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Life-cycle water use, nutrient cycling and solid waste generation of a large-scale organic dairy

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ABSTRACT

Aurora Organic Dairy (AOD) is a leading U.S. provider of private-label organic milk and butter, managing over 12,000 milking cows and processing over 84 million liters of milk annually. Building on a previous life-cycle energy and greenhouse gas study, this paper benchmarks AOD's nutrient cycling, water use and solid waste generation across the life cycle of producing, processing and distributing fluid milk. Nutrient flows relevant to the impact categories of aquatic eutrophication and acidification were calculated. The acidification potential of AOD fluid milk across the full life cycle is estimated at 1.2 moles H+/ liter packaged milk. The eutrophication potential is 0.66 g N eq. / liter packaged milk. Water use refers to all water that is withdrawn from the natural hydrological cycle and used in various production processes and is divided into consumption and utilization according to Koehler (2008). This study includes all direct water use at AOD's facilities, as well as indirect water use associated with feed production, electricity generation, and the production of liquid transportation fuels. Total life cycle water consumption equals 808 liters water per liter of packaged milk, and life cycle water utilization is 12.3 liters water per liter of packaged milk. Municipal solid waste (MSW) generation at AOD facilities was estimated and characterized. National averages on recycling rates for AOD packaging types were utilized for end of life impacts. Across the whole life cycle, the production of one liter of packaged milk results in 42.3 g direct, 41.2 g indirect MSW, and 24.8 g recycled MSW. Packaging for the milk itself comprises a large portion (71%) of the direct MSW. Water use, eutrophication, acidification, and solid waste from farm operations are compared with total life cycle results to highlight the key inputs, processes, and stages influencing sustainability performance.

Keywords: milk, water use, nutrient cycling, nutrient use efficiency, solid waste

1. Introduction

Aurora Organic Dairy (AOD) is a large scale, vertically-integrated U.S. dairy, managing over 12,000 milking cows and processing over 84 million liters of private-label organic milk annually. To inform corporate sustainability reporting and improve upon environmental performance, AOD has engaged in a life cycle analysis of its fluid milk product. Life cycle energy use and greenhouse gas (GHG) emissions for AOD's fluid milk production have been previously reported (Heller & Keoleian, in review). This report investigates nutrient cycling (acidification and eutrophication potential), water utilization and consumption, and solid waste generation across farm operations, milk processing and distribution, consumer use and final waste disposal.

2. Methods

The AOD milk production system has been described in detail previously (Heller et al., 2008, Heller & Keoleian, in review; Gough et al., 2010). Data were analyzed over one year, from April 2008 to March 2009. The functional unit is defined as one liter of packaged fluid

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milk, composed of the fat-content and packaging-size product mix sold by AOD over the time period. The following sections provide a brief description of the methods used for the indicators considered in this report; for greater detail, please refer to Gough et al. (2010).

2.1 Nutrient Cycling

Agricultural productivity depends on the availability of nitrogen (N), phosphorus (P), and other elemental nutrients in farm systems. In order to meet the nutrient demands required for milk production, AOD imports large quantities of N and P nutrients embodied in feed, which then is converted into milk and manure in the farm systems. The nutrients contained within manures can then be released to the environment and lead to a variety of impacts. These impacts were quantified using eutrophication and acidification impact categories in LCA. The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) 2 v3.0 (Bare et al., 2002; Norris, 2002) was used to quantify eutrophication and acidification impacts over the life cycle, and SimaPro software datasets were used for emissions outside of the farm operations stage. Within the farm operations stage, nitrous oxide (N2O), ammonia (NH3), nitrate (NO3-), and phosphate (PO4-3) releases were calculated. AOD records and expert opinion were used for direct data inputs and to configure models of the farm system. IPCC guidelines for reporting greenhouse gas emission were used for N2O releases and adapted to calculate NH3 emissions at the farm operations stage (IPCC, 2006). Nutrient contents in feeds, manure, milk, pasture leaching, and all other flows were calculated along with full farm-gate, soil-surface, and herd utilization balances for each farm system and nutrient (see Tables 9 and 10 and associated paragraphs in Gough et al. (2010) for methodological details).

