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Review

Environmental impacts of organic and conventional agricultural products – Are the differences captured by life cycle assessment?

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ABSTRACT

Comprehensive assessment tools are needed that reliably describe environmental impacts of different agricultural systems in order to develop sustainable high yielding agricultural production systems with minimal impacts on the environment. Today, Life Cycle Assessment (LCA) is increasingly used to assess and compare the environmental sustainability of agricultural products from conventional and organic agriculture. However, LCA studies comparing agricultural products from conventional and organic farming systems report a wide variation in the resource efficiency of products from these systems. The studies show that impacts per area farmed land are usually less in organic systems, but related to the quantity produced impacts are often higher. We reviewed 34 comparative LCA studies of organic and conventional agricultural products to analyze whether this result is solely due to the usually lower yields in organic systems or also due to inaccurate modeling within LCA. Comparative LCAs on agricultural products from organic and conventional farming systems often do not adequately differentiate the specific characteristics of the respective farming system in the goal and scope definition and in the inventory analysis. Further, often only a limited number of impact categories are assessed within the impact assessment not allowing for a comprehensive environmental assessment. The most critical points we identified relate to the nitrogen (N) fluxes influencing acidification, eutrophication, and global warming potential, and biodiversity. Usually, N-emissions in LCA inventories of agricultural products are based on model calculations. Modeled N-emissions often do not correspond with the actual amount of N left in the system that may result in potential emissions. Reasons for this may be that N-models are not well adapted to the mode of action of organic fertilizers and that N-emission models often are built on assumptions from conventional agriculture leading to even greater deviances for organic systems between the amount of N calculated by emission models and the actual amount of N available for emissions. Improvements are needed regarding a more precise differentiation between farming systems and regarding the development of N emission models that better represent actual N-fluxes within different systems. We recommend adjusting N- and C-emissions during farmyard manure management and farmyard manure fertilization in plant production to the feed ration provided in the animal production of the respective farming system leading to different N- and C-compositions within the excrement. In the future, more representative background data on organic farming systems (e.g. N content of farmyard manure) should be generated and compiled so as to be available for use within LCA inventories. Finally, we recommend conducting consequential LCA – if possible – when using LCA for policy-making or strategic environmental planning to account for different functions of the analyzed farming systems.

1. Introduction

Agriculture's impacts on the environment are substantial (Foley et al., 2005, 2011). In particular modern agriculture is accelerating the rate of biodiversity loss and is one of the major drivers of climate change and human induced changes to the nitrogen cycle,

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with these three processes having already exceeded the Earth's boundaries (Rockström et al., 2009). In order to become more sustainable farming systems should be developed and applied that minimize externalities by optimizing the use of internal production inputs (e.g. of farmyard manure) (Nemecek et al., 2011b) and/or implement ecological intensification, which involves replacing external inputs with ecosystem services (e.g. by enhancing natural biocontrol) while maintaining or even increasing yield levels (Bommarco et al., 2013).

Organic farming is often proposed as solution to reduce agriculture's impacts on the environment (Seufert et al., 2012b). However, yields in organic agriculture are usually lower than in conventional agriculture. For example, crop yield differences between organic and conventional systems range – while strongly depending on system and site characteristics – from 5 to 34% (de Ponti et al., 2012; Seufert et al., 2012a). So, more land is usually required to produce the same amount of food in organic farming systems than in conventional farming. Thus, the environmental benefits per product unit of organic farming might be outweighed; as was argued in the recent meta-analysis by Tuomisto et al. (2012).

In order to develop more sustainable farming systems, researchers and decision-makers need information about the strengths and weaknesses of different farming systems with respect to productivity and environmental impacts within the ecosystems' carrying capacity. Therefore, assessment tools are required that allow for comprehensive environmental impact assessments of different farming systems to enable informed conclusions.

