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Assessing environmental impacts of nursery production: methodological issues and results from a case study in Italy

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ABSTRACT

A nurseryis aprimary system,providingmaterials used in secondary areas of production such as horticulture, orchards, or forestry. Although the young plants produced in a nursery constitute the fundamental unit of many manufacturing processes, the application of environmental indicators in nursery systems is rare. Several studies indicate that the role of the nursery specifically in theimpact assessment of fruit products is usually underestimated or not acknowledged. Reference models for the application of an environmental assessment method, such as ecological footprint analysis (EFA), in nursery systems are also scarce.

In this study, a general model of a nursery system isdeveloped taking into considerationthe available literature on the topic, adopting a life cycle approach, and the suitabilityin the application of several environmental assessment methods.

An EFA was applied to a real case study in northern Italy in order to validate the model. Strengths and weakness of two units (100 grafted plant to be sold and one hectare production surface) are discussed in the light of the results obtained in the case study. Among other case specific results, plastic hadthe highest relative environmental impact in the nursery system (about 80% of the value of the total footprint),making it the main resource used which should be re-considered to improve the environmental performance of the system.According to the proposed model, the nursery stage accounts for almost 17% of the entire environmental impact of themain orchard system connected to the nursery in the case study.

KEYWORDS

Ecological footprint analysis, Life cycle inventory, protected cultivation, nursery model, sustainable agriculture

INTRODUCTION

Environmental impact assessment of food products

The evaluation of sustainability is nowadays an important aspect in the study of agricultural systems and the number of projects and methods for impact assessment of food production systems is increasing (Notarnicola et al., 2012). Although several studieshighlight the importance of harmonising impact assessment protocols (van der Werf et al., 2013), each framework for environmental product declaration on foods developed specific guidelines and rules. One of the most widely used declaration protocolsfor food products is the International EPD® System, standardised as type III labelling (ISO 14025). This declaration system works with rules based on a hierarchical approach following the international standards ISO 9001, ISO 14001, ISO 14040, ISO 14044, and ISO 21930. As a consequence, the life cycle approach is a mandatory procedure and reference is made to life cyclebased information as content for consideration for product category rules (PCRs) (Del Borghi, 2013). In the International EPD® system, fruit products are covered by a general PCR (fruits and nuts – 2012:07) for the sector and five other specific PCRs (Cerutti et al., 2013 a). Another important international framework for environmental declaration is the Product Environmental Footprint (PEF). This protocol was developed by the European Commission’s Joint Research Centre and is based on existing methods that have been tested and used extensively (European Commission, 2013). In this framework, Product Environmental Footprint Category Rules (PEFCRs) are used, but, up to now, the protocol has covered the testing phase and as yet there are only draft PEFCRsavailablefor fruit.

In both thesecontexts, the role of the nursery in theimpact assessment of fruit products is usually underestimated or not acknowledged (Cerutti et al., 2013 a). Nevertheless, several studies (Milà I Canals et al., 2006; Bessou et al., 2013) have already pointed out that notincluding the impact of thenursery in the evaluation of the environmental performance of an orchard could lead to misleading results.

Furthermore, nurseries can be defined as primary systems, which producethe raw material used in relatedactivities, such as fruit farming. The plants produced in the nursery constitute, therefore, the fundamental unit of many manufacturing processes (Hartmann et al., 2002). It is clear how useful it can be to acquire information about the sustainability of a basic production system for the quantification of production systems connected to it.

Moreover, despite increasing application of environmental assessment methods, such as life cycle assessment (LCA) and ecological footprint analysis (EFA), in the fruit sector (Cerutti et al., 2013 a), studies with detailed application of the indicator to the nursery sub-systems are very rare. As a consequence, methods for modelling nursery systems for environmental assessment methods are as necessary as specific quantification of the impact ofnurseries (Russo et al., 2008).

The objectives of this work were:

(I) to model nursery production systems for the application of an environmental assessment method;

(II) to validate the model thorough the application of the EFA to a real case study; and

(III) to verify the applicability of the method in terms of significance of the results compared withenvironmental impacts of the whole orchard.