2.2 Water Utilization and Consumption

Previous studies measure water use in terms of the water inputs to an industrial system, but because it is more important to understand the fate of water when it leaves the system, this study focused on water outputs from the milk production life cycle. Two types of water outputs are distinguished: water consumption – water that is evaporated, transferred to a different watershed, or incorporated into the final product; and water utilization – water that is used and then returned to the watershed from which it is withdrawn (Koehler, 2008).

This study quantifies water consumption and utilization in each stage of the milk life cycle. In the feed and bedding production stage, irrigation water that is evapotranspired by crops is counted as water consumption. The specific irrigation practices of feed growers were not known, so the U.N. Food and Agriculture Organization's CROPWAT 8.0 and CLIMWAT 2.0 (FAO, 2010) programs were used to determine the amount of irrigation water required to produce AOD's feed and bedding, taking growing locations into consideration. CROPWAT 8.0 provides theoretical estimates of crop water needs and tends to overestimate the amount of irrigation water used.

In the farm operations and milk processing and management stages, water consumption and utilization at AOD facilities were quantified based on AOD records, consultation with AOD experts, and literature sources. Additionally, the water consumption and utilization associated with electricity generation (Kenny et al., 2009; Torcellini et al., 2003) and transport fuel production (Wu et al., 2009; Younos et al., 2009) were estimated. In the later lifecycle stages (cold storage, distribution, retail and consumer/end-of-life), only water use associated with electricity and fuel was included.

2.3. Municipal solid waste

Municipal solid waste (MSW) is generated at every stage of the milk production life cycle and can cause significant environmental impacts. Recycling of MSW is one solution for reducing these impacts, but the U.S. Environmental Protection Agency states that "source reduction" of waste is the best strategy for reducing MSW impacts (EPA, 1999).

This study quantifies three different flows of MSW in the milk life cycle: direct MSW, indirect MSW, and the portion of MSW that is recycled. Direct MSW encompasses all solid waste generated as a direct result of AOD operations; major components include disposable udder wipes, filter socks, nitrile milking gloves, various types of packaging, and milk containers. Indirect MSW encompasses all solid waste generated during the production of electricity and processing of fuels (ash, sludge, etc). Recycled MSW encompasses a variety of waste flows diverted from the waste stream and returned for use as an input in an industrial process.

Data on direct MSW and recycled MSW were gathered from AOD purchase records, from AOD experts, and from literature sources referencing national average recycling rates (US EPA, 2008). This study excludes direct MSW generated during feed and bedding production due to lack of specific data. Indirect MSW was inventoried using Ecoinvent processes for electricity and fuel production (Ecoinvent, 2007).

3. Results and Discussion

3.1. Nutrient cycling

Figure 1 shows the distribution of acidification potential across the fluid milk life cycle. The acidification potential for the full life cycle is 1.2 moles H+/ liter packaged milk. Feed and bedding production and farm operations (which includes manure management) dominate the acidification impacts, with ammonia emissions contributing the most to overall acidification potential. It is important to note, however, that, due to a lack of appropriate data for organic production of major feed crops, datasets for conventional production of feed crops were used.

