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Environmental impacts (LCA) of red raspberry production. A comparative case study of open field and tunnel production in Finland

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Abstract

Red raspberry has traditionally been grown as perennial open field crop in Finland. However, due to winter injuries and fruit quality losses under bad weather conditions, 70% of the Finnish raspberry yield is now produced in tunnels as annual production. While agronomic benefits are widely known, the environmental impacts of tunnel production have been less studied. The Life Cycle Assessment (LCA) approach was used to compare the environmental impacts of open field (OF) and tunnel (TU) production of red raspberry. The system boundaries included the production chain from input production until a ready-to-sell product. Growing data for three years were collected from four representative Finnish raspberry growers to assess environmental impacts in nine impact categories such as climate change impact, eutrophication impact, and land occupation. Environmental impacts were allocated for yield mass (kg). Up to ten times higher yields in TU than in OF equalized the difference between the input-intensive TU and the low-input OF. In most of the categories no differences between the production systems were found, but the environmental impacts came from different sources. E.g., in TU, production of the inputs such as fertilizers and substrate, and tunnel structures and other materials caused two thirds of the climate change impact whereas in OF, share of the growing activities made up over a half of the climate change impact. Eutrophication impact and land use were 60% and 70% lower in TU, respectively, as compared to OF. The results indicate that resource efficiency and growing expertise to achieve high yields are important factors to decrease environmental impacts.

Key words: berry production, eutrophication impact, cultivation system, land occupation, life cycle assessment, use of chemical plant protection products

INTRODUCTION

Red raspberry (*Rubus idaeus*) has traditionally been grown as perennial open field crop in Finland. However, the lack of winter hardy modern cultivars and fruit quality losses under bad weather conditions have decreased open field production. Even 70% of the Finnish raspberry yield is now produced in tunnels as annual production (Luke, 2022). Along the better controllability of the production, yield levels increase in the tunnels but at the same time intensive annual production requires more inputs than perennial open field production, such as annual long-cane plants, substrate, pots, and tunnel structures.

Life cycle assessment (LCA) is a standardized method that quantifies inputs, outputs, and the potential environmental impacts of a product or service through its whole life cycle from cradle to grave (ISO 2006a; ISO 2006b). Earlier studies of the environmental impacts of berry crops have been focused on strawberry. Soode-Schimonsky et al. (2017) found that open field strawberry production had a lower product environmental footprint (European Commission, 2013) compared to tunnel production in Germany. Also, Valiante et al. (2019), assessed LCA of strawberry production in twelve impact categories and concluded that biennial strawberry crop cycle in the open field in Italy has a lower impact than annual, soil-based tunnel

production of strawberries in Switzerland. In UK, the covered strawberry cultures had higher climate change and energy use impacts than open field production (Warner et al., 2010).

Only few reports on the environmental impacts of raspberry are available, as studied in Italy (Girgenti et al., 2013; Peano et al., 2015) and UK (Foster et al., 2014). However, comparative studies between different production methods are lacking. In this study we report for the first time a comparative case study between open field and tunnel production of raspberry in northern climate, in Finland.

MATERIALS AND METHODS

The Life Cycle Assessment (LCA) method was used to study the environmental impacts of raspberry open field production (OF) and tunnel production (TU) considering several environmental impact categories (Table 1).

Table 1. Impact categories used in the Life cycle assessment

Impact category (unit)	Method details
Climate change impact (CO ₂ -eq)	EF 3.0: Climate Change (Fazio et al., 2018)
Eutrophication (PO ₄ -eq)	Heijungs and Guinée (1992); Seppälä et al. (2004, 2006)
Cumulative energy demand (MJ)	Cumulative Energy Demand, V1.11 (Single issue)
Resource use, fossils & Resource use, minerals and metals (MJ & kg Sb-eq)	EF 3.0: Resource use, fossils & Resource use, minerals and metals (Fazio et al., 2018)
Land occupation (m ² a)	Selected LCI results, V1.05 (Single issue): Land occupation, m ² a
Water use (m ³ -eq)	EF 3.0: Relative Available Water Remaining (AWARE) (Boulay et al., 2018)
Use of plant protecting products	

The system boundaries included the production chain from input production until a ready-to-sell product, cradle to farm gate (Table 2). Thus, cooling after harvest and temporary storage at farm were included, as well as waste management, but not delivery into to the wholesale or retail chain. Travel and accommodation of workers were excluded, too. The functional unit used was 1 kg of fresh berries.

