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PROCEEDINGS OF THE LATVIAN ACADEMY OF SCIENCES. Section B,
Vol. 76 (2022), No. 4 (739), pp. 526–530.

DOI: 10.2478/prolas-2022-0081

Original Paper

LIFE CYCLE ASSESSMENT FOR OLIVE PRODUCTION: A CASE STUDY FOR THE REGION OF TRÁS-OS-MONTES, PORTUGAL

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Communicated by Andis Lazdiņš

*The olive tree (*Olea europaea *L.), widely cultivated in the Mediterranean countries for olive oil and table olive production, has an important economic role. In the age of climate change, it is crucial to know the importance of environmental impacts associated to the production system. Thus, the aim of this study was to characterise the environmental impacts of a semi-intensive olive orchard drip irrigated with ground water, located in the Northeast Region of Portugal. Life cycle analysis was conducted according to ISO 14040. We used* openLCA *software, the Agribalyse V. 3 database, and a* cradle-to-gate *analysis in the impact assessment (Recipe Midpoint (H) V1.13). In the climate change category, the results indicated that for production of 1 kg olives, a total of 0.249 kg CO_2-Eq. were emitted to the atmosphere. Regarding the direct impact of production system, a total of 0.177 kg CO_2-Eq. (71.5%) were emitted, followed by indirect impacts associated with raw material of the irrigation system (0.032 kg CO_2-Eq. total, 12.7%), and electricity needed to pump ground water (0.012 kg CO_2-Eq., 4.8%). In relation to inputs for production, the raw material for urea production contributed 0.013 kg CO_2-Eq. (5.0%) of total emissions. To the best of our knowledge, this study was the first carried out in this region, and contributes to a better understanding of environmental impacts that will allow their minimisation and ensure olive orchard sustainability.*

Keywords: *environmental impacts, GWP, LCA, olive orchard.*

INTRODUCTION

Olive (*Olea europaea* L.) is a Mediterranean crop widely cultivated mainly in Greece, Spain, Italy, Tunisia, Portugal, Syria, Lebanon and others (Rajaeifar *et al*., 2014). In recent years, production has increased in new producing countries outside of Mediterranean basin, such as Australia, EUA and others in the American Continent (Salomone *et al*., 2015).

The global olive oil and table production in the crop season of 2019/2020 was 3.207 and 3.0575 million tons, respectively; while the global table olive and olive oil consumption been continuously increasing —3.049 and 3.234 million tons in the same season (IOC, 2021), respectively.

Portugal is a key global producer and exporter of olive oil. This country had significant growth of olive oil production, reaching 140.5 thousand tons in 2019/2020, representing 40% growth in comparison to the crop season 2018/2019. However, table olive production was only 22 thousand tons in the same season (IOC, 2021). The increase of olive production in Portugal occurred after introduction of an inten-

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sive system (from about 205 tree/ha to 900 trees/ha) and a super-intensive production system (more than 900 trees/ha) of olive orchards established in the Alentejo region through the Project Irrigation of Multiple Purposes of Alqueva (EFMA). In 2020, within this irrigation system, 68.346 ha of olive groves were registered, of 120.000 ha available for agriculture in this stage of the project (EDIA, 2020). The EFMA is located in Alentejo, the main olive producer region of Portugal with 188 194 ha orchards, followed by the Trás-os-Montes region, with a total area of 361.177 ha olive orchards (INE, 2019).

The increase of global greenhouse gases emissions (GHG) affects climate change, causing change in precipitation, temperature and other climate characteristics (Krysanova *et al*., 2010). Thus, climate change is a reality that may harmfully affect the olive orchards (Tanasijevic *et al*., 2014). Nowadays, living in a climate change environment, it is crucial to identify environmental impacts associated with the production system.

