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Life Cycle Inventory of the Italian citrus fruit supply chain: Modelling the agricultural phase inventory through statistical data processing

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ABSTRACT

In the application of Life Cycle Assessment (LCA) methodology, the main data resources are represented by commercial databases, which scarcely describe Italian production realities. Given the importance of the LCA methodology for assessing the environmental impacts generated by agricultural processes, the creation of a regionalised and site-specific inventory for Italian agri-food production, which includes all life cycle phases of the main national agri-food chains, is a relevant tool to support the ecological transition towards development models based on the circular economy. This paper is part of the research activities of a project aimed to develop an Italian Life Cycle Inventory (LCI) database of agri-food products and is aimed to propose an approach for the collection of inventory data based on secondary sources specific to Italian agricultural production. In particular, this contribution reports the first results of modelling the national citrus fruit supply chain by using an integrated approach of data processed from statistical sources, regional production specifications and technical-professional manuals. Inputs about macronutrients, determined through an adjustment of the standard doses in normality situations reported within the Agronomic Technical Guides, are on average 7.30 kg of nitrogen, 3.58 kg of Phosphorous and 5.58 kg of potassium per ton of oranges production.

The active ingredients most used in cultivation are Pyriproxyfen, Phosmet, Azadirachtin and Mineral Oils for the control of the principal pest insects and mites, while the recurring use of cupric products and Mancozeb is strictly linked to the control of fungal diseases. The analysis resulted in 47 process sheets for the cultivation of orange, lemon, mandarin, clementine, and minor citrus fruits.

1. Introduction

Studies on the environmental impact assessment of agri-food products are currently increasing, given their importance in guiding the ecological transition towards sustainable production and consumption models. Combining different requirements, such as food security, mitigation of the effects of ongoing climate change, soil protection and biodiversity preservation, remains at the basis of the ecological transition objectives converging on European agri-food systems. Based on these considerations, scientific research remains a key tool for the pursuit of these objectives, as well as to guide the identification of sustainable and resilient strategies without generating negative repercussions for the productivity and competitiveness of the primary sector (Gava et al., 2018). Even in agriculture, tracking and generating quantitative information flows on the environmental impacts generated by individual production processes is possible through the application of methodological tools such as Life Cycle Assessment (LCA) (Sala et al., 2015). The LCA methodology accounts all inputs and outputs related to the life cycle of an agricultural production process, considering geographical, temporal, and technological aspects. However, as pointed out by Notarnicola et al. (2015), the application of LCA methodology suffers from the lack of specific inventory data for Italian agrifood supply chains. Geographic representativeness is one of the main criteria used to describe the quality of data; with reference to the agro-food sector, this criterion becomes crucial, due to the enormous influence that all the phenomena characterising a specific territory have on the primary production process, by virtue of the biological element that characterises it and, consequently, on the relative ecoprofiles. To improve the quality of the available data and better represent the peculiarities of their products, as well as the supply chain processes, in several countries, such as France (Agribalyse), Denmark (Food LC DK), Germany (Agrifootprint) and Switzerland (World Food Database) have

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been already developed specific inventory databases for agri-food chains (Morais et al., 2016). Currently, as reported by Notarnicola et al. (2022), the modelling of Italian agri-food product systems relies on secondary data from international databases such as, for example, Ecoivent or GaBi, which do not provide much specific data (lack of data or limited quality) on the Italian agri-food sector and fail to represent the heterogeneity that characterises the country's primary sector. This paper is part of the research activities of a project whose main objective is the creation of a database related to the most representative Italian agri-food supply chains: cereal, wine, olive-oil, and citrus supply chains. The Italian database will be built following the approach described in Notarnicola et al. (2022), consistent with the provisions of ISO 14040:2006 and 14044:2006 (ISO and ISO 14040, 2006; ISO and ISO 14044, 2006). In particular, the project phases will be the following: *i)* definition of a consistent and common method to be applied to all products; *ii)* data collection and construction of the inventory data for each product; *iii)* evaluation of data quality, through the development of a pedigree matrix, with reference to their reliability.

While conducting an agricultural LCA study, a practitioner will try whenever possible to use reliable and accurate inventory data collected from the field (primary data), which was the main approach followed in phase *ii*, just described, of the Italian LCI Database building. However, this approach requires considerable economic, labour and time resources; for this reason the current agricultural database was limited to four supply chains.

