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Life cycle assessment of Indian silk

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ABSTRACT

The environmental impact of textiles is an area of increasing interest for consumers and legislators. Life cycle assessment (LCA) is the commonly used decision support tool for quantifying environmental impacts, and has been applied to most all major textiles. So far there has, however, been no cradle-to-gate assessment of raw silk production.

On the basis of a review of literature on silk production, this paper constructs a first life cycle inventory of the production of high-quality silk under tropical conditions in southern India. Values are calculated for the following environmental impact indicators: global warming potential, ecotoxicity, freshwater eutrophication, land occupation, cumulative energy demand and blue water footprint. The functional unit is defined as 1 kg raw silk, at factory gate. The analysis compares best practice recommendations with observed farm practices. Where applicable, data gaps have been highlighted.

Results indicate that silk production following recommended practices is input intensive and that on a mass basis, environmental impacts are above those reported for other natural fibres. The majority of environmental impacts stem from cocoon production, in particular fertilization. Farm practices diverge from recommendations significantly and the observed impact per functional unit is higher. The multiple stages required to manufacture raw silk result in a large amount of co-products. Increasing the efficiency in utilisation of these could reduce the high impact observed in this study.

1. Introduction

The environmental impact of agriculture and textile production is of growing interest for legislators and consumers that demand environmental credentials of products and services. In order to quantify environmental impact and understand best ways to improve production processes, life cycle assessment (LCA), is often used as a decision support tool to compare production systems (e.g. conventional vs. organic farming), and analyse tradeoffs between them. LCA has been extensively used to understand the impact of fibre production and analyse advantages and disadvantages of manmade vs. natural fibres (Van der Velden et al., 2013). Despite its long history and unique properties as a biomaterial, what literature is available on the environmental impact of current silk production has to our knowledge never been synthesised using a common methodological framework such as LCA.

Silk is a natural fibre consisting of the protein fibroin, and used in textiles for at least 5000 years. Over 90% of commercially produced silk is extrusion spun by the domesticated silkworm *Bombyx mori*, a monophagous insect whose diet is restricted to the leaves of the mulberry tree. In regions such as South India, mulberry plants are harvested five to six times per year and used to feed silkworms in specialised rearing facilities. The silkworms go through 5 instars before spinning their cocoons, a process taking about 28 days. In India, once spinning is complete but before the moth emerges, cocoons are sold to reelers at regulated markets. In temperate regions storage of cocoons prior to further processing is necessary as generally only two crops a year are harvested. Cocoons are dried with hot air, killing the pupae and preventing eclosion of the moth. Importantly, correct drying increases both silk yield and quality, and is recommended practice even in tropical areas with year-round availability (Yong-woo, 1999). Reeling requires immersing the cocoons in hot water, in order to soften the sericin protein which binds the fibres together to form the tough cocoon shell. Softening enables brushes to find and pull the end of the silk filament. The free silk ends of several cocoons are attached to a reeling machine and unravelled onto spools. Finally, the silk is dried and re-reeled onto standardised spools. The resulting consolidated fibre is ‘raw silk’. Raw silk is an internationally traded commodity (United Nations, 2013) and further processing steps are largely similar to those of other textiles. Co-products generated in reeling are unreelable silk, sericin and pupae.

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Detailed information on silk production methods is available from sericulture manuals (Dandin et al., 2003; Ganga, 2003a,b) and guidance to farmers provided by public sericulture extension agencies. In India this function is performed by the Central Silk Board and associated agencies, as well as state-level sericulture departments. Several surveys of sericulture are available, analysing productivity, profitability and yield gaps. Mulberry yields are usually assessed (Mattigatti et al., 2009; Reddy et al., 2008), input use is, however, rarely reported. Balasaraswathi et al. (2006) conducted a survey of 100 bivoltine sericulture farmers in Tamil Nadu, reporting fertilizer use, leaf yields and cocoon yields, one of the more complete snapshots of farm practices.

Few studies analyse the direct or indirect environmental impact of silk production. Akter et al. (1998) documented health and safety issues in small-scale silk production in Bangladesh. Fabiani et al. (1996) and Dai-gang (2013) documented emissions to water from the reeling and degumming processes, where the sericin 'binder' is removed, leaving only the silk fibre. Mande et al. (2000) and Shenoy et al. (2010) reported on energy and water use in the silk reeling industry in Karnataka, India. Vollrath et al. (2013) compiled a first life cycle inventory LCI of farm practices based on a pilot survey in Karnataka, focussing on energy use. Results showed that energy requirements for silk were above other natural fibres and farm practices diverged significantly from guideline values. A full LCA incorporating co-products has to our knowledge not been performed previously on either the agricultural or reeling aspects of silk production. Sara and Tarantini (2004, 2003) performed a pilot life cycle assessment of silk yarn and fabric production.