With growing concern about environmental impacts of human activity, life cycle assessment (LCA) is an important tool of research, which considers all stages of raw materials used in production to estimate the final lifetime output, considering also recycling or rejection of the product and its by-products (ISO, 2006). LCA can be focused on a cradle-to-gate or cradle-to-grave scope, of for different applications like determining the most efficient harvesting machinery type in operations in an olive orchard (Bernardi *et al*., 2018) or same to evaluate the consumption of raw materials and emissions of pollutants to producing 1 kg extra-virgin olive oil (Avraamides and Fatta, 2008).

The aim of this work was to use the LCA methodology to evaluate the environmental impacts associated with production in a semi-intensive olive orchard, as well to clarify the hotspots of each impact category.

MATERIALS AND METHODS

Study area and olive orchard crop management. This study was conducted in a semi-intensive drip irrigated olive orchard (204 plants/ha) planted with 12-year-old cv. Madural, located at Mirandela, in the Northeast of Portugal. The average annual rainfall of the region is 434 mm (ADVID, 2021), with a typical Mediterranean climate — the average annual temperature is 14.3 ^{o}C and the average in the warmest months of the year (July and August) is 31.8 ^{o}C and in the coldest month (January) — 1.2 ^{o}C (IPMA, 2021).

Annually, 61.2 kg·ha^{-1} of NPK fertilizer (20-06-09), 3 kg·ha^{-1} Gliphosate isopropylamine salt (31.2% a.i.) for weed control and 5 kg·ha^{-1} copper oxychloride (50% a.i.) as a fungicide for diseases control are applied.

Life Cycle Assessment methodology and crop management. This approach of LCA follows the principles and framework requirements of the International Organisation for Standardisation 14040 standard series (ISO 14040, 2006).

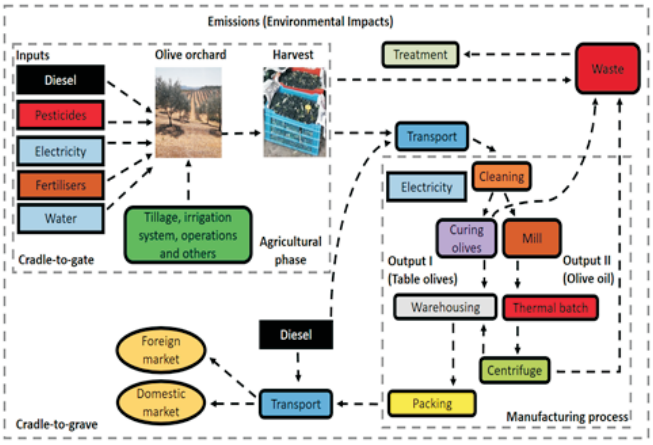


Fig. 1. Supply chain flowchart for the life cycle of olive crop.

In this study, although the olive supply chain is wide (Fig. 1), it was only assessed for the agricultural phase of production of olives and inputs to production, like pesticides and fertilisers, with several processes that originated upstream of the farm stage (e.g., production of raw material, transport, storage, etc.). The transport of olives for industrial extraction of olive oil was not considered in this study.

For the evaluation of the production system, the "cradle-to-farm-gate" approach was used, i.e., considering all input and output flows of materials and resources for olive production. For analysis, the lifetime of the olive orchard was considered to be 100 years. The production of 1 kg of olives was adopted as the functional unit (FU), as a reference.

Software, database and LCIA method used. We used open LCA software for information processing. All inputs and outputs associated with the process were extracted from the Agribalyse (v.3) database — a French Life Cycle Inventory (LCI). Inputs values were based on inventory by the farmer, and the life cycle impact assessment (LCIA) method (Recipe Midpoint (H) V1.13) was applied.

RESULTS

Table 1 shows inputs and outputs used for olive production standardised in FU (1 kg of olives). Beyond olive production, other outputs were generated from inputs applied to the soil, for example, inputs of nitrate (NO_3^-), nitrogen in organic matter and other factors in the SQCB-NO3 model (Sustainability Quick Check for Biofuels) proposed for Emmenegger *et al*. (2009). It should be highlighting that all agrochemical products that were used for agricultural production should be both considered as inputs as well as outputs, due to emissions to the soil and air (Nemecek and Schetzer, 2011).