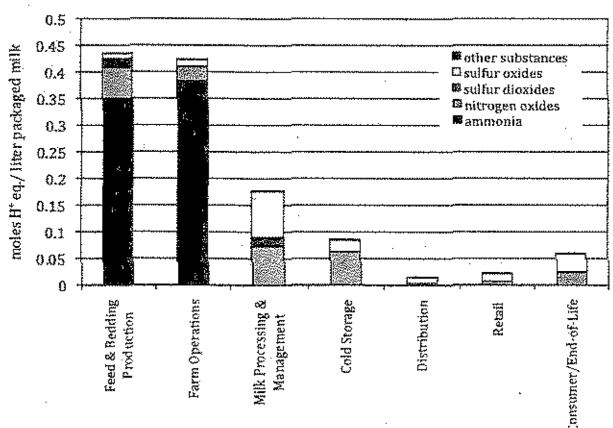

Figure 1: Acidification potential across the fluid milk life cycle. Figure also shows contributions from major emission substances.

Figure 2 shows the distribution of eutrophication potential across the fluid milk life cycle. Eutrophication contributions for the whole life cycle total to 0.66 g N eq. / liter packaged milk. Again, feed and bedding production is the major contributor to eutrophication, with nitrate leaching from fertilizer application being the dominant source. Eutrophication impacts remain uncertain, however, due to reliance on conventional crop production datasets.

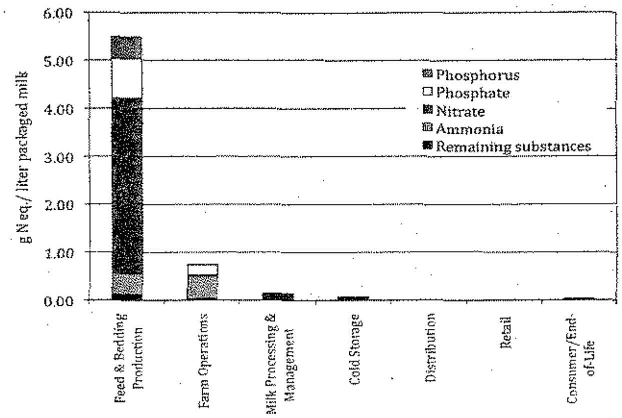

Figure 2: Eutrophication potential across the fluid milk life cycle. Figure shows contributions from major emission substances.

3.2. Water utilization and consumption

Life cycle water utilization and consumption is summarized in Figure 3. Irrigation of feed and bedding crops dominate water use (utilization plus consumption), accounting for 94% of the total life cycle water use. Pasture irrigation (included in "farm operations" in Figure 3) accounts for 3.2% of total life cycle water use. Total life cycle water consumption equals 808 liters water per liter of packaged milk, and life cycle water utilization is 12.3 liters water per liter of packaged milk. Irrigation practices on farms providing feed and bedding to AOD were not known; thus, irrigation requirement estimates were made using the evapotranspiration methods of FAO's CROPWAT software. This method often overestimates crop water needs for many crops (Pfister et al., 2009).

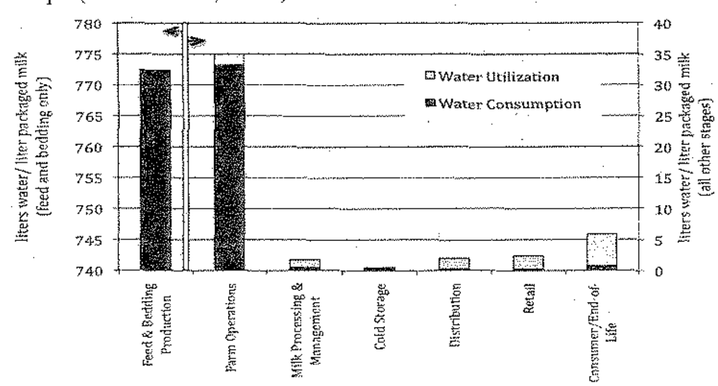

Figure 3. Water utilization and consumption across the fluid milk life cycle. Note that "feed & bedding production" scales to the left axis whereas all other stages scale to the right axis.