2. Material and methods

2.1. Background analysis of the citrus fruit sector

According to Falcone et al. (2020), Italy is the second largest producer of citrus in Europe. The national distribution of citrus in Italy shows a higher concentration in southern regions such as Sicily and Calabria, with values above 80% (ISTAT and Coltivazioni, 2022). The Italian range of citrus fruits consists of oranges, clementines, lemons, mandarins, grapefruits, Satsuma Miyagawa and other citrus fruits such as bergamot, lemon and chinotto, which have a rich and diverse heritage of varieties and excellences associated with different areas in Sicily, Calabria, Puglia, Basilicata and Campania. Oranges represent more than 60% of the total supply, followed by clementines (17%), lemons (16%), mandarins (5%), grapefruits and other citrus fruits. One of the most important characteristics of Italian citrus cultivation is the close link between the products and the territory. This is the case of the PGI "Sicilian Red Orange" from the plain of Catania and the PGI "Clementines of Calabria", whose production is concentrated in the Piana di Sibari. These two products alone represent an important segment of the national citrus market. However, the richness of the areas dedicated to citrus cultivation is also evident in the PDO "Ribera Orange" in the province of Agrigento, in the PGI. "Amalfi Lemon", "Sorrento", "Syracuse", "Messina" and "Rocca Imperiale" (CS), in the PGI "Gargano Orange" and "Lemon", in the PGI "Clementine" in the Gulf of Taranto and in the PGI "Bergamot" in Reggio Calabria (Rete Rurale Nazionale – RRN, 2020). The areas under citrus cultivation, grown according to the rules of organic farming, amount to about 35,660 hectares; of these, more than 6,000 hectares are in conversion (Sinab, 2019). Among the different species, oranges predominate with more than 18 thousand hectares, representing 52% of the area under organic citrus cultivation. They are followed by small citrus with about 10 thousand hectares, lemons with 6 thousand hectares and grapefruits with about 150 hectares. Most of the production is for fresh consumption, but a large part goes to the juice extraction industry, and a smaller amount, mainly bergamot and small citrus, is used for essential oil extraction.

2.2. Methodological approach

As mentioned in the introduction section, LCA is standardised method according to ISO 14040/14044 (ISO and ISO 14040, 2006; ISO and ISO 14044, 2006). LCA can be defined as a "steady-state" methodology (Udo de Haes and Heijungs, 2007), however, the use of specific inventory data from a particular region or area, as reported in the literature, especially for the life cycle phase of agriculture is very important (Yi et al., 2011; Yang et al., 2018). Considering the specificities of inputs or emissions, geographical/spatial, temporal, and technological aspects as well as the choice of functional unit (FU), the definition of the system boundary and how to deal with allocation are the parameters that will define which data are needed to represent all life cycle phases included in the LCA study (Notarnicola et al., 2022). The methodological approach adopted envisages, for the agricultural phase, also the integration of statistical data such as cultivated areas, production yields, etc., with the agronomic information described in the regional agricultural specifications concerning the quantification of diesel and lubricating oil consumption and the use of pesticides and fertilisers (Notarnicola et al., 2022). In the present study, the collection of inventory data on the inputs and outputs of each unit processes, which make up the production process, was carried out through an integrated approach based on the consultation of the Italian National Institute of Statistics (ISTAT) databases, the consultation of the regional integrated production specifications for the year 2021 and the aid of the tabulated values reported in the Prontuario di Agricoltura (Ribaudo, 2017). The collection of all information was performed on an Excel spreadsheet to enter the raw data in a standardised format and with the aim of minimising input diversity by defining default values and ensuring uniformity of descriptions. All data collected refer to the Functional Unit (FU) of 1 tonne of fresh product.