Life cycle assessment (LCA) is increasingly used to assess the ecological sustainability of food products and is seen as a useful tool to evaluate environmental impacts of food products and production systems (Roy et al., 2009). LCA is the most comprehensive method available and useful for avoiding problem-shifting e.g., from one phase of the life cycle to another because it analyzes potential environmental impacts throughout a product's life cycle (ISO, 2006) including the supply chain and downstream processes (Finnveden et al., 2009). Results from LCAs may form the basis for making decisions for policy makers, producers as well as for consumers in selecting sustainable products and production processes (Roy et al., 2009).

A growing number of LCA studies has compared the environmental impacts of the same products produced in organic vs. conventional agriculture (see Table 1). Most of these LCA studies have found a lower environmental burden from organically produced products on a per area and year basis, but higher impacts have been found when evaluating emissions per product unit (e.g. Nemecek et al. (2011a) and the studies reviewed therein). Lower yields of organic farming systems leading to higher environmental impacts on a per product basis are seen as their main drawback (Tuomisto et al., 2012).

However, contemporary LCA studies report a wide variation in the resource efficiency of products from organic and conventional agriculture (e.g. studies on milk by Cederberg and Mattsson (2000), Williams et al. (2006), Thomassen et al. (2008b), van der Werf et al. (2009)). Some of this variation may be explained by yield differences between organic and conventional agriculture, while some of the variation may depend more on farmer's management choices than on the farming system itself (Tuomisto et al., 2012). Alternatively, some of the variation reported by comparative LCAs of products from different farming systems may also be due to inaccurate modeling of characteristics specific to the farming systems related to the assessed products.

The objectives of this review are:

a) to determine the parameters leading to differences in environmental impacts between organic and conventional products within comparative LCAs; and
b) to analyze, whether these parameters reflected farming system specific differences adequately.

Further, we analyze whether comparative LCA studies on organic and conventional products can be used to draw general conclusions on the environmental performance of organic and conventional farming systems. Finally, the objective is to show how LCA can be improved to better differentiate between products from different farming systems.

2. Methods

2.1. Review of peer-reviewed comparative LCA studies and LCA study reports

2.1.1. Literature search

We searched the ISI Web of Knowledge literature database (www.isiwebofknowledge.com) and the Scopus database (www.scopus.com) for LCA studies that compared organically and conventionally (i.e. non organic) produced commodities with no restriction on publication year or geographical context although review articles were excluded from the analysis. The search string "life cycle assessment AND organic AND conventional" was used in combination with different keywords including milk, beef, pig, poultry, arable crops, fruits and vegetables. In peer reviewed journals and conference proceedings, we found 31 comparative LCA studies and studies using LCA methodology to assess only a single impact category (e.g. carbon footprint studies). Since we searched academic literature databases, this review includes only studies which primarily aimed at answering academic questions. However, such studies may serve as the scientific basis for decision making, such as on a regulatory level.

In addition we included three scientific reports, which were available on the internet, on comparative LCAs from the UK (Williams et al., 2006), Sweden (Cederberg and Flysjö, 2004), and Switzerland (Alig et al., 2012). These three reports were not peer reviewed although they are well known within the LCA community dealing with food and agriculture. The report from Sweden was the basis for the peer reviewed study by Flysjö et al. (2012) and the report from the UK was the basis for the peer reviewed study by Williams et al. (2010). Both peer reviewed studies were also included in this review. All of the 34 studies that were reviewed are listed in Table 1, which also indicates the commodities, the country, and the underlying data basis.

Further, we added inventories on organic and conventional products from ecoinvent v2.2 and from ESU-services Ltd. (Jungbluth et al., 2013) to the studies found in literature and included them in our analyses (see Section 2.2).

2.1.2. Evaluation criteria

The main focus of this review of LCA studies and inventories is on the question of how organic and conventional farming systems were differentiated and modeled within comparative LCAs in order to assess and compare environmental impacts of agricultural food products. The review was guided by the following evaluation criteria:

1. Goal and scope definition
   - What was the goal of the LCA?
   - Was the LCA conducted with an attributional or consequential perspective?
   - What allocation rules were applied?