Science of the Total Environment 625 (2018) 486–495

Contents lists available at ScienceDirect

Science of the Total Environment

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

Environmental impacts and resource use of milk production on the North China Plain, based on life cycle assessment

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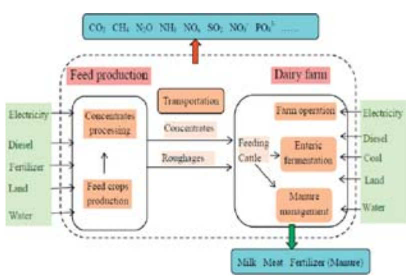
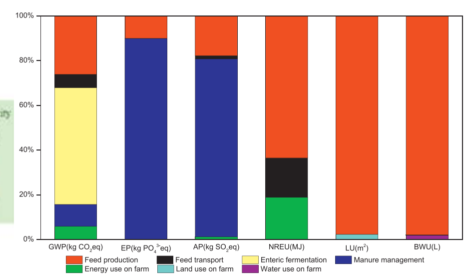
HIGHLIGHTS

- Environmental burden of milk production in China was evaluated using LCA.
- Feed production significantly affected global warming, energy use, land use and blue water use.
- Acidification and eutrophication potentials were determined by manure management.
- Environmental burden can decrease with improved cow productivity and herd structure.
- Environmental burden shifting was observed with different feeding options.

GRAPHICAL ABSTRACT



System boundary for the dairy farming system on the North China Plain



Relative contribution of processes in the dair y farm system to the impact categories

ARTICLE INFO

Article history:
Received 28 September 2017
Received in revised form 21 December 2017
Accepted 21 December 2017
Available online xxxx

Editor: Simon Pollard

Keywords:
Global warming
Eutrophication
Acidification
Dairy
Manure management
Feed strategy

ABSTRACT

Life cycle assessment methodology was used to quantify the environmental impacts and resource use of milk production on the North China Plain, the largest milk production area in China. Variation in environmental burden caused by cow productivity was evaluated, as well as scenario analysis of the effects of improvement practices. The results indicated that the average environmental impact potential and resource use for producing 1 kg of fat and protein corrected milk was 1.34 kg CO_2eq., 9.27 g PO_4^{3-}eq., 19.5 g SO_2eq., 4.91 MJ, 1.83 m^2 and 266 L for global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), non-renewable energy use (NREU), land use (LU) and blue water use (BWU; i.e. water withdrawal), respectively. Feed production was a significant determinant of GWP, NREU, LU and BWU, while AP and EP were mainly affected by manure management. Scenario analysis showed that reducing use of concentrates and substituting with alfalfa hay decreased GWP, EP, AP, NREU and LU (by 1.0%–5.5%), but caused a significant increase of BWU (by 17.2%). Using imported soybean instead of locally-grown soybean decreased LU by 2.6%, but significantly increased GWP and NREU by 20% and 6.9%, respectively. There was no single perfect manure management system, with variable effects from different management practices. The environmental burden shifting observed in this study illustrates the importance of assessing a wide range of impact categories instead of single or limited indicators for formulating environmental policies, and the necessity of combining multiple measures to decrease the environmental burden. For the North China Plain, improving milking cow productivity and herd structure (i.e. increased proportion of milking cows), combining various manure management systems, and encouraging dairy farmers to return manure to nearby crop lands are promising measures to decrease multiple environmental impacts.

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https://doi.org/10.1016/j.scitotenv.2017.12.259

1. Introduction

Milk production plays an important role both for the human diet and the economy in most countries (Muehlhoff et al., 2013). However, the global dairy sector also has a major effect on environmental degradation and resource depletion (Steinfeld et al., 2006; Chobtang et al., 2016), not only as one of the most important anthropogenic sources of greenhouse gas (GHG) emissions (Pirlo, 2012; Gerber et al., 2013), but also as a significant contributor to other impacts including eutrophication, acidification and water scarcity (Steinfeld et al., 2006). China is the third-largest global milk producer (Hagemann et al., 2012) with an increasing milk production and consumption (DAC, 2015), while at the same time facing a huge challenge from various resource and environmental issues. Thus, it is critical to estimate the environmental impacts and resource use of milk production in China and investigate potential measures for decreasing the resource use and environmental burden on the nation.

Life cycle assessment (LCA) is a widely used tool to estimate the environmental impact and resource use of products and reveal environmental hotspots through the whole supply chain (Finnveden et al., 2009). Application of LCA in dairy production studies has increased recently, but most focus has been on dairy systems in European or other OECD (Organization for Economic Co-operation and Development) countries (Yan et al., 2011; Chobtang et al., 2016; Baldini et al., 2017). There are very few studies on Chinese dairy farming, which is different from other major milk-producing countries such as European countries, USA, India or New Zealand (Wang et al., 2016). Although several studies have included Chinese dairy farming, only GHG emissions and land use were considered in these studies (Gerber et al., 2013; Wang et al., 2016).