Data on the raspberry production were collected from four representative Finnish raspberry growers covering three years. Secondary data related to the production of inputs were obtained from the Ecoinvent 3 database (Ecoinvent Association, Zurich, Switzerland). Data on the direct emissions caused by transport was obtained from the Lipasto database (Technical Research Centre of Finland VTT, 2017)

Table 2. Main and sub-groups of the feeds included in the system boundaries.

Main group	Sub-group
Inputs (production and use)	Plants, fertilizers and lime, substrates, pesticides, refrigerants
Growing activities at farm	Land use, irrigation water, greenhouse gas emission and leakage originating in use of fertilizers and degradation of plant debris
Packages	Packets, boxes, plastic bags
Use of energy	Electricity, machinery work, use of light oil, logistics at farm
Transport and waste management	Transport of inputs to the farm, transport of waste, composting of biodegradable waste, management of hazardous waste
Structures and other materials	Plastic based materials: mulches, fleece, tunnel foil, irrigation tubes, pots; tunnel structures

RESULTS AND DISCUSSION

Yields in the tunnel produced raspberry (TU) were even ten times higher (20-35 t/ha) as compared to open field (OF) production (0.9-4.6 t/ha). As the functional unit used in calculations was the produced fresh fruit, the environmental impacts were frequently equalized between the input-intensive, high-yield TU and the low-input OF with remarkably low yields in Finland. Hence, no clear differences in most of the impact categories were found (Table 3). Eutrophication, use of chemical plant protection products, land occupation and food waste were lower in TU than in OF, however.

Climate change impact in OF varied from 0.6 to 1.3 kg CO₂-eq/kg, whereas in TU it was 0.5 – 0.95 CO₂-eq/kg (Fig. 1A). In UK, Foster et al. (2014) ended up much higher values (> 7 CO₂-eq/kg), whereas Peano et al. (2015) found that in northern Italy climate change impact for raspberries was 0.4 CO₂-eq/ kg. Both studies included transportation to the point of sale. Even if the share of transportation, which was 4% in Italian study (Peano et al., 2015), is considered, it seems that Finnish raspberry production does not cause excessive environmental burden despite the northern conditions. However, different system boundaries and differences in the calculation methodology do not support straight-forward comparison between different regions.

Eutrophication impact and land occupation were 60% and 70% lower in TU, respectively, as compared to OF (Figs.1C-D). Major part of the eutrophication impact was formed at the farm due to growing activities in the both production systems. However, in TU the fertigation of the substrate could be adjusted more precisely according to plant needs.

The magnitude of the observed eutrophication impacts (1.3 and 3.2 g PO₄-eq/kg in TU and OF, respectively) was quite similar to the results of earlier studies; it was somewhat lower than observed in raspberry by Foster et al. (2014) but higher than that reported for tunnel strawberry in soilless cultivation (Ilari et al., 2021).

The use of unrenovable resources (minerals and metals) was on average higher in TU (7.8 mg Sb-eq/ kg) than in OF (5.7 mg Sb-eq/ kg) (Fig. 1B). Though, there was overlapping variation between the production systems. To our knowledge, the use of unrenovable resources has not been studied in raspberry production before. For the tunnel strawberry in soilless cultivation, much lower values (1.7 mg Sb-eq/kg) were observed in Italy, which is largely explained by the two- to three-fold yield levels (Ilari et al., 2021) as compared to Finnish raspberry yields.

Environmental impacts came from different sources in TU and OF. In TU, the share of the production of inputs and structures was over two thirds of the total impact values both in the climate change impact category and the use of unrenovable resources category (Fig 1 A-B). Half of the land occupation was sourced from the production of inputs. In total, one kg of fresh raspberry produced in OF required nearly four times more land than that produced in TU (Fig. 1D).

Improvement options for reducing the environmental impacts have been suggested by several authors. These include replacing the plastic package materials by biodegradable materials with lower environmental impacts (Girgenti et al., 2013; Peano et al., 2015; Bell et al., 2018), use of renewable energy (Soode et al., 2015; Romero-Gómez and Suárez-Rey, 2020), optimization of fertilization and use of recycled materials or materials with longer service life (Romero-Gómez and Suárez-Rey, 2020), or higher yields per area (Tabatabaie and Murthy, 2016). In our data, both the use of different inputs (energy, fertilizers, plant protection products), and materials (including tunnel structures, mulching films, irrigation pipes etc.) contributed considerably to the results, as did the yield levels.

In the categories, in which the share of the inputs was relatively high such as climate change impact and use of unrenovable resources, environmental burden of the production can be decreased by the optimized use of resources.

