Journal of Cleaner Production xxx (2016) 1–11

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Life cycle environmental impacts of high and low intensification pasture-based milk production systems: A case study of the Waikato region, New Zealand

Jeerasak Chobtang [a, b, c], Stewart F. Ledgard [a, c, *], Sarah J. McLaren [b, c], Daniel J. Donaghy [d]

[a] AgResearch, Ruakura Research Centre, Hamilton 3240, New Zealand
[b] Institute of Agriculture and Environment, Massey University, Palmerston North 4442, New Zealand
[c] New Zealand Life Cycle Management Centre, c/o Massey University, Palmerston North 4442, New Zealand
[d] Institute of Veterinary, Animal and Biomedical Sciences, Massey University, Palmerston North 4442, New Zealand

ARTICLE INFO

Article history:
Received 22 December 2015
Received in revised form
16 March 2016
Accepted 14 June 2016
Available online xxx

Keywords:
Dairy
Environmental impact
Intensification
Life Cycle Assessment
New Zealand
Pasture-based system

ABSTRACT

Intensification of pasture-based dairy farming systems is usually associated with increased use of off-farm inputs to increase milk production per hectare, and additional environmental impacts may be associated with upstream production and delivery of these off-farm inputs. The objective of this study was to compare two levels of dairy farming intensification (i.e. high versus low) in pasture-based milk production systems with respect to (i) farm production and (ii) life cycle environmental indicators. The study considered 53 dairy farms in the Waikato region, New Zealand. Three farm attributes (stocking rate, amount of brought-in feeds and amount of nitrogen fertilizer used) were used to define a level of farming intensification (Intensification Index) for each dairy farm. The upper and lower quartiles of the dairy farms ranked on their Intensification Indices were chosen to represent high and low intensification groups, respectively. Twelve midpoint environmental indicators of the dairy systems were assessed using attributional Life Cycle Assessment with one kg of fat- and protein-corrected milk as a functional unit and a cradle-to-farm gate perspective as a system boundary. Compared with the low intensification group, the high intensification group had (on a per hectare basis) higher ($P < 0.001$) stocking rate, total brought-in feeds and nitrogen fertilizer use, which led to greater milk yield per cow ($P < 0.01$) and per hectare ($P < 0.001$). The different levels of farming intensification did not affect total feed conversion efficiency ($P > 0.05$). However, for the high intensification group, the results for 10 out of 12 environmental indicators per kg of fat- and protein-corrected milk were higher ($P < 0.05$) than those in the low intensification group. The main drivers for the increases in most environmental indicator results were the production of brought-in feeds, manufacturing of agrichemicals and transportation of off-farm inputs for use on dairy farms. In contrast, increased pasture intake was negatively correlated ($P < 0.05$) with all environmental impacts, indicating that efficient pasture management is also critical to mitigate environmental impacts. In conclusion, while an increase in intensification of pasture-based dairy farming systems led to increased milk production per cow and per hectare, it also resulted in increased environmental impacts for most indicators. Apart from increased resource use efficiency, increased pasture utilization efficiency is a promising measure to improve environmental sustainability of pasture-based dairy farming systems.

1. Introduction

The increasing global population and rising levels of affluence are driving an increased demand for food. At the same time, increasing environmental problems at both global (e.g. climate change; FAO (2006)) and local (e.g. degradation of waterways; Foote et al. (2015)) scales have focused attention on the realization of more environmentally-friendly food systems (Echeverría et al., 2014). As a consequence, consideration is being given to sustainable intensification of food production systems in order to increase

* Corresponding author. AgResearch, Ruakura Research Centre, Hamilton 3240, New Zealand.
E-mail address: stewart.ledgard@agresearch.co.nz (S.F. Ledgard).

http://dx.doi.org/10.1016/j.jclepro.2016.06.079
0959-6526/

productivity within environmental limits (Byerlee et al., 2014; Tilman and Clark, 2014) and to changing food consumption patterns (Hallström et al., 2015).

From an increased productivity perspective, one of the most promising approaches that can contribute to meeting the increasing demand for food products is agricultural (farming) intensification, which is associated mainly with increased use of off-farm inputs (Tilman et al., 2011). However, the increased use of off-farm inputs (e.g. fossil fuels, chemical fertilizers, pesticides and brought-in feeds) to support farm intensification can result in increased total environmental impacts associated with food products (Stoate et al., 2009; Tscharntke et al., 2012).

In the dairy sector in particular, intensification of farming systems is generally interpreted as an increase in milk yield either per unit of farm input (Udo et al., 2011) or per unit of dairy farmland (Crosson et al., 2011). This is achieved partly through using a high animal stocking rate coupled with increased use of off-farm inputs (MacLeod and Moller, 2006). The increased use of off-farm inputs contributes additional environmental impacts to the life cycle of milk (Vitousek et al., 2009) and may result in increased net environmental impacts per unit of milk produced (MacLeod and Moller, 2006).

