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Environmental impact assessment of organic and conventional tomato production in urban greenhouses of Beijing city, China

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ABSTRACT

Urbanization has contributed to rapid development of greenhouse vegetable production in Northern China resulting in negative environmental impacts caused by the overuse of agricultural inputs. A shift towards organic consumption and production has been promoted as one of the potential solutions to this challenge. Early indications for such a shift can already be observed in many major Chinese cities. In this paper, a life cycle assessment (LCA) approach was used to examine the environmental impacts of organic and conventional production of tomatoes in greenhouses in suburban Beijing, China. Results showed clear environmental benefits associated with a 54.87% lower environmental impact index for organic tomato production compared to its conventional counterpart. For the organic system, eutrophication and soil eco-toxicity contributed the most with 56.39% and 37.87%, respectively, mainly due to manure application. For the conventional system, aquatic eco-toxicity ranked first with 59.45%, followed by eutrophication (25.70%) and soil eco-toxicity (12.12%) – mainly due to the application of chemical pesticides and fertilizers. The results of the LCA analysis suggest a positive environmental evaluation of current trends towards organic production and consumption in urban China. However, the implications of accompanying trends towards direct, cold chain delivery as well as greater land demands within the organic system should be considered. Also, more effort should be made to help organic farmers to apply organic fertilizers more efficiently in order to reduce remaining significant soil eco-toxicity impacts from manure application.

1. Introduction

Urbanization has contributed to rapid development of greenhouse vegetable production in Northern China to improve the quality and quantity of the produce. The total area of protected vegetable cultivation estimated to be approximately 3200 ha in Beijing in 2013 (Beijing Statistical Yearbook, 2014). Among that, tomato is one of the most widely grown vegetables, which is typically produced in poly-tunnel greenhouses, occupying more than 2133 ha in Beijing area, accounting for 68.1%.

Protected cultivation has resulted in negative environmental impacts caused by the overuse of agricultural inputs, such as fertilizers and pesticides (Muñoz et al., 2008a,b) contributing to rising environmental and, crucially connected, food safety problems – both increasingly prominently discussed within societal issues in China (Liu et al., 2013; Bai et al., 2013). For example, Chen et al. (2004) reported that greenhouse tomato crops in Beijing received more than 1000 kg N ha^{-1} per growing season from manure and fertilizer applications. Many actors from the corporate, civil society, academic and governmental sector have suggested a transition towards organic consumption and production as a more sustainable alternative as well as one of the potential solutions to this challenge.

A large number of comparison studies between organic and conventional farming systems carried out on a range of products and in different contexts suggest organic production as more environmentally sound, due to its lower consumption of fossil

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energy and greenhouse gas (GHG) emissions with less contribution to global warming (Pimentel et al., 1983; Flessa et al., 2002; Gündogmus, 2006; Hoeppner et al., 2006; Olesen et al., 2006; Kaltsas et al., 2007; Liu et al., 2010). Moreover, organic products have been presented as a healthier and safer food choice (Dendler and Dewick, this volume) driving up consumption figures, especially in China's first tier cities like Beijing, Shanghai, Guangzhou, or Shenzhen (CNCA, 2014).

However, research on the environmental performance of organic and conventional production in greenhouses nearby cities is still insufficiently available, especially regarding environmental pollution due to excessively applied agricultural inputs in greenhouse cultivation. Nowadays, more and more vegetables are produced intensively in greenhouses, including organic vegetable production.

This study aims to address the environmental impacts of greenhouse production of organic and conventional tomato in suburban Beijing – China's second largest city and one of the largest cities in the world through a Life Cycle Analysis (LCA).

LCA is a tool to analyze the environmental impact of a product in all stages in its life cycle, including resource extraction, production of materials, product parts and the product itself; transportation, usage and disposal – either through recycling or final discard. It has been mainly used for: (a) analyzing the origins of environmental impacts, such as global warming, acidification, eutrophication, human toxicity, aquatic toxicity, soil toxicity related to a particular product; (b) comparing factors for improvement for a given product; (c) designing new products; and (d) choosing between a number of comparable products (Guinee, 2004).

The specific objectives of the study are 1) to describe the stages of the greenhouse production system and its components 2) to compare the environmental impacts from conventional versus organic greenhouse production per ton of tomatoes produced and 3) to assess the environmental impacts from agricultural inputs applied during the greenhouse cultivation. After outlining the material and methods used to conduct this analysis, we will present the main findings of our LCA and discuss the results with the literature and wider sustainability implications. The last section will conclude the potential benefits and challenges associated with a transition to organic production and consumption in urban China.