2.3. Data Collection

In particular, the national databases made it possible to obtain information on the area and production data of all the citrus fruit categories studied and grown in Italy. These data were extrapolated for a total period of 6 years, taking into account a period between 2015 and 2020. Extending the time base to the medium-term period made it possible to obtain average values in which the influence (negative or positive) of the fluctuations of certain production factors was minimised. Detailed information was extrapolated from the statistical database at regional level and by category of citrus grown/produced to identify regions affected by significant production (ISTAT and Coltivazioni, 2022). The collection of accurate data on production yields is crucial for the LCA of agricultural products, as it directly affects the functional unit and the quantities of relevant inputs such as fertiliser use, pesticide use, water consumption and agricultural equipment used. The species of the genus Citrus considered are orange, lemon, mandarin and clementine; smaller citrus fruits such as lemon, grapefruit, satsuma, sour lime, chinotto, bergamot and other hybrids were grouped into a single category. The average values of area invested and quantity produced for the period under consideration were then calculated to determine the impact of each category on the national market and the relative production yields (ISTAT and Coltivazioni, 2022). Data from various sources were extrapolated and then integrated for the most important production factors, which are grouped under the terms fertilisers, pesticides, herbicides, irrigation water, fuels, lubricating oil and electricity. Citrus cultivation inputs are influenced by many variables, such as farm size, species and variety grown, planting, cultivation techniques (conventional, integrated, organic), degree of mechanisation, cultivation practises (fertilisation, irrigation, weed control, etc.), geographical location of the farm (plain or sloping) and soil characteristics, as well as strong dependence on weather and climate. For each region, the specifications in the Integrated Production Specifications (IPD) and in the Agronomic Techniques Guides (ATG) for the year 2021 were considered for the aspects of fertilisation, weed and pest control (MASAF, 2022). The specifications of some regions (Molise, Tuscany, Abruzzo and Liguria) didn't include data on citrus cultivation, so the determination of

Table 1
Example of process inputs considered for the construction of the datasheet on the average Italian production of 1 tonne of oranges.

Type	Name	Quantity	Units of measurement
Natural Resources	Land occupation	6.71E-02	ha/year
Intermediate material input	N (Nitrogen)	7.30E+00	kg
Intermediate material input	P (Phosphorous)	3.58E+00	kg
Intermediate material input	K (Potassium)	5.58E+00	kg
Intermediate material input	Copper (Kg)	2.69E-01	kg
Intermediate material input	Mancozeb (Kg)	2.01E-01	kg
Intermediate material input	Pyriproxyfen (L)	1.01E-01	kg
Intermediate material input	Phosmet (L)	1.68E-01	kg
Intermediate material input	Azadirachtin	2.01E-01	kg
Intermediate material input	Mineral oil	2.01E+00	kg
Intermediate material input	Carfentrazone	2.01E-03	kg
Intermediate material input	Diflufenican	3.02E-02	kg
Intermediate material input	Diesel	3.52E+00	kg
Intermediate material input	Lubricant	9.94E-02	kg
Water inputs (mains, surface water bodies, groundwater, etc.)	Water	3.95E+02	m^3
Energy Inputs	Electricity	3.69E+01	kWh
Intermediate material input	Transport	1.15E+01	tkm

these values was based on the information in the specifications of the geographically closest regions. The quantities of fertiliser used were calculated taking into account the main macronutrients (nitrogen - N, phosphorus - P and potassium - K) and determined according to the average yields per hectare of each citrus category and region, taking into account the application thresholds. For pest and weed control, the active ingredients most frequently used in relation to biotic adversities affecting species of the genus Citrus were considered. The values for the useable doses were extrapolated according to the information on the label. The data on water consumption during the cultivation cycle, fuel, lubricating oil and electricity consumption were taken from (Ribaudo, 2017), which doesn't provide data for each region, but determines the distinction into areas according to the type of cultivation and the place where the most production takes place.

The definition of a consistent and common method is crucial to align all inventory contents of each product. Even if LCA is standardised according to ISO 14040/14044 and even if all databases are based on a common framework, there are numerous unresolved issues concerning the food sector. Indeed, certain methodological choices, can drastically influence the outcome of an agro-food LCA (Notarnicola et al., 2012, 2015, 2017a, 2017b; Sala et al., 2017). The cultivation of citrus fruits in Italy is influenced by numerous variables related to the type and environment of cultivation. Considering all production areas, datasets will be generated for each of the above-mentioned variables in line with the objectives of other databases and to ensure better temporal representativeness, the collection of area and production data was carried out with the aim of being as recent as possible, using averages of no less than five years. Area and production data, by individual category of citrus fruit cultivated in the country, were taken from the 2015–2020-time frame and processed to obtain regional averages.