Table 3. In most of the LCA categories no differences between open field (OF) and tunnel production (TU) were found.

No difference between the production method	Lower impact in the TU compared with OF
Climate change impact	Eutrophication
Cumulative energy demand	Land occupation
Use of unrenovable resources, fossil fuels	Use of plant protecting products
Use of unrenovable resources, minerals and metals (MM)	
Available water remaining (AWARE)	

CONCLUSIONS

Environmental impacts between the two studied production systems, input-intensive tunnels and low-input open-field, were quite similar in most of the studied impact categories. Raspberry production in either of the systems at northern conditions did not cause excessive environmental burden. In all impact categories, the environmental impacts can be decreased with cultivation expertise to achieve high yields. However, number of existing studies in raspberry is low and more research is needed to have a better, holistic overview of the environmental impacts in different production systems in various geographical regions.

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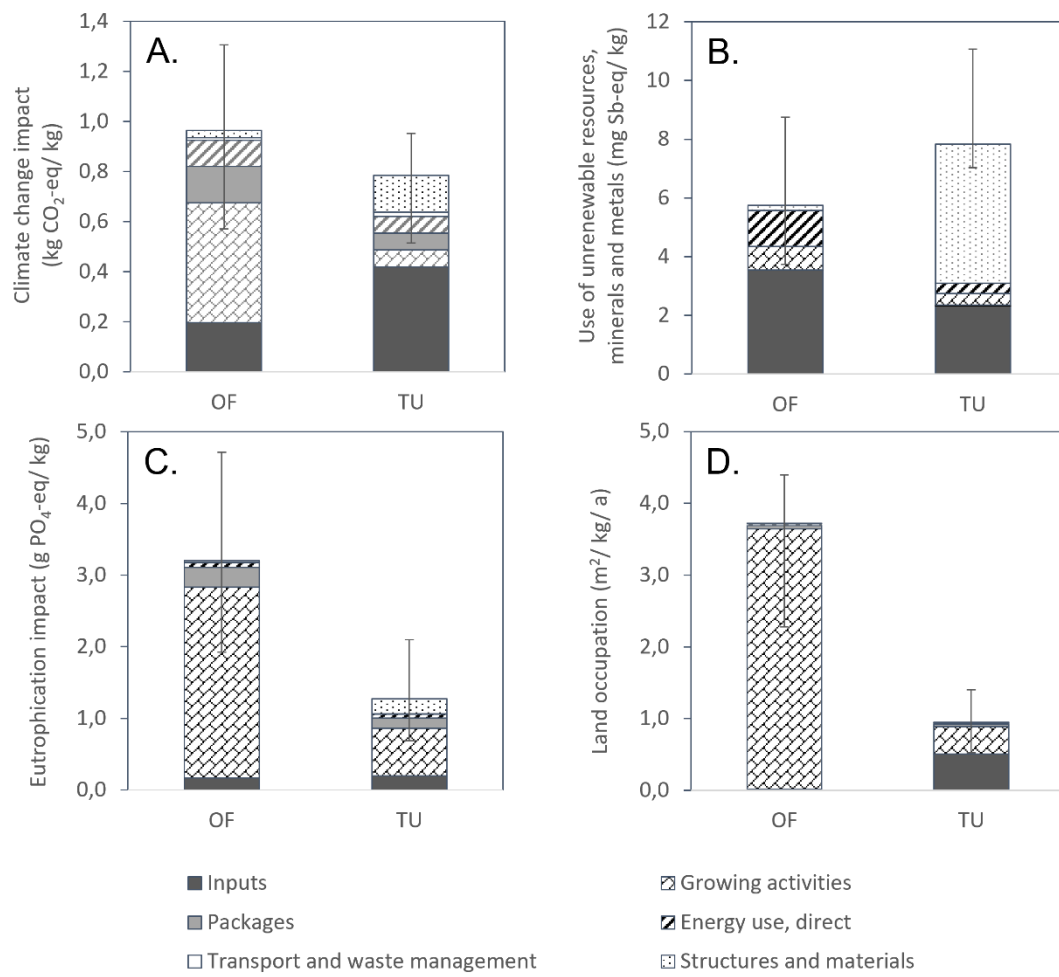


Figure 1. A) The climate change impact, B) the use of unrennewable resources, minerals and metals, C) land occupation, and D) eutrophication impact in the OF and TU production of Finnish raspberry. Vertical bars indicate variation between the farms (min and max value).