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Cradle to farm gate life cycle assessment of strawberry production in the United States

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The goal of this study was to develop a cradle to farm gate life cycle inventory and assess the environmental impacts of strawberry production in four major strawberry producing states of the United States: California, Florida, North Carolina and Oregon, representing 99% of the United States strawberry production. Life cycle environmental impacts depend strongly on geographic location and production practices. Data for California and North Carolina strawberry production were collected in collaboration with agricultural economists from those states using the "LCA Extended Enterprise Budget" Excel sheet (version 4.11). Data for Florida strawberry production were collected from the state's existing enterprise budget (a detailed accounting of production costs and returns which estimates profitability of an enterprise). Data related to Oregon strawberry production were obtained through interviews with strawberry producers. OpenLCA software was used to conduct life cycle assessment for strawberry production. Missing unit processes for production of agricultural machinery, pesticides, fertilizers and materials were modeled based on existing literature. In order to better assess the sustainability of strawberry production, three metrics encompassing nitrogen productivity, phosphorous productivity and fossil energy productivity were introduced. Global warming potential for California, Florida, North Carolina and Oregon strawberry production was estimated to be 1.75, 2.50, 5.48 and 2.21 kg CO_2-eq per 1 kg of strawberry, respectively. The difference between LCA results was due to variation in yield and management practices which depend on geographic location. Plastics, fuels and fertilizers were the inputs with the highest contribution to environmental impact categories. California strawberry production scored the highest on three sustainability metrics mainly due to having the highest strawberry yield.

1. Introduction

The total value of the United States (U.S.) strawberry production in 2014 was $2.4 billion and surpassed that of the fresh apple industry for the first time in 2010 (AgMRC, 2013). Strawberries are the fourth most valuable fruit produced in the U.S. and the total production of strawberry has been reported by the United States Department of Agriculture (USDA) as 1.4 million tonne in 2014 (USDA, 2015). Increasingly, producers, food retailers and consumers are becoming conscious of the environmental impacts of the products they produce, sell and/or consume. Therefore, assessing environmental impacts of strawberry production is essential to enable more sustainable production practices and to inform consumers of their choices. Communicating environmental impact information to stakeholders in an easy-to-understand format is critical for the move towards more sustainable production practices (Peano et al., 2015).

There are two main types of strawberry plants, distinguished by the date that they begin to produce fruit: June-bearing and day-neutral. June-bearing strawberries produce fruit in the late spring and early summer, while day-neutral strawberries produce their fruits continuously from early summer to fall (Demchak et al., 2010). In the U.S. strawberry transplants are used for strawberry production purposes and they mostly come from California nurseries. Strawberry transplants are produced from meristem plants after they are propagated under controlled conditions and numbers are increased up to three generations in nursery fields. Transplants are used to prevent transfer of diseases and pests to fruit production fields (Murthy et al., 2014). There are two main production systems for strawberries in the U.S.: matted-row and plasticulture. Matted-row production is an old and less expensive system in which strawberry plants are set out on cultivated lands at regularly

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spaced intervals within regularly spaced rows. This system allows strawberry runners to grow and establish daughter plants within the rows and it is also suitable for cooler regions. This system requires to be renovated each year. In the plasticulture system, strawberry plants are grown on raised beds covered with black plastic (plastic mulch). June-bearing and day-neutral strawberry plants can be cultivated under either system. The cultivated plants can be dormant plants or plug plants (plants grown from rooted runner tips) (Demchak et al., 2010). In recent years, plasticulture has become the main commercial growing system for strawberry production across most of the U.S. due to higher productivity and quality than the matted-row system (Fernandez et al., 2001; Poling, 2005).

A previous life cycle assessment (LCA) study for strawberry production in Italy indicated that most of the GHG emissions could be attributed to the plastics used in production (Girgenti et al., 2014). Similar studies were performed to assess life cycle impacts of strawberry production in Australia (Gunady et al., 2012), the United Kingdom (U.K.) and Spain (Williams et al., 2008). However, to date, there is no LCA for strawberry production in the U.S. to the best of our knowledge. This study represents the first LCA for strawberry production in the U.S. in multiple geographic locations. Life cycle environmental impacts depend strongly on geographic location and production practices. The main goal of this study was to perform LCA for strawberry production using the plasticulture method in four states across the U.S. A second goal of this paper was to propose simple producer/consumer friendly metrics that indicate the overall efficiency of nitrogen, phosphorous and fossil energy use during strawberry production.