2. Materials and methods

2.1. Case study area

The case study was conducted in the suburbs of Beijing, namely the districts of Pinggu, Chaoyang, Daxing, Changping, Shunyi, Huairou and Yanqing County. Eight organic and eight conventional farms were visited in pairs (Fig. 1), with two organic farms in Pinggu district and one organic farm the other six organic farms evenly distributed in each of the other six districts.

Beijing has a population of 21 million inhabitants with a vegetable consumption of 11 million tons every year (Wang and Mu, 2015). Beijing has a typical continental monsoon climate with an average annual precipitation of 447–580 mm and an average temperature ranging between 10 and 12 °C. During the winter season, vegetables can therefore only be produced in greenhouses. In 2013, 67% of the total vegetable production in Beijing was produced in greenhouses (Li and Han, 2015).

2.2. Life cycle assessment methodology

The principles of LCA are described in the ISO standards 14040 and 14044 (ISO, 2006a,b), which define four phases: goal and scope definition, inventory analysis, impact assessment, and interpretation. The main decisions made during these four phases are briefly described in the following sections.

2.2.1. Goal and scope definition

The framework of the study was designed in the goal and scope definition, encompassing the functional units and system boundaries. The study focused on the tomato production chain, including cultivation and distribution but not covering consumption. Consequently, the system boundaries of the LCA extended from mineral and fossil fuel extraction to the market, excluding the stages of retailing, home consumption and waste management (Fig. 2). While the eight organic farms delivered their organic tomatoes directly to downtown Beijing,[1] the conventional farms distributed their produce to local farmers' markets with short transportation. The organic and conventional tomato greenhouse production system in this study was divided into three subsystems: production of agricultural input materials, farming and transportation (Fig. 2). The functional unit for the analysis was one metric ton of tomatoes.

2.2.2. Life cycle inventory analysis

An inventory of production data, emissions and resources used was compiled for the entire life cycle. Data was collected during the course of 2013 through questionnaire-based interviews with the directors of the relevant organic and conventional farms (Table 1). All farms cultivated tomatoes as well as other vegetables.

While information on the amount of diesel used during the production process was derived from the interviews, data on fossil energy needed for fertilizer and pesticide production was calculated through the consumption of primary energy factors in China (Liang, 2009). The 'Environmental Impact Assessment of Circular Agriculture' was used to obtain information on emissions, such as CO, CO_2, NO_x, SO_2, CH_4 and N_2O, which derive from the energy required during agriculture material production (Liang, 2009).

During the farming stage, ammonia volatilization and nitrate leaching were 23.77% and 12.50%, respectively, of the nitrogen input for tomatoes (Hao et al., 2012; Zhao et al., 2010; He et al., 2005). Direct N_2O emissions emerged during the application of inorganic nitrogen, organic fertilizer, and biological nitrogen fixing (1.25% of the N released as N_2O). Induced emissions from ammonia and nitrate losses were also considered. The respective factors were 1% for ammonia-N and 2.5% for nitrate-N. NO_x-N was calculated as 10% of the N_2O emissions (Brentrup et al., 2004). Phosphorus loss was calculated as 0.2% of inputs from chemical/organic phosphorus sources (Wang et al., 2007).

In conventional tomato production, airborne pesticide residues were determined using a standard residue rate of 10% per unit weight of pesticides, 1% of freshwater, and 43% of soil (Wang et al., 2012).

In organic tomato production, different agriculture measures are used to control pests, with some physical measures such as color plate traps.[2] Sometimes farmers also use small amounts of bio-pesticides instead of chemical pesticides. The toxicity of bio-pesticides was not considered in our analysis as farmers usually apply a small amount of bio-pesticides that easily decomposes in the environment with little toxicity for human beings.

Heavy metal (Cd, Pb, As, Cu, Zn) losses were considered in terms of inputs of agricultural materials and farming. Inputs of heavy

[1] Normally, conventional vegetables bought by consumers in downtown Beijing come from commercial production bases from provinces such as Shandong or Hainan Province, but less likely from Beijing suburbs.

[2] The environment impact of traps production is insufficient and will not be considered in this calculation.

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