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Location and technology options to reduce environmental impacts from agriculture

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ABSTRACT

Production-location and production-technology affect environmental impacts from agriculture and therefore managing these will contribute in the discussion of sustainable agriculture. This research builds on previous research and illustrates the application of current developments in life cycle assessment (LCA) to identify location and technology options to reduce environmental impacts from tomato production systems in Australia. In addition to climate change and water scarcity impacts reported in previous research, this paper presents land use, ecotoxicity and eutrophication footprints based on location specific factors wherever applicable. The results indicated that land use footprints (based on location specific Net Primary Productivity – NPP_0 of tomato production systems) varied from 0.03 to 0.2 m^2.yr-e for each kg tomato at the farm gate (where 1 m^2.yr-e represents 1 m^2 of land occupation for 1 year at the global average NPP_0). Results for ecotoxicity and eutrophication were up to 500 times that of the normalised results of other environmental indicators for open field cultivation and low-technology greenhouse tomato production systems. Ongoing efforts to quantify location-specific emissions to the environment from the use of pesticides and fertilisers from various production systems, and the development of local/regional characterisation factors in impact assessment, will further progress identification of locations which have the least ecotoxicity and eutrophication impacts. Relocation of greenhouse production to places which require no/limited heating and/or the substitution of fossil fuels in artificial heating by PV are some of the options which should be further discussed for ongoing environmental improvement in vegetable production systems.

1. Introduction

There is a general consensus that current food production and consumption patterns degrade the environment and must change to become sustainable. This research is based on the premise that environmental impacts from agriculture are predominantly a function of production-location and production-technology and these should be identified for moving towards sustainable agriculture. Agricultural development is dependent on production-location which dictates the environment; and, technology, which alters the environment to a greater or lesser degree by cropping and reclamation methods. Previous research has shown that an efficient environmental regulatory approach must therefore consider local circumstances (Lavee, 2013). In contrast to the territorial distribution of industry, geographic location limits agricultural production. The combination of geographic factors such as terrain, climate, soil properties, and soil water allows specific crops to be grown in specific locations which in turn have varying effects on the environment. On the other hand technological development has helped to address unfavourable environmental features in a region; as a result different farming systems are economically possible and expedient in different kinds of environments. Although modern agriculture facilitated through technological development has been hailed in several locations for increasing production, trade, and in general the standard of living, it has also been blamed for many negative changes. In recent times food production and consumption has been consistently ranked amongst the top three sectors having significant impacts on the environment (Millennium Ecosystem Assessment, 2005; Tukker et al., 2006; United Nations Environment Program, 2009, 2012). As a result there is a general consensus towards the need to develop sustainable agricultural systems based on practices which not only produce food but are also less damaging to the environment (Cunningham et al., 2013; OECD, 2001; Pretty, 2008).

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Life cycle thinking, applied through Life Cycle Assessment (LCA) is a standardised and established tool for the quantification of potential environmental impacts of agriculture. The aim of LCA is to generate data which can be used by stakeholders along the production and supply chain for informed decision making in the areas of environmental improvement and sustainability. This paper builds on previous research and applies current developments in LCA to identify production-location and production-technology to reduce environmental impacts from tomato production systems in Australia. First, it reports land use footprints of tomato production systems based at a particular location in addition to climate change and water use impacts reported in previous research. Agriculture is a dominant land use as compared to other sectors occupying close to 40% of global land area; in response there is an increasing interest in harmonising land use impacts in LCA (de Baan et al., 2013; Koellner et al., 2013; Milà i Canals et al., 2007). Productive land is in competition with other sectors of society; as such it is a scarce resource which makes land availability and expansion a constraint to the future food security and environmental sustainability (FAO, 1999; Lotze-Campen et al., 2008). This means occupying productive land at a particular location increases pressure on global land resources more than occupying similar areas of non-productive land. As such it is useful to consider location specific ability of land to produce food and associated environmental impacts in LCA rather than just the land area (FAO, 1999). This research addresses this issue by incorporating a recently developed method of land use footprinting based on location specific factors (Ridoutt et al., 2014) and enables meaningful comparisons between land use impacts from geographically distributed production systems.