2. Methods

The methodology employed in this analysis was LCA according to ISO 14040/44. We constructed models of mulberry cultivation, silkworm rearing, and silk reeling. The resulting life cycle inventory was parameterised using literature data from peer-reviewed publications and government reports and guidelines. Two sets of results are presented, for silk production according to published guidelines and for observed farm practices. Mulberry production is assumed to take place under irrigated conditions, silk reeling by multiend machine.

The following impact assessment categories were studied; Cumulative energy demand v 1.08 (CED) (Hischier et al., 2010), divided in renewable (R CED) and not renewable (NR CED), Global warming potential over 100 years (GWP_{100}) v1.02 (IPCC, 2006), Ecotoxicity through USEtox (Rosenbaum et al., 2008), urban and agricultural land occupation (ALO) and freshwater eutrophication (FE) ReCiPe E v.1.09. (Goedkoop et al., 2013). The Blue water Footprint (BWF) is calculated following Hoekstra et al. (2011). Calculations were performed in Simapro v 8.0.2 (Table 1).

2.1. Goal and scope

The goal of the study is to analyse Indian production of gradable raw silk under recommended and observed farm practices, in order to identify gaps in available data and possibilities for improvement. The functional unit is one kg of raw silk from monobivoltine (MBV) cocoons at factory gate, allowing comparison with internationally traded silk.

Table 1
Impact categories and employed assessment models (implemented in Simapro v. 8.0.2).

Impact category	Assessment model
Cumulative energy demand (CED)	CED v.1.08
Global warming potential (GWP_{100})	IPCC (2006) GWP 100a v.1.02
Blue water footprint (BWF)	Hoekstra et al. (2011)
Ecotoxicity	USEtox (default)
Freshwater eutrophication (FE)	World ReCiPe midpoint E v.1.09
Agricultural land occupation (ALO)	
Urban Land occupation (ULO)	

The analysis focuses on the largest Indian silk producing state Karnataka and neighbouring states Andhra Pradesh and Tamil Nadu. Within system boundaries are mulberry cultivation, egg production, silkworm rearing, transport of inputs, and silk reeling (Fig. 1). Establishment of mulberry fields and capital goods within system boundaries were included. Emissions to soil, air and water were included, as was direct blue water footprint. For consistency with the Ecoinvent v2 database the embodied solar energy in mulberry was included, as was bound carbon in raw silk. Given the large amount of co-products produced, two allocation approaches are compared, system expansion and economic allocation. A one at a time sensitivity analysis was performed to evaluate robustness of the results in light of unknown representativeness of farm-level data, and to clarify where further efforts to increase data availability and quality should be focused.

2.2. Modelling emissions

Emission factors (EF) for fuelwood combustion in India were taken from Saud et al. (2013) and Venkataraman et al. (2010), based on eucalyptus wood, commonly used in the reeling industry. Nitrate emissions, biological and chemical oxygen demand (BOD and COD) to water from reeling were estimated based on sericin losses, assuming total oxidization and nitrification. We used standard Intergovernmental Panel on Climate Change (IPCC) N_2O EF for synthetic and organic fertilizer application as values compiled for India (Bathia et al. 2004) may not be representative (Tirado et al., 2010). Phosphate and NH_3 emissions from fertilizer application were estimated according to Nemecek and Kägi (2007). Due to a lack of reliable data, erosion induced phosphorus emissions to freshwater were estimated assuming phosphorus lost per hectare equal to that of Ecoinvent module for Indian kenaf. Heavy metals in fertilizer and farmyard manure (FYM) were considered as emissions to soil based on composition (Nemecek and Kägi, 2007). The fate of active ingredients in pesticides in the field was modelled as in Berthoud et al. (2011). Pit composting under anaerobic conditions is recommended practice (Dandin et al., 2003). We modelled gaseous emissions from compost based on Amlinger et al. (2008), assuming backyard composting is a valid approximation of local practice. Survey data (Vollrath et al., 2013) confirm open pit or heap composting is common practice.

It is assumed all carbon uptake in mulberry growth is returned to the atmosphere within the boundaries of the system, with the exception of the carbon content (45%) of silk fibres. Where the carbon is emitted in the form of compounds with a different characterization factor (CF) this is accounted for.

Changes in soil organic carbon (SOC) are not included, as there is no evidence of changes in management practices over time. Nevertheless, there is evidence that fertilization on the basis of soil tests increases SOC compared with common farm practices (Vedavyasa et al., 2011).

2.3. Life cycle inventory

Recommended practices were based on government guidelines (Govt. of Andhra Pradesh, 2013a,b). Current practices are based on the survey of Balasaraswathi et al. (2006) of MBV cocoon production in Dharmapuri district. As silkworms were not produced in summer, excess of mulberry is assumed to be given as fodder for livestock. Lacking data were approximated using Dandin et al. (2003) and Ganga (2003a,b). Irrigation, field operations and