3.3. Municipal solid waste

The distribution of MSW across the major milk life cycle stages is shown in Figure 4. Across the whole life cycle, the production of one liter of packaged milk results in 42.3 g direct MSW, 41.2 g indirect MSW, and 24.8 g recycled MSW. Not surprisingly, the consumer/end of life stage accounts for the most MSW, contributing 71% of direct and 38% of indirect. Paper towels used for wiping udders during the milking process were the largest contributor to MSW in the farm operations stage, composing 73% of the direct MSW at this stage.

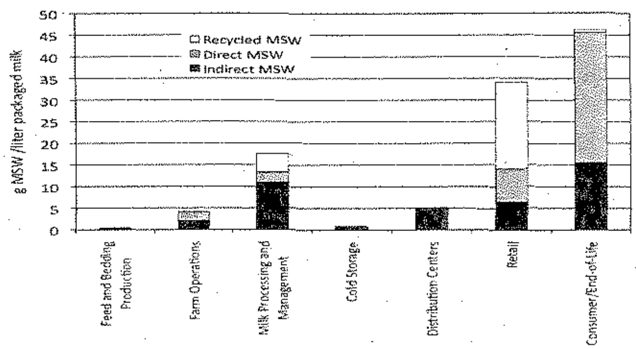

Figure 4: Municipal solid waste (MSW) generation across the fluid milk life cycle.

3.4. Impact distribution

Figure 5 summarizes the distribution of life cycle environmental impacts, including energy use and GHG emissions, across the major stages of the AOD fluid milk life cycle. Note that the impacts in this figure are weighted equally across impact categories, so the magnitude of peaks should be interpreted carefully. This begins to offer an interesting look at the "landscape" of environmental impacts for organic milk production via AOD's system. While some impact categories, such as water use and eutrophication, are highly concentrated in one life cycle stage (feed and bedding production), others, such as energy use, are relatively distributed across the life cycle.

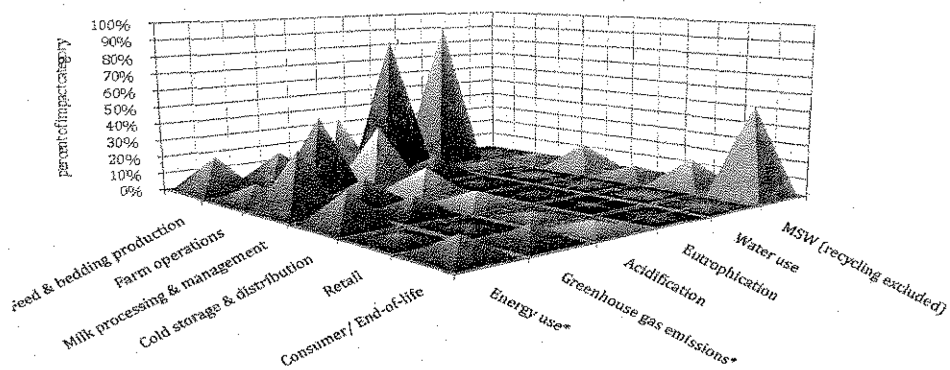

Figure 5: The environmental impact "landscape" across the AOD fluid milk life cycle. Percentages add to 100 for each impact category. *Energy/GHG reported in Heller & Keoleian (in rev.)

4. Conclusions

Life cycle assessment of food and agricultural systems is an emerging field challenged with difficult methodological decisions and sparse data resources. These challenges must be kept in mind when interpreting LCA results. Still, a concentrated case study, such as the AOD organic fluid milk system presented here, begins to offer a look at the complex interaction between an agricultural business and environmental performance. The pervious study (Heller et al., 2008; Heller and Keoleian, in review) introduced new approaches to coproduct allocation, while this study adds impact categories especially relevant to agricultural systems. The present study is limited by poor data resolution in the "feed & bedding production" life cycle stage, important to nutrient, water, energy and GHG indicators. For studies such as this to move forward in properly informing decision-making, there is a strong need for LCA data on U.S. crop production for varying production practices (e.g., organic vs. conventional) and climatic regions.

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