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Combining cleaner production and life cycle assessment for reducing the environmental impacts of irrigated carrot production in Brazilian semi-arid region

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ABSTRACT

Agriculture is the activity that contributes most to the emission of greenhouse gases, water quality degradation, soil loss and nutrient runoff worldwide. These harmful environmental impacts are issues in irrigated agriculture in the Brazilian semi-arid region. The rational use of natural resources and the efficiency of agricultural systems can reduce the environmental impacts and are essential for a more sustainable agriculture. However, a limited amount of data concerning the environmental impacts of horticultural practices is available. To date, no evaluation of a carrot crop life cycle in Brazil could be found in the literature. The purpose of this paper is to present a methodological approach combining Life Cycle Assessment (LCA) and Cleaner Production (CP) principles in the environmental and economic evaluation of irrigated carrot farming. Life Cycle Impact Assessment was carried using the International Reference Life Cycle Data System (ILCD, 2011) method, including data uncertainty. We evaluated the base scenario based on management practices widely adopted in the studied area, and the recommended scenario based on adoption of CP selected opportunities using agronomic recommendations for the carrot production system. By these means, the environmental impacts can be reduced between 15 and 70% in the evaluated categories from the base to the recommended scenario. Most environmental impacts were related to fertilizer production and field emissions. The global warming effect related to the emission of 0.12 kg CO_2 eq/kg product from the base scenario can be reduced to 0.07 kg CO_2 eq/kg product in the recommended scenario. This represents a lower value than most global warming rates for carrots found in literature. The costs of inputs were reduced by 49% from in the recommended scenario. Most costs of inputs were related to fertilizers and seed purchasing. The combined use of the two methods proved feasible as LCA identifies the main hotspots of the analyzed system, while CP support practices that reduce costs and the use of inputs such as water, energy, fertilizers, seeds and pesticides. CP provided a higher level of compliance with the technical requirements for the studied system and proved to be more economically and environmentally efficient than 'end of pipe' practices. The complementary use of CP and LCA provided better support for a more sustainable irrigated carrot production in the semiarid region of Brazil.

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List of acronyms

AC	Acidification
AFOLU	Agriculture, forestry and other land use
ANEEL	Brazilian electricity regulatory agency
BS	Base scenario
CONAMA	Environmental national council
CP	Cleaner production
ESRI	Environmental systems research institute
ET-f	Freshwater ecotoxicity
EU-f	Freshwater eutrophication
EU-m	Marine eutrophication
EU-t	Terrestrial eutrophication
FAO	Food and agriculture organization of the united nations
Fig	Figure
GSD	Geometric standard deviation
GW	Global warming
HT-c	Human toxicity, cancer effects
HT-n	Human toxicity, non-cancer effects
IBGE	Brazilian institute of geography and statistics
IH	Water index
ILCD	International reference life cycle data system
INEMA	Institute of environment and water resources
IPCC	International panel on climate change
IR-e	Ionizing radiation to ecosystem
IR-h	Ionizing radiation to humans
ISO	International organization for standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LU	Land use
MAPA	Ministry of agriculture, livestock and supply
N	Nitrogen
NPK	Nitrogen, phosphorus, potassium
OD	Ozone depletion
pH	Potential of hydrogen
PM	Particulate matter
PO	Photochemical ozone formation
RD	Mineral, fossil and renewable resource depletion
RS	Recommended scenario
UNEP	United nations environment programme
UNIDO	United nations industrial development organization
USA	United states of america
WD	Water resource depletion

Units

Eq	equivalent
G	gram
Ha	hectare
Hp	horse-power
Kg	kilogram
Km	kilometer
kWh	kilowatt-hour
L	liter
M	meter
Mg	milligram
MJ	mega joules
Mm	millimeter
T	tonne
Tg	teragram
USD	United States dollar

1. Introduction

The Food and Agriculture Organization (FAO, 2014) estimated that greenhouse gas emissions from agriculture, forestry, other land use (AFOLU), energy use in agriculture and fisheries have doubled in the last fifty years. This increase was mainly due to the expansion of agriculture in developing countries and it could additionally rise by 30% by 2050 if no efforts are made to counter it (FAO, 2014).

In 2010, AFOLU emissions accounted for 24% of global greenhouse gases (IPCC, 2014) and have continuously increased, even though deforestation is declining, mainly due to the application of synthetic fertilizers. Nitrous oxide from this source, is among the largest agricultural greenhouse gas contributions (Smith et al., 2008).

Food crops worldwide use 95% of irrigated land, consume 92% of water for irrigation and 70% of the nitrogen and phosphorus applied to agricultural land, which in turn are excessively deposited in the soil (West et al., 2014).

In 2010, global emissions of reactive nitrogen totaled 189 Tg, of which 161 Tg came from industries and agriculture (Oita et al., 2016). They calculated the nitrogen demand per capita and found that it ranges from 7 to 100 kg N per year. China, India, USA and Brazil accounted for 46% of global emissions of reactive nitrogen.

Agriculture also contributes to the degradation of water quality and water scarcity (Carpenter et al., 1998), by the use of pesticides that are harmful to local and regional biodiversity, water, soil and human health. According to Lima Junior et al. (2014), irrigation increases the yield and improves the quality of carrots, however, either a deficit or an excess of water and inadequate management affect their development. Improper management of the production system increases the cost of electricity and contaminates the water with fertilizers and pesticides. According to Figueirêdo et al. (2016), the modification of fertilization and pest management is the best way to improve the environmental performance of agricultural production.

The Irecê region, Bahia State, Brazil, is a semi-arid region where agriculture is the main economic activity. The study location is a karst[1] region with large groundwater reserves (Leal and Silva, 2004). The availability of surface water is low, but its fertile soils, flat land, and underground water resources favor intensive irrigated agriculture. The groundwater in this region is brackish and its continued use causes soil salinization (Nossa, 2011), nevertheless irrigated carrot cultivation in Irecê has been carried out on a large scale since 1990. Monitoring of groundwater conducted by Maia et al. (2010) in 1969 and 2003 showed a continuous lowering of the aquifer level in the Irecê region due to the intense exploitation of water for irrigation.

Worldwide carrot consumption is approximately 4.29 kg per person per year, making them one of the most economically valuable root vegetables (Freitas et al., 2009). Carrot production in Brazil is concentrated in the States of Minas Gerais, São Paulo, Paraná and Bahia (Freitas et al., 2009). According to the Brazilian Institute of Geography and Statistics (IBGE, 2006), the Irecê region produced

[1] Karst is the term used to describe a type of natural landscape characterized by the chemical dissolution of rocks that lead to the appearance of caves and extensive groundwater systems in rocks such as limestone, marble, and gypsum. Approximately 20–25% of the global population depends on a large extent or entirely of groundwater obtained from Karst regions (Ford and Williams, 1989).