In 2019, the studied year, the yield of the olive orchard was 3209 kg·ha^{-1} (average 15.7 kg olives per tree). The annual water amount applied for olive orchard irrigation (input)

was 452.7 $m^3 \cdot ha^{-1}$, resulting in use of 0.14107 m^3 water to produce one FU (1 kg of olives).

Table 2 shows the results for 14 of 18 impact categories at the Recipe Midpoint (H) V.1.13. Four impact categories were not considered as their values were null. All estimations were made for one FU (1 kg of olives).

Besides the total values estimated for each impact category in the production of one FU, the main hotspots with most impact were identified and estimated as percentage of the total effect of the impact category.

Considering the impact on climate change (GWP 100), the agricultural phase of production system was responsible for 71.5% of total impact. This was due to two existing flows resulting in atmospheric emissions of carbon dioxide from fossil fuels and dinitrogen monoxide (N_2O). The production of raw material used in the irrigation system, such as pipes, had the second highest impact (12.74%) on climate change. in addition, electricity needed to pump groundwater contributed 4.77% to this category. As expected, volatisation of N pollutants from urea fertiliser was the main hotspot in the category of Ozone depletion (ODPinf), contributing 26.7% of the total environmental impact.

Table 3 shows our results on impact to climate change in comparison with some other studies the used different LCIA methods in other countries, aimed at assessment of olive production. All of them used a cradle-to-farm-gate scope applied. Two of them used 1 ton of olives as a FU

Table 1. Input and output products for olives production in a semi-intensive olive orchard (FU 1 kg of olives ha^{-1})

Input (application of agrochemical products, process or agricultural practices)	Amount	Output	Amount
Application of plant protection product, by field sprayer	0.00062 ha	Ammonia (NH_3)	0.00140 kg
Fertilizing, by broadcaster	0.00031 ha	Carbon dioxide, fossil	0.00598 kg
Establishing orchard	0.00064 Item(s)	Copper oxychloride	0.00078 kg
Fruit tree seedling, for planting	0.00064 Item(s)	Dinitrogen monoxide (N_2O)	0.00057 kg
Carbon dioxide, in air	0.55355 kg	Glyphosate	0.00029 kg
Copper oxide	0.00078 kg	Nitrate	0.11274 kg
Glyphosate	0.00029 kg	Nitrogen oxides	0.00012 kg
Phosphate fertilizer, as P_2O_5	0.00108 kg	Water	0.14107 m^3
Phosphate Rock, as P_2O_5, beneficiated, dry	6.86000E-5 kg	Olives production	1 kg
Potassium chloride, as K_2O	0.00172 kg		
Urea, as N	0.00381 kg		
Transformation, from permanent crop, irrigated	0.03116 kg		
Transformation, to permanent crop, irrigated	0.03116 kg		
Occupation, permanent crop, irrigated	3.11623 m^2*a [1]		
Irrigating, drip, electricity powered	0.14107 m^3		
Energy, gross calorific value, in biomass	7.16200 MJ		
Transport, tractor and trailer, agricultural	0.00156 t*km		

[1] m^2 per year.

Table 2. Life cycle impact assessment (LCIA) results at recipe midpoint (H) V.1.13 level (FU 1 kg of olives ha^{-1})