2. Material and methods

2.1. Goal and scope definition

The primary goal of this study was to develop a cradle-to-farm-gate life cycle inventory (LCI) and assess the environmental impacts of the plasticulture method of non-organic strawberry production in four major strawberry producing states in the U.S.: California, Florida, North Carolina and Oregon. These four states produced 99% of strawberry in the U.S. from 2012 to 2014 (USDA, 2015). Obtaining high-quality LCI data is critical for a reliable LCA. Since such data do not as yet exist for strawberry production, a modified enterprise-budget tool that collects necessary LCI data in the background while performing economic analysis for production was developed. The scope of this study was intended to provide a preliminary dataset for conducting strawberry LCAs in four geographic regions of the U.S. Moreover, an uncertainty analysis was performed to evaluate the impact of variations in inputs on LCA results. Since the strawberry is a fresh market product, the functional unit of 1 kg at farm gate (before transporting to point of sale) was chosen for the LCA.

2.2. System boundaries

System boundaries define which unit processes and inputs are included in the LCA (Fig. 1). Strawberry production has several inputs such as fertilizers, pesticides, fuels and materials. Plastic mulch, drip tubes, floating row covers and packaging baskets were considered as materials. In addition to these material inputs, field operations require using agricultural machinery for land preparation, planting, application of fertilizer and pesticides. These inputs, including the fuel used for operation of agricultural machinery, were considered in the LCI. N_2O emissions due to applied nitrogen fertilizer and flows associated with harvesting and packaging processes were included in the LCI. Due to lack of information, the strawberry nursery phase was excluded from the LCI.

2.3. Life cycle inventory

Farmers, agricultural economists and other stakeholders commonly use enterprise budgets for planning purposes. Enterprise budget is a detailed accounting of production costs and returns which provides an estimate of profitability. In this study the “LCA Extended Enterprise Budget Tool” was developed to capture LCI data in conjunction with the enterprise budget analysis. The LCI was necessary to evaluate variations in both the format and content of the various enterprise budgets and to capture the most common strawberry management practices currently used. Plasticulture and matted-row practices were represented in enterprise budgets for each state. Enterprise budgets for each state also provided quantity and cost estimates for materials and activities associated with strawberry production, based on surveys of growers, retailers, extension agents, crop advisors, and other market participants. In addition, the enterprise budgets provided the baseline format for the LCA Extended Enterprise Budget tool (v. 4.11). The first version of this tool was distributed to an internal advisory group for an “in-process” review and was updated based on the advisory group's comments. Details of tool development, reviewer comments and user tutorials can be found in Murthy et al. (2014). The updated tool was distributed to five state economists, four horticulturalists, and three extension agents from California, North Carolina, Florida, Washington, Oregon, New York, and Pennsylvania to test its usability and collect data about current strawberry production (41% response rate: 5 out of 12). Data for California and North Carolina strawberry production were collected in collaboration with agricultural economists from these states using the LCA Extended Enterprise Budget Tool. Data for Florida strawberry production were collected from the state's existing enterprise budget, while those for Oregon were obtained through interviews with strawberry producers. The process of data collection was mentioned in detail by Murthy et al. (2014). Both datasets were manually entered into the LCA Extended Enterprise Budget Excel sheet. The lists of all inputs used and outputs produced in strawberry production for four states were tabulated (Appendix A, Supplementary Materials). After extraction of LCI data, the UWDFE (University of Washington Design for Environment) lab Excel-to-ILCD (International Life Cycle Database) File Generator (LCA Commons, 2014) was used to create intermediate flows for strawberry production. Generated intermediate flows were imported into Open LCA v. 1.4.2 software to perform a LCA for strawberry production. The U.S. LCI Database (2014) contained processes for the production of fuels and nitrogen fertilizer but not for some specific inputs including materials, other fertilizers, pesticides and agricultural machinery. Therefore, these processes were created using existing raw material and energy flows in the U.S. LCI Database (see next paragraph). Mass allocation method was used to allocate the emissions to co-products in upstream processes. Direct N_2O emissions from agricultural soils from applied nitrogenous fertilizers were estimated as 1.25% of applied nitrogen (IPCC, 2006).

2.4. Flows and processes

Production processes for agricultural machinery (e.g. tractor, disc, plow, leveler, chisel plow, cultivator) consisted of manufacturing, assembly, repair and maintenance stages. In the manufacturing process, still and rubber were the main raw materials. For steel, the existing process flow (“steel billet” production) from the U.S. LCI Database was used, however, there were no processes for rubber, machine assembly, repair and maintenance in the