Second, an additional area built on previous research on LCA of tomato production systems relates to the comprehensiveness, arguing that relevant environmental impacts should be considered simultaneously (Finkbeiner, 2009). For example although carbon and water scarcity footprints reported in previous research on tomato production systems in Australia (Page et al., 2011, 2012) assisted in strategic decision making for addressing climate change and water use impacts, the effect of production systems on other key environmental issues is unknown. Therefore, other relevant impacts need to be considered along-side the mainstream indicators such as carbon and water scarcity footprints to give a more systemic profile of environmental issues. As such other impacts such as ecotoxicity and eutrophication which are predominantly local impacts are reported in this paper using established methods in LCA. A third area explored in this research is to do with scenario analysis based on renewable technologies as a potential substitute to fossil fuels for reducing environmental impacts from tomato production systems. This analysis is based on the assumption that everything else remaining at par certain alternative technologies will have lower impacts on the environment as compared to those using business as usual technologies. The purpose in this paper is therefore threefold: to analyse the environmental profile of tomato production systems by complementing previous research on carbon and water scarcity footprints by reporting on location specific impacts wherever possible for land use, ecotoxicity and eutrophication; to explore renewable technologies for reducing environmental impacts from tomato production systems, and; discuss production-location and production-technology options for ongoing environmental improvement in vegetable production systems. This paper is divided into following sections: Section 2 is methodology which describes various tomato production systems studied in this research and the methods used for estimating carbon, water scarcity, ecotoxicity, eutrophication and land use footprints respectively; Section 3 presents results and discusses production-location and production-technology options and the need for developing local/regional factors in impact assessment, and; Section 4 concludes the main findings from this research.

2. Methods and data

2.1. Tomato production systems

Tomatoes in Australia are grown in the field or in the greenhouse either in the soil or using soilless medium. Depending upon the level of technology and the yields, three types of greenhouses are identified: the low-technology (low-tech), medium technology (med-tech) and high technology (hi-tech) (Page et al., 2012). This study is based on four geographically defined tomato production systems in two eastern states of Australia: New South Wales (NSW), and Queensland. These included field production, low-tech greenhouse, med-tech greenhouse and hi-tech greenhouse tomato production systems (Table 1). The selected production systems represent some of the most important locations for growing tomatoes in Australia as well as different levels of technology used in their cultivation. The system boundary was from cradle to farmgate and included all of the direct farming inputs (fertilisers, fuel, electricity, water requirement, pesticides) and the greenhouse construction. The functional unit was 1 kg of fresh tomato at farm gate. Information on key resources typically used in a cropping season was collected through a face to face interview with one or more growers/managers for each of the four production systems (Table 1). For detailed inventory of the production systems refer to Page et al. (2012).

2.2. Modelling carbon footprints (CF), water scarcity footprints (WF), ecotoxicity and eutrophication impacts

The carbon emissions and water scarcity footprint modelling for the studied tomato production systems are detailed elsewhere (Page et al., 2011, 2012). In summary the carbon footprint indicates the GHG emissions based on Australian and Ecoinvent database from LCA Simparo software (version 7.3.2). Carbon footprint was estimated based on the latest 100-year global warming potential for GHGs published by the IPCC. The water scarcity footprint is estimated as consumptive water use (CWU, which relates to the removal of fresh water from a water body). The CWU is estimated

Table 1
Key information of the geographically defined tomato production systems in this study.

	Field production	Greenhouse (GH) cultivation		
		Low-tech	Med-tech	Hi-tech
Location	Bundaberg	Sydney	Sydney	NSW Tableland
Water stress index[a]	0.012	0.397	0.397	0.015
Land use (m^2 yr kg^{-1})	0.11	0.04	0.03	0.02
Mean max temp (°C)	26.6	21.7	21.7	17.5
Rainfall (mm)	1032	1214	1214	919
Key inputs				
Crop period (weeks)	16	20	48	49
Yield (kg. m^{-2})	6	16	34	57
Fertiliser				
N (g kg^{-1} tomato)	3.3	6.8	4.7	5.9
P (g kg^{-1} tomato)	1.6	1.2	1.4	0.8
K (g kg^{-1} tomato)	6.6	11.2	7.6	9.6
Diesel (g kg^{-1} tomato)	21	6.2	6.1	5.6
Water requirement (L kg^{-1})	50	38	50	39
Electricity (kWh kg^{-1} tomato)	0.10	0.06	0.09	0.08

[a] Pfister et al. (2009).