Production input data, obtained from various sources as described in the previous section, were used to determine field emissions from fertiliser application, pesticide distribution and combustion of fuels for field operations. Chemical transport data were estimated based on national averages taken from the EUROSTAT statistical database. The determination of the emissions of the different inputs (Table 1) introduced in the citrus chain was carried out according to the methodological line described by Notarnicola et al., 2020, 2022. About fertilisers, through the IPCC methodology (IPCC, 2006), CO_2 emissions related to the application of lime and urea were estimated. Through the approach followed in the JRC - Technical Reports Suggestions for updating the Organisation Environmental Footprint (OEF) method described by Zampori and Pant (2019), atmospheric emissions of N2O, NOX, NH3 and NO3 to water were estimated. The calculation of emissions was performed through the application of the following formulae:

[Eq. 1] Emissions N_2O (synthetic fertiliser and manure) in air = **[*kg N**0.14]* 44/28**

Conversion factor= 0.022 kg N_2O/1 kg N fertiliser applied

[Eq. 2] Emissions NO_X (synthetic fertiliser and manure) in air =**0.21***(**1**)

Conversion factor = 0.0046 kg NO_X/1 kg N fertiliser applied

[Eq. 3] EmissionsNH_3(synthetic fertiliser) in air = **[*kg N**0.1]* 17/14**

Conversion factor= 0.12 kg NH_3/1 kg N fertiliser applied

[Eq. 4] Emissions NH_3 (manure) in air = **[*kg N**0**.2]* **17/14**

Conversion factor = 0.24 kg NH_3/1 kg N fertiliser applied

[Eq. 5] Emissions NO_{3-} (synthetic fertiliser and manure) in water = **[*kg N**0.3]* 62/14**

Conversion factor = 1.33 kg NO_{3-}/1 kg N fertiliser applied

[Eq. 6] Emissions $CO_2(urea)$ in air =**[*kg Urea**0.2]* 44/12**

Conversions factor = 0.73 kg CO_2/1 kg urea applied

Finally, P emissions to water were estimated using SALCA-P emission models (Prasuhn, 2006). By adopting this approach, it was it was possible to distinguish emission pathways to soil from those to surface water. The determination was performed using the following formula:

[Eq. 7] Emissions P (synthetic fertiliser) in water=**[*kg* P_2O_5*0.05]* 62/142**

Conversion factor= 0.022 kg P/1 kg P_2O_5 fertiliser applied

The quantities of active ingredients used in the control of citrus pests and for weed control were estimated by integrating: data on pesticide consumption for different crops in the various European states reported in the report "The use of plant protection products in the European Union" (Eurostat, 2007), data on the number of treatments and active ingredients provided for in the Integrated Production Regulations (IPR) and in the Agronomic Technical Guides (GTA) (MASAF, 2022), and data on the maximum quantities allowed per treatment of each active ingredient taken from the labels of commercial products. Pesticide data are expressed as quantity or volume per unit area (kg/ha; L/ha), but related to the active ingredient considered. Emissions are estimated assuming 90% absorption on the ground, 9% in air, and 1% in water. Emissions to soil, air and water were calculated according to the assumptions, based on expert judgement, reported in Zampori and Pant (2019). Consumption of fuel, lubricating oil, electricity and water used in irrigation practice were calculated based on data reported in the Prontuario di Agricoltura (Ribaudo, 2017) re-parameterized using the indications of Tassielli et al. (2019). Emissions from fuel combustion were estimated according to Nemecek and Kagi (Nemecek and Kägi, 2007).

3. Result and discussion

Like all activities in the agri-food sector, Italian citrus production and processing contribute significantly to the environmental impacts of global warming, eutrophication, and acidification (Pardo and Zufía, 2012; Ruviaro et al., 2012; Saarinen et al., 2012). As with other databases (e.g. Agri-footprint), this work used consistent data for all citrus categories and regions considered. For example, all values and types of fertilisers, pesticide use etc. are based on the same methodologies and data sources for all cultivated citrus categories. Data collected in our studies showed that the average (from 2015 to 2020) national area

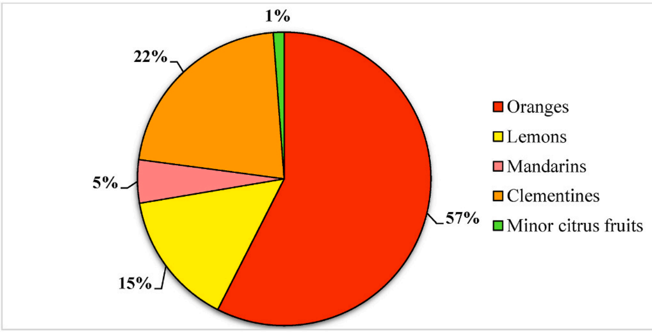

Fig. 1. Percentage distribution of the average national production, by mass, (2015–2020) of citrus fruit by category (Source: ISTAT, 2022).

