of organic agriculture because some environmental benefits, such as the lower pesticide contamination of drinking water and foods, were not included in our analyses. The implications of our research highlight the requirement for the ecological intensification of conventional agriculture, particularly in the integration of crop production with animal husbandry. This study strongly suggests more additional long-term observations and studies of organic and conventional agriculture under different natural conditions and management practices.

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Table 1 Impact indicators adopted in the comparison of organic (ORG) and conventional agriculture (CON)

Impact category	Impact indicator	Indicators adopted in this study	Rationales	Studies referred
Economic viability				
Fixed costs	Fixed costs: house, road, etc.	No	No differences between ORG and CON.	Crowder and Reganold, 2015
Variable costs	Purchased fertilizer	Yes	Manure and N fixation are recycled within ORG. Synthetic fertilizer was purchased in CON.	Meier et al., 2015; Crowder and Reganold, 2015
	Purchased pesticide and other pest control materials	Yes	In ORG, pest control materials accounted for a small proportion of the variable costs, so were not considered. Chemical pesticide was purchased in CON.	Meier et al., 2015; Tuomisto et al., 2012; Crowder and Reganold, 2015
	Energy: electric power, oil, etc.	Yes	Similar for ORG and CON.	Halberg, 2008; Crowder and Reganold, 2015
	Labor	Yes	Higher labor costs but could also provide benefits (increasing employment) to social well-being in ORG. Labor costs are also quite variable depending on social and natural conditions. Herein quantified as neutral and no difference between ORG and CON.	Halberg, 2008; Crowder and Reganold, 2015
	Seeds, etc.	No	No differences between ORG and CON.	
Productivity	Yield	Yes	Key function of agriculture.	Badgley and Perfecto, 2007; Kirchmann et al., 2008; Gomiero et al., 2011;Seufert et al., 2012
Environmental impacts	C sequestration	Yes	Higher soil C due to higher organic materials recycled or input within ORG.	Tuomisto et al., 2012; Gattinger *et al*., 2012
	GHG emission	Yes	Less indirect N_2O emissions in ORG caused by no synthetic fertilizer inputs. Direct N_2O and	Tuomisto et al., 2012; Skinner et al.,

			CH_4 emission were considered to be similar for ORG and CON.	2014
	Nitrogen leaching	Yes	Nitrate leaching may cause eutrophication and resource (N) and energy waste. Less nitrate leaching in ORG due to no synthetic fertilizer inputs.	Torstensson et al., 2006; Bergström et al., 2008; Schader et al. 2012; Meier et al., 2015
	Biodiversity	Yes	Beneficial effects on fauna and flora, landscape and ecosystem functions due to no synthetic fertilizer and pesticide applied and the use of environmental friendly farming measures (e.g., rotation).	Lynch, 2009; Mondelaers et al., 2009; Schader et al., 2012; Reganold and Wachter, 2016
	Ammonia emissions	No	Few studies, and a study also found that it was almost equal in the two farming systems. Higher NH3 emissions are mostly found in organic animal production rather than in conventional animal production. Organic crop production in China has a high organic fertilizer input, a similar level to conventional crops, so the NH_3 emissions should be similar.	Oelofse et al. 2010; Schader et al., 2012; Tuomisto et al., 2012
	Phosphorus losses	No	Compared with N, phosphorus leaching and erosion are negligible and are even lower in the organic system. Most studies concluded that organic and conventional agricultures have similar phosphorus losses.	Mondelaers et al., 2009; Schader et al., 2012; Tuomisto et al., 2012
	Energy use	Yes	Considered in economic viability.	
	Land use	No	Environmental impacts, productivity and inputs are assessed per area unit. Not applicable.	
Social well-being	Social well-being	No	Lack of appropriate methodologies due to the complex relationships between farming activities and social well-being.	Pretty et al., 2000; Forman et al., 2012; Schader et al., 2012

Table 2 Reduction of pesticide use in organic agriculture

	Organic farmland	Rate of pesticide use in conventional farming†	Price of pesticide	Economic value of reduction in pesticide use in organic agriculture
	×10^3 ha	kg ha^{-1}	RMB kg^{-1}	×10^6 RMB
Vegetables	48	4	300	58
Fruits	211	6	300	380
Tea	53	5	300	80
Soya and other beans	236	1.5	300	106
Cereals	588	1.5	300	265
Others	22	1.5	300	10
Total	1158			899

† Data from the National Agricultural Standard of the Ministry of Agriculture (2002).