Impact category	Unit	Total emissions	Main hotspot
Agricultural land occupation (ALOP)	m^2 year	3.11623e+0	PS = 3.11623e+0 (100%)
Climate change (GWP100)	kg CO2-eq	2.47391e-1	PS = 1.77000e-1 (71.5%)
Freshwater ecotoxicity (FETPinf)	kg 1,4-DCB-eq	7.39194e-4	COP = 5.812e-4 (78.6%)
Freshwater eutrophication (FEP)	Kg P-eq	6.99977e-5	COP = 5.248e-5 (74.9%)
Human toxicity (HTPinf)	kg 1,4-DCB-eq	1.16893e-1	COP = 9.764e-2 (83.5%)
Ionising radiation (IRP_HE)	kg U235-eq	1.12206e-2	MELV = 7.55e-3 (67.3%)
Marine ecotoxicity (METPinf)	kg 1,4-DB-eq	1.07185e-3	COP = 8.767e-4 (81.8%)
Marine eutrophication (MEP)	kg N-eq	2.60900e-2	PS = 2.60626e-2 (99.9%)
Ozone depletion (ODPinf)	kg CFC-11-eq	6.57298e-9	MU = 1.7570e-9 (26.7%)
Particulate matter formation (PMFP)	kg PM10-eq	6.89048e-4	PS = 4.74065e-4 (68.8%)
Photochemical oxidant formation (POFP)	kg NMVOC-eq	4.88660e-4	PS = 1.20498e-4 (24.7%)
Terrestrial acidification (TAP100)	kg SO2-eq	4.05215e-3	PS = 3.49405e-3 (86.2%)
Terrestrial ecotoxicity (TETPinf)	kg 1,4-DCB-eq	2.08463e-5	COP = 7.050e-6 (33.8%)
Water depletion (WDP)	m^3 water-eq	1.03366e-1	PS = 1.03366e-1 (100%)

1 m^2 year = m^2 per year; PS = production system, COP = copper oxide production; MELV = market for electricity, low voltage; MU = market for urea, as N.

Table 3. Comparison of results on climate changes between different studies (kg CO_2-Eq. ton of olives)

Authors	Country	FU	Climate change (kg CO_2-Eq. per ton of olives)	LCIA method
This work	Portugal	1 kg olives	247	Recipe midpoint (H) V1.13
Aguilera *et al*., (2015)	Spain	1 kg of olives	Between –10 and 324	IPCC 2006
Romero-Gámez *et al*., (2017)	Spain	1 t olives	Between 95.4 and 309	ILCD 2011 midpoint V.1.05
Salomone and Ioppolo (2012)	Italy	1 t olives	Between 467 and 510	CML v.2 2000

(Salomone and Ioppolo, 2012; Romero-Gámez *et al*. 2017). Thus, to allow comparison with our results and those from Aguilera *et al*. (2015), the values were standardised for one ton of olives.

DISCUSSION

Considering all impact categories (Table 2), copper oxide production located upstream of the agricultural phase was a hotspot in five of them: freshwater ecotoxicity (FETPinf), freshwater eutrophication (FEP), human toxicity (HTPinf), marine ecotoxicity (METPinf) and terrestrial ecotoxicity (TETPinf). Several copper-based products have been used for control against some fungal diseases of many crops. When indiscriminately applied, these products can contaminate soils and sediments in some olive orchards in Greece, exceeding in most cases the critical limit value of copper concentration in soils (100.00 $mg \cdot ha^{-1}$) as set by the European Union (Avramidis *et al*., 2019). Thus, these substances pose a threat to vegetation and animals and humans. There is also a potential risk of leaching and transport of accumulated residues of these toxic products to other sites, including water bodies (Wightwick *et al*., 2010). Therefore, it is essential to monitor the copper concentrations in evaluate risk according to the limits established by European legislation.

The olive production system (agricultural phase) was the main hotspot in seven categories (including GWP100): agricultural land occupation (ALOP), marine eutrophication (MEP), particulate matter formation (PMFP), photochemical oxidant formation (POFP), terrestrial acidification (TAP100) and water depletion (WDP). The agricultural phase has the most impact along the olive supply chain, independent of the adopted scope (Avraamides and Fatta, 2008; Salomone *et al*., 2015; Espadas-Aldana *et al*., 2019). Generally, in conventional systems, this phase has direct links to inputs of fertilisers, pesticides, electricity needed to pump water to irrigation, and other factors.