In principle, accounting for a range of intensification-defining farming practices and combining them to produce an 'Intensification Index' provides a comprehensive categorization of farming intensification (Bava et al., 2014). To achieve this, a mathematical technique has been recommended using to determine degrees or levels of farm intensification (Legendre and Legendre, 1998). By using this technique, a number of farm traits defining farming intensification are averaged to form a single Intensification Index. This technique has been widely used in ecological studies of agricultural systems, e.g. Allan et al. (2014), Blüthgen et al. (2012) and Herzog et al. (2006) but has not been used to quantify levels of dairy farm intensification.

Life Cycle Assessment (LCA) is a systematic approach used for assessing the potential environmental impacts of a product system over its life cycle (International Standard Organization, 2006a,b). The approach can be used to assess multiple environmental indicators which can help in avoiding problem-shifting both between different environmental impacts and between different life cycle stages of a product (Finnveden et al., 2009). In addition, contribution analysis can help to identify environmental hotspots along the life cycle of product systems which can facilitate development of mitigation options to reduce environmental impacts (Verbeeck and Hens, 2010).

There are a number of studies assessing a single environmental impact category (e.g. carbon footprint) (Dalgaard et al., 2014; Flysjö et al., 2011) or only a few impact categories (Battini et al., 2016; Bava et al., 2014; Guerci et al., 2013) of dairy farming systems. However, to our knowledge, there are no published studies directly comparing multiple environmental indicators derived from different quantitative intensification levels of pasture-based dairy farming systems. Therefore, the objective of the present study was to use LCA to quantify the environmental impacts and identify environmental hotspots in pasture-based milk production systems at two contrasting intensification levels (i.e. high versus low), using data from 53 pasture-based dairy farms in the Waikato region, New Zealand.

2. Methods

There were four main steps in this study. Firstly, computation of an 'Intensification Index' indicator for each of the 53 dairy farms was undertaken using three main attributes of dairy farms to represent on-farm intensification in pasture-based dairying systems; stocking rate, total amount of brought-in feeds and total amount of nitrogen (N) fertilizer use (see Section 2.1). Secondly, dairy farms were ranked based on their intensification indices and the farms in the lower and upper quartiles were selected to represent low and high levels of farm intensification, respectively (see Section 2.2). Thirdly, a set of environmental indicators per kg standardized milk produced for each farm were calculated using an attributional LCA (see Section 2.3). Finally, a statistical analysis was carried out in order to compare the impacts between the low and high levels of dairy farming intensification and to investigate relationships between farm attributes and impact categories (see Section 2.4).

2.1. Development of an Intensification Index for defining the level of farm intensification

In order to investigate the influence of farm intensification level on the environmental impacts associated with pasture-based dairy farming systems, it was necessary to first develop a quantitative indicator to determine the level of intensification on a farm. However, as there is no existing well-defined indicator for measuring levels of farming intensification (Bava et al., 2014), the degree of land-use intensity was used as a proxy, as recommended by Kleijn et al. (2009). In addition, Kleijn et al. (2009) recommended that using farm inputs (e.g. N fertilizers and stocking rates) as indicators is more suitable than using farm outputs (e.g. milk yields) to determine land-use intensity. Therefore, an Intensification Index indicator for each dairy farm was calculated based on three farm inputs identified by other researchers as determining pasture-based on-farm intensification (MacLeod and Moller, 2006; Oenema et al., 2014; Pinares-Patiño et al., 2009), i.e. stocking rate (livestock unit per ha), N fertilizers (kg N per ha), and brought-in feeds (kg dry matter (DM) per ha).

It should be noted that one or more of these inputs have been used in a qualitative way in other studies for defining the level of dairy farm intensification (e.g. Basset-Mens et al. (2009); Ledgard et al. (2004)). However, these attributes have not been treated as quantitative indicators.

In order to formulate an Intensification Index, these three farm attributes (each quantified per-ha of effective dairy farmland basis, i.e. land used for feeding/grazing dairy cows, excluding farm lanes and buildings) were individually scaled to a non-unit indicator according to Legendre and Legendre (1998), i.e. a minimum value was subtracted from a measured value, then divided by a range (i.e. maximum value minus minimum value) of the corresponding farm attribute. As a result, the indicator ranged between 0 and 1; where 0 refers to the lowest intensity and 1 to the highest intensity (see Table A1). The three quantified intensification indicators for individual farms were then averaged (arithmetic mean) to give the result for that farm on the Intensification Index; equal contribution of these farm attributes to dairy farm intensification was assumed.

2.2. Ranking dairy farms using an Intensification Index

All of the 53 dairy farms were ranked using this Intensification Index. Dairy farms in the lower and upper quartiles were chosen to represent the low and high levels of farm intensification respectively, resulting in 14 farms for each intensification group (see Table A1).

2.3. Life Cycle Assessment of dairy farming systems

An attributional LCA was used to assess environmental impacts of the life cycle of milk for all 53 dairy farms in the Waikato region of New Zealand for the production year 2010/11. Details of general