Milk production potentially affects a wide range of resource and environmental impact categories (Meul et al., 2014; Battini et al., 2016; Chobtang et al., 2016), and a farm with a low effect on one impact category does not always have a low effect on other categories although they may be correlated (Yan et al., 2013). Environmental burden shifting can also happen between impact categories within the same farm when mitigation strategies are applied (de Boer et al., 2011). Thus, it is critically important to include multiple resource and impact categories (Chobtang et al., 2016) in a life cycle assessment of dairy production, especially when carrying out an analysis on abatement strategies (de Boer et al., 2011).

Water is a key resource for dairy farming and water use (WU) has largely been investigated as a single issue. Livestock production is a large consumer of water resources (Ran et al., 2016) and 19% of animal WU is related to dairy production (Mekonnen and Hoekstra, 2010). Therefore, it is important to evaluate WU together with other multiple resource and environmental impact categories to understand the total effects of mitigation measures. The use of blue water (from surface and groundwater sources) is important, particularly for dairy farming in low rainfall regions where there is competition for water (Zonderland-Thomassen and Ledgard, 2012).

Therefore, for the present study, resource use and environmental impact categories were selected according to critical issues in China and data availability, to quantify the resources and environmental burden of milk production on the North China Plain, the largest milk production area in China (DAC, 2015). The effects of feed strategies (i.e. feed type and source) and manure management systems on various impact categories were investigated.

2. Materials and methods

2.1. Dairy farming systems on the North China Plain

The North China Plain is the second largest plain in China, located in the middle of east China, and is the largest milk production region. For all dairy farms in the area, animals are housed year-round, and are mainly fed on concentrates and maize silage. Most dairy farms don't have crop land on farm and buy in all feed. There is a large variation in productivity, farm scale and herd structure (the proportion of milking cows in the herd). Twenty-five dairy farms were selected to cover a range of different production systems on the North China Plain. Farm data were collected for one production year (2015/2016) (Table 1). As for most dairy farms on the North China Plain, all 25 farms bought in all their feed. Manure was stacked with infrequent turning for 0–-3 months depending on season, and either sold to nearby orchards and vegetable farms or discharged. Female calves were raised as replacements for culled dairy cows, while all bull calves and surplus female calves were sold for meat production after calving.

2.2. The scope definition

2.2.1. System boundary

Based on a cradle-to-farm gate perspective, a system boundary (Fig. 1) was defined, including feed crop production, processing of concentrates and transportation of feed to dairy farms. Animal components included enteric methane and manure management. Resource use on dairy farms accounted for land occupation, water and energy use.

2.2.2. Functional unit and allocation

The functional unit used was defined as 1 kg of fat and protein corrected milk (FPCM) (IDF, 2015) at the farm gate. The dairy farms also sold surplus calves and culled cows for meat production, and part of the manure was sold to orchard or vegetable farmers. Thus, the total environmental burden was distributed between milk, meat and manure. As frequently applied in LCA of milk production (Baldini et al., 2017), an economic allocation method was used in the present study to handle dairy co-products, as well as for co-products associated with the production of feeds.

2.3. Inventory analysis

2.3.1. Feed production

Feed production processes and related activities accounted for included: 1) fertilizer production; 2) application of N fertilizer resulting

Table 1
Mean values and range of farm characteristics of the 25 case–study dairy farms on the North China Plain for 2015/2016.

Item	Unit	Mean	SD	Min	Max
Total cattle	Number	531	334	231	1850
Proportion of milking cows	% of total cattle	47	7	35	61
Milk production[a]	kg/cow	7132	1227	4753	9157
Surplus calves sold[b]	number	124	73	43	370
Cull cows sold[c]	number	51	47	12	200
Feed consumption (per cattle per year)					
Concentrate[d]	kg dry matter	1213	795	491	4096
Maize silage	kg dry matter	837	587	325	3192
Maize straw silage	kg dry matter	35	96	0	301
Alfalfa hay	kg dry matter	183	119	0	427
Leymus chinensis	kg dry matter	353	237	91	883
Resource use on farm (per farm per year)					
Electricity	1000 kWh	156	85	60	329
Coal	tonne	0.8	2.9	0	10
Diesel	l	6922	3234	2471	16,000
Land occupation	ha	7	4	2	17
Water (withdrawn)	1000 m^3	24	2	9	70

[a]The price of 1 kg milk is 3.8 Yuan.
[b,c]Calves are sold for 500 Yuan per head, and a cull cow for 5500 Yuan. The weight of calves is 38 kg, and cull cows 550 kg.
[d]According to type and brand of concentrate, the ingredients were maize grain, soybean meal, wheat bran, cotton seed meal, rape seed meal and others, accounting for 40–57%, 7–26%, 9–15%, 3–18%, 0–9% and 5–10% of the total, respectively.