invested in citrus fruit cultivation is 138,425 ha and that the highest percentages of cultivation are in the southern regions of the peninsula. In relation to the citrus fruit categories, with a percentage of 57%, oranges occupy first place in terms of cultivation and production followed by clementines with 18%, lemons with 17%, mandarins 6% and minor citrus fruits with 1%. In terms of production, the percentages are similar (Fig. 1). At a territorial level, Sicily (59.17%) represents the area of greatest cultivation, followed by Calabria (25%), Basilicata (6.18%), Apulia (4.38%), Sardinia (2.85%) and Campania (1.96%). Smaller orange or citrus productions (<1%) are present in Abruzzo, Liguria, Tuscany, Molise, and Lazio (ISTAT, 2022).

In addition to the active molecules allowed for the integrated control of biotic adversities, the integrated production specifications also contain the intervention criteria and limitations of use. From a comparison of the individual regional documents, it emerged that the active ingredients most used in cultivation are Pyriproxyfen, Phosmet, Azadirachtin and Mineral Oils for the control of the main pest insects and mites, while the recurring use of cupric products and Mancozeb is strictly linked to the control of fungal diseases. Generally, regarding the estimation of pesticide field emissions, within the most used LCI databases, such as Ecoinvent and WFLDB (World Food LCA Database), for simplification 100% of the applied dose is assumed to be emitted into the soil. This approach has also been adopted in the development of the Agrifootprint, Agribalyse, WFLDB and Ecoinvent (Table 2). However, in line with Product Environmental Footprint method (Zampori and Pant, 2019), the processing of the data collected in the integrated production guidelines allowed the distribution of pesticide emissions in the different environmental compartments (water, soil, and air) to be estimated. In fact, it is internationally recognised that the distribution of pesticides in the field also generates emissions to air and water, however, the percentages of products dispersed in different compartments depend on many factors such as type of pesticide, geographical location, time of application and application technique.

These elements, if available, can be used in more complex and accurate pesticide emission estimation models (Birkved and Hauschild, 2006; Dijkman et al., 2012; Fantke and Weidema, 2019), however the approach proposed by (Zampori and Pant, 2019) and used in this paper allows reasonable approximations to be made.

Unlike previous cited databases, DB Food LCA DK does not include the inventory of pesticides used (Notarnicola et al., 2022). Among the active ingredients used for pest control, Carfentrazone and Diflufenican are identified as the most indicated herbicide molecules in the Agronomic Technical Guides (GTA) of all regions (MASAF, 2022). Even databases such as the WFLDB, the amount of input per group of active ingredients such as herbicides, insecticides, and fungicides used per crop and country of cultivation is extrapolated from an existing dataset for a country with similar agronomic and economic conditions through the application of the MEXALCA approach (Roches et al., 2010; Nemecek et al., 2012) (Table 2). With reference to nutrient inputs, the regional production specifications state the average values allowed on a production basis. In the practice of fertilisation, the inputs of macronutrients such as Nitrogen (N), Phosphorous (P_2O_5) and Potassium (K_2O) were determined through an adjustment of the standard doses in normality situations reported within the GTAs (MASAF, 2022), with the individual regional production yields of each production category considered. Generally, the mineral input is calculated based on nutrient uptake by the category of citrus fruit in question. For N, harvested produce and crop residues such as litter (consisting of dead leaves) and pruning residues left in the field are considered. This approach is because, unlike P and K, the nitrogen contained in plant biomass is not readily available to plants. Based on these considerations, for P and K, only the citrus quantities taken from the field are considered (Bengoa et al., 2014).

Table 2
Summary comparison of the main databases containing agri-food datasets.