The nursery system and its environmental impacts

Europe is one of the most important areas for nursery systems (AIPH, 2011). In 2011, Europeproduced 44.1% of flowers and potted plants in the World, compared to 12.9% in China and 11.8% in U.S.A. (AIPH, 2011). The nursery industry in Europe is well rooted: in 2012 the EU28 production of flowers and plants counted 21.096 million euros (DG AGRI, 2013) with highest values in Netherlands (6.552 million euros), Italy (2.699 million euros), Germany (2.483 million euros) and France (2.303 million euros). Taking into account the number of holdings, in 2007 (last year of statistics specifically for nurseries) more than 40000 farms were present in the EU27 Countries, with peaks in Poland (9120 farms), Italy(8450 farms), Hungary(4390 farms) and France (3560 farms) (DG AGRI, 2013).

The nursery is conventionally divided into three parts (Vezzosi, 1985): the nursery buildings;the propagation area, and the final cultivation area.The nursery buildings are made up of structures that allow production and marketing activities; for example, theyinclude warehouses that hold fertilisers, pesticides, stock materials, the offices for administrative activities, loading and unloading area, possibly sheltered from the rain, garages containing machinery and agricultural vehicles, and the exhibition area for customers (Hartmann et al., 2002; Russo et al., 2008).

The propagation area includes facilities for the multiplication of plants, with the objective of providing guaranteed and healthy commercial material. It is not present in all nurseries: some of them purchase raw propagation materials from other nurseries. However, it is essential that the nurserymen produce and sell high-quality plants that fulfil the requirements of a highly competitive market (Vezzosi, 1985).

The cultivation area is the largest nursery surface; it is divided into different sections, depending on the different species and on the development stage of the plants (Russo et al., 2008). The cultivation area can include the raw material collections, where the mother plants from which propagation material (such as cuttings or buds to be grafted) is producedare grown. The area is not present in all nurseries and is usually associated with large propagation centres (Hartmann et al., 2002).

The cultivation area can also include the seedbed where seedlings are produced, and the rooted cuttings area where cuttings are produced: this area can take placein a field or on benches, which can be associated with basal heating and nebulisation (fog and mist) systems (Zamanidis et al., 2013).The grafting area is a cultivation sector that can be located in the open field or, in the case of grape, in a dedicated room. Finally, the storage plant area is the warehouse, in which the plants are stationed before selling (Fideghelli et al., 2005).

Nursery activity, which plays a relevant economical role in the agriculture sector, also represents a source of potential risk for the ecosystem because, as a form of specialised and intensive agriculture, it highly consumes environmental resources that are not easily replenished (such as groundwater).Moreover,nursery activity greatlycontributes to the contamination of surface water and groundwater due totheconsistent use of fertilisers and pesticides (Cambria et al., 2011). The use of chemicals such as herbicides, fungicides, and insecticides is massive in nursery activity since the market requires plants with a high-quality aesthetic aspect and phytosanitary laws (with some variations in the different countries)impose the absence of pests and diseases in commercialised materials.

Nurseries that produce plants in containers use different types of mulching such as plastic semi-permeable sheets; alternatively, pots are placed on concrete floors that severely limit or completely prevent the infiltration of water into the aquifer (Bilderback, 2002). In addition, the use of plastic for pots, covers, and irrigation systems leads to relevant resource consumption and environmental pollution due to their disposal. The areas covered by heated greenhouses or plastic tunnels often use a large amount of diesel oil to ensure satisfactory thermal regimes for the crops. Furthermore, this resource is also used for field operations by means of machinery (Latimer et al., 1996).

Impact assessment methods applied to nurseries

According to recent studies (Cerutti et al., 2011; Bessou et al., 2013; Cerutti et al., 2013 a), the application of environmental assessment methods havegiven lower importance to nursery production as compared withother agricultural production systems such as orchards. In the case of fruit production, the small number of studies on environmental impacts is bound by the lack of knowledge on theimpact of plant production, while all the other inputs, such as fertilisers and pesticides, are well known.

Although in some perennial plantation systems its relative contribution may be negligible (Yusoff and Hansen, 2007), the nursery production process may play an important role for plants that need special production agrotechniques in the early stages, such as specific growth substrates (Ingram, 2012) or plastics for greenhouses (Russo and Scarascia-Mugnozza, 2005, Khoshnevisan et al., 2013). A recent study on protected crops (Cellura et al., 