Table 3 Reduction of synthetic fertilizer use in organic agriculture

	Organic farmland	Rate of chemical fertilizer use in conventional agriculture			Equivalent amount of reduction in commercial fertilizer use†			Economic value of reduction in fertilizer use††
		N	P_2O_5	K_2O	Urea	Diammonium phosphate	Potassium chloride	
	$\times 10^3$ ha^{-1}	kg ha^{-1}			$\times 10^3$ t yr^{-1}			$\times 10^6$ RMB
Vegetables	48	375	235	253	32	23	22	157
Fruits	211	330	210	200	122	94	76	599
Tea	53	536	68	53	59	9	5	116
Soya and other beans	236	98	160	75	22	81	33	338
Cereals	588	213	115	114	226	145	122	983
Others	22	150	60	50	6	2	2	18
Total	1158				467	353	260	2211

† Nutrient contents: urea (N 45%), diammonium phosphate (N 16%, P_2O_5 47%), and potassium chloride (55%).

††Prices of urea, diammonium phosphate and potassium chloride were 1350, 3000 and 2000 RMB t^{-1}, respectively.

Table 4 Decrease of crop production in organic agriculture

	Organic production	Decrease in organic production compared with conventional farming†	Price of organic products††	Economic value of decrease in organic production
	×10^6 kg	×10^6 kg	RMB kg^{-1}	×10^6 RMB
Vegetables	726	81	16	1296
Fruits	1363	151	14	2114
Tea	103	11	18	198
Soya and other beans	549	97	5	485
Cereals	3260	575	3	1725
Others	155	27	11	297
Total	6156	943		6115

† Compared with conventional farming; yield decrease of organic farming was set to 10% for vegetables, fruits and tea and 15% for all other crops.

†† Data were collected from the Certification and Accreditation Administration of China (CNCA) in 2014.

Table 5 C sequestration and GHG emission reduction in organic agriculture

	Reduction in fertilizer use			Direct and indirect N_2O reduction†	Organic farmland	Soil C sequestration††	Economic value of C sequestration and N_2O reduction †††
	N	P_2O_5	K_2O				
	10^3 t yr^{-1}			$\times 10^3$ t CO_2-eq yr^{-1}	$\times 10^3$ ha^{-1}	$\times 10^3$ t CO_2-eq yr^{-1}	$\times 10^6$ RMB
Vegetables	18	11	12	246	48	35	21
Fruits	70	44	42	955	211	124	81
Tea	28	4	3	367	53	31	30
Other crops	151	107	86	2064	846	124	164
Total	267	166	143	3632	1158	314	296

† According the IPCC Tier 1, the default emission factor, or direct emission, of N fertilizer when applied to the soil was set at 1% (100 kg N fertilizer emits 1 kg N_2O-N). The GWP effect of N_2O is 298-fold that of CO_2 for a 100-year timeframe (IPCC, 2007). The emission of GHGs during fertilizer manufacture, transportation and application (indirect) was set as 8.3 kg CO_2-eq kg^{-1} N, 0.59 kg CO_2-eq kg^{-1} P_2O_5 and 0.47 kg CO_2-eq kg^{-1} K_2O (Smith et al., 2010).

†† The SOC sequestration rate was set as 0.20, 0.16, 0.16 and 0.04 t C ha^{-1} for land used for vegetables, orchards, tea gardens and other crops, respectively.

††† Price of GHG emission reduction was set as 75 RMB t^{-1} CO_2-eq.

Table 6 Farmland biodiversity enhancement in organic agriculture

	Organic farmland	Unit value of increase in ecosystem services	Economic value of increase in ecosystem services
	$\times 10^3$ ha	RMB ha^{-1}	$\times 10^6$ RMB yr^{-1}
Vegetables	48	325	16
Fruits	53	260	14
Tea	211	260	55
Other crops	846	240	203
Total	1158		287

Table 7 Reduction of nitrate leaching in organic agriculture

	Unit reduction of nitrate leaching	Organic farmland	Total reduction of nitrate leached	Economic value†
	kg N ha^{-1} yr^{-1}	$\times 10^3$ ha	$\times 10^3$ kg N yr^{-1}	$\times 10^6$ RMB yr^{-1}
Vegetables	20	48	960	96
Fruits	15	53	795	79.5
Tea	15	211	3165	316.5
Other crops	10	846	8460	846
Total			13380	1338

† Price of nitrate removal from water bodies was set at 100 RMB kg^{-1} N yr^{-1}.