It is estimated that ammonia volatilisation during mineral nitrogen fertilisation (mainly urea) is responsible for 1/5 of total ammonia emissions emitted from agriculture (Skorupka and Nosalewicz, 2021). For each GWP impact category, it is very important to estimate GHGs emitted during the life cycle of product, because significant sources of emissions can be identified in the chain, allowing thus a better characterisation of the carbon footprint in each step. Therefore, this knowledge allows to make comparisons between products or to make a better decision in prioritisation of achieving greater reduction of the carbon footprint in the production process (Fernández-Lobato *et al*. 2021).

As seen in Table 3, our results are in line with those of similar studies carried out in Spain, but they are lower by about half of the values reported in Italy. In a study on evaluation of several olive cropping systems, negative average values of greenhouse gas emissions were observed in an organic system (–10 g CO2-Eq. per kg of olives) in relation to the observed average values (324 g CO2-Eq. per kg of olives) in a conventional system (Aguilera *et al*., 2015). Organic production of olives reduced the carbon footprint of the system due to efficient carbon sequestration, operating as carbon sink. Good management of by-products as well as application of pruning residues to the soil and use of cover crops help to increase the C sequestration rates (Aguilera *et al*., 2015). The conventional agroecosystem had a number of used inputs, as well as a lot of occurred interventions.

CONCLUSION

The production system (agricultural phase) is the main hotspot of half (seven) of the impact categories assessed, followed by the copper oxide production as a hotspot in five impact categories. This study allowed to achieve better knowledge of the intensive production system of olives in the region of Trás-os-Montes, that will contribute to the development of new guidelines and strategies to minimise the carbon footprint and to mitigate the main impact categories associated with the chain, to ensure that production becomes more sustainable.

Therefore, we anticipate that study results will be a starting point in the development of more studies on olive orchards cultivated in the Portuguese region of Trás-os-Montes, to acquire a better understanding of the level of its environmental sustainability.

ACKNOWLEDGMENTS

Authors are very grateful to the farmer Manuel Pinto for the allowing to develop this study.

This work was funded by Project Olive Oil Operational Group — SustentOlive: Improvement of irrigation and fertilization practices at olive farms in Trás-os-Montes for its sustainability (PDR2020-101-032178), financed by the European Agricultural Fund for Rural Development (EAFRD) and Portuguese State under Ação 1.1 "Grupos Operacionais", integrada na Medida 1. "Inovação" do

PDR 2020 — Programa de Desenvolvimento Rural do Continente. This work was developed with collaboration of National Funds by FCT — Portuguese Foundation for Science and Technology (project UIDB/04033/2020).

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Received 10 September 2021
Accepted in the final form 13 July 2022

OLĪVU RAŽOŠANAS DZĪVES CIKLS: SITUĀCIJAS IZPĒTE TRÁS-OS-MONTES REĢIONĀ, PORTUGĀLE

Olīvkokam (*Olea europaea* L.), ko Vidusjūras valstīs plaši audzē olīveļļas un galda olīvu ražošanai, ir svarīga ekonomiska nozīme. Klimata pārmaiņu laikā ir ļoti svarīgi zināt, cik būtiska ir ar ražošanas sistēmu saistītā ietekme uz vidi. Šī pētījuma mērķis bija raksturot daļēji intensīva olīvu dārza, kas apūdeņots ar gruntsūdeņiem, izmantojot pilienu tehnoloģiju, ietekmi uz vidi Portugāles ziemeļaustrumu reģionā. Tika noteikta tiešā CO_2 emisija, kā arī netieša ietekme, kas saistīta ar apūdeņošanas sistēmā izmantotiem materiāliem un elektroenerģiju, kas nepieciešama gruntsūdeņu sūknēšanai. Veiktais pētījums veidos labāku izpratni par olīvu ražošanas ietekmi uz vidi, kas savukārt dos iespēju samazināt to līdz minimumam un nodrošināt olīvu dārzu ilgtspēju.