Issue	DATABASE				
	Agri – Footprint	Ecoinvent	WFLDB	Agribalyse	LCA FOOD DK
Citrus fruit (n. of datasets related to Italian product systems)	0	0	0	0	0
Production	Statistics	Direct measurement and statistics	Direct measurement and statistics	Direct measurement and statistics	Statistics
Fertilizers consumption	Statistics and aggregate data	Average crop requirement corrected for estimated yields	Average crop requirement corrected for estimated yields	Data from national database	Based on norms
Pesticides consumption	Literature and Statistics	Average active ingredient used per crop corrected for estimated yields	Average active ingredient used per crop corrected for estimated yields	Data from national database	Not included
Fuel Consumption	Primary data and expert estimation	Literature and expert estimation	Literature and expert estimation	Literature and expert estimation	Data based on average scenario
Water consumption	Model-based emission	Estimation	Estimation	Estimation	Estimation
Electricity	Average electricity consumption	Country based Estimation	Country based Estimation	GESTIM Model	Average electricity consumption
Transports	Feedprint methodology	Expert estimation	Expert estimation	GESTIM Model	Expert estimation
Fertilizer field emissions estimation	Model-based emission estimation	Model-based emission estimation	Model-based emission estimation	Model-based emission estimation	Model-based emission estimation
Pesticide field emissions estimation	100% in soil	100% in soil	100% in soil	100% in soil	Not included
Fuel combustion emissions estimation	Literature	Model-based emission estimation	Model-based emission estimation	Model-based emission estimation	Data based on average scenario

Table 3
Example of estimated outputs for the average Italian production of 'one tonne of oranges'.

Type	Name	Quantity	Unit
Product	Oranges	1	t
Emissions to air	N_2O	1.61E-01	kg
Emissions to air	NO_x	3.36E-02	kg
Emissions to air	NH_3	8.77E-01	kg
Emissions to air	Copper(kg)	7.25E-03	kg
Emissions to air	Mancozeb (Kg)	1.81E-02	kg
Emissions to air	Pyriproxyfen (L)	9.06E-03	kg
Emissions to air	Phosmet (L)	1.51E-02	kg
Emissions to air	Azadirachtin	1.81E-02	kg
Emissions to air	Mineral oil	1.81E-01	kg
Emissions to air	NMVOC=HG	1.48E-02	Kg
Emissions to air	Nox	2.19E-01	Kg
Emissions to air	CO	4.53E-02	Kg
Emissions to air	Carbon Dioxide	1.10E+04	Kg
Emissions to air	Sulphur Dioxide	3.55E+00	Kg
Emissions to air	Methane	4.54E-01	Kg
Emissions to air	Benzene	2.57E-02	Kg
Emissions to air	PM. 2.5	4.32E-02	Kg
Emissions to air	Cadmium	3.52E-05	Kg
Emissions to air	Chromium	1.76E-04	Kg
Emissions to air	Copper	5.98E-03	Kg
Emissions to air	Nitrogen monoxide	4.22E-01	Kg
Emissions to air	Nickel	2.46E-04	Kg
Emissions to air	Zinc	3.52E-03	Kg
Emissions to air	Benzo(a)pyrene	1.06E-04	Kg
Emissions to air	Ammonia (HH_3)	7.04E-02	Kg
Emissions to air	Benzo(Aa)-Anthracene	2.81E-04	Kg
Emissions to air	Benzo (b)-Fluorantrhacene	1.76E-04	Kg
Emissions to air	Chrysene	7.04E-04	Kg
Emissions to air	Dibenzo(a,H)-Anthracene	3.52E-05	Kg
Emissions to air	Fluoranthene	1.58E-03	Kg
Emissions to air	Phenanthene	8.80E-03	Kg
Emissions to air	PAH	8.20E-02	Kg
Emissions to air	Selenio	3.52E-05	Kg
Emissions to water	NO3	9.72E+00	kg
Emissions to water	P2O5	7.87E-02	kg
Emissions to water	Rame (kg)	8.06E-04	kg
Emissions to water	Mancozeb (Kg)	2.01E-03	kg
Emissions to water	pyriproxyfen (L)	1.01E-03	kg
Emissions to water	Fosmet (L)	1.68E-03	kg
Emissions to water	Azadiractine	2.01E-03	kg
Emissions to water	Mineral Oil	2.01E-02	kg
Emissions to soil	Copper(kg)	7.25E-02	kg
Emissions to soil	Mancozeb (Kg)	1.81E-01	kg
Emissions to soil	Pyriproxyfen (L)	9.06E-02	kg
Emissions to soil	Phosmet (L)	1.51E-01	kg
Emissions to soil	Azadirachtin	1.81E-01	kg
Emissions to soil	Mineral oil	1.81E+00	kg
Emissions to soil	Cadmium	4.56E-05	kg
Emissions to soil	Lead	1.97E-04	kg
Emissions to soil	Zinc	1.21E-03	kg

The values for irrigation water volumes and fuel, lubricant and electricity consumption were obtained by summing the values given in the agricultural manual for each farm in the full production phase of the production category. The modelling of impacts generated by water consumption was carried out considering only the volumes of water used for irrigation, excluding green water (precipitation) as it does not affect environmental impacts. The general approach for the calculation, as stated in the Ecoinvent V3.0 guidelines "Good practice for life cycle inventories – modelling of water use" (Lévová and Pfister, 2012), is based on the water consumed (or blue water footprint) for different crops (Pfister et al., 2011).

In relation to the modelling of emissions generated by fuel consumption, the sources used allowed us to obtain technical information on the tractors and agricultural implements used for citrus cultivation and for each crop operation, diversifying the data by field type classes. This approach made it possible to consider both data on the fuel used in the individual farming operation and the consumption related to the number of trips made by farmers to return to the field and complete the specific operation (Notarnicola et al., 2022). It is assumed that the distance covered by the tractor from the farm's fleet to the cultivated field is 2 km. A similar value is also assumed for the WFLDB (Table 2).

Table 4
Summary matrix of the 47 data sheets derived from the collation of secondary data.

	Oranges	Lemons	Mandarins	Clementines	Minor citrus fruit
Liguria	✓	✓	✓	✓	✓
Tuscany	✓	✓		✓	
Latium	✓	✓	✓	✓	
Abruzzo	✓				
Molise	✓	✓		✓	
Campania	✓	✓	✓	✓	
Apulia	✓	✓	✓	✓	
Basilicata	✓	✓	✓	✓	
Calabria	✓	✓	✓	✓	✓
Sicily	✓	✓	✓	✓	✓
Sardinia	✓	✓	✓	✓	
National	✓	✓	✓	✓	✓

In the reference guideline for the WFLDB it is stated that to estimate data on total machinery input per hectare for a specific crop in a specific country (without specifying the crop operation performed in the field), the Ecoinvent process "Agricultural machinery, general (kg)" is used as the basic dataset and the machinery input is estimated according to the MEXALCA approach (Roches et al., 2010; Nemecek et al., 2012) taking into account the machinery intensity indices in a specific country. In order to obtain detailed data on the impacts of different agricultural operations, the MEXALCA approach is supported by the Cranfield model (Williams et al., 2006), which takes into account land cultivation with an increase in the portion of clay in the soil. In Ecoinvent, the modelling of the impacts of fuel combustion in agricultural processes was performed by defining six classes of agricultural machinery based on information provided by the Federal Agricultural Research Stations. The data on average fuel consumption are taken from Rinaldi and Stadler (2002), while the operating times of the machines can be known or alternatively approximated with the average values given in the reference documentation.

In the application of the LCA methodology, water inputs in agriculture are considered as a potential receptor of pollutant emissions. Eutrophication, acidification and ecotoxicity are the impact categories most considered about water quality. The application of the formulas described in the adopted methodology (Notarnicola et al., 2020, 2022) made it possible to determine the direct emissions to air, water and soil generated by the agricultural phase of the supply chain (Table 3). The overall output of the implementation of the described methodology consists of the 47 datasheets summarised in Table 4 and reported in the supplementary materials.

4. Conclusions

The LCA methodology is highly dependent on the availability of data on the basis of which the life cycle inventory can be drawn up and on the basis of which an assessment of environmental impacts can be made. The quality of these data significantly influences the results, both quantitatively and qualitatively, and is thus the cornerstone for sound results. The most widely used international commercial databases are an indispensable tool for any expert, but of course they cannot reflect local production realities in any particular way. This becomes even more problematic in the case of agricultural and food products, as the production processes used to make these products are closely linked to the environment in which they're produced, due to the biological nature of agricultural production. The research project within which this work was developed aims to create a database of inventory data representative of the production realities of the main Italian agri-food chains. The results presented in this work represent a first intermediate status with regard to the citrus fruit chain. Using statistical data representative of national production realities and technical specifications representative of cultivation techniques, it has been possible to produce 47 national data sheets that can be used as a reference at regional level. The data sources used in this paper make it possible to extend the approach used in this paper to some 140 crops, adapting the technical data to the regions where they are cultivated. The data here presented will be complemented by data on heavy metal emissions. Project activities will continue with the collection of primary data on agricultural and industrial processes in the field, which, together with the results presented in this paper, will form a solid, complete and truly representative database of Italian food production. All data on the 4 mentioned supply chains (cereal, wine, olive oil, and citrus supply chains) will be made available free of charge on the project website (https://www.lcafoodilcidaf.it/).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cesys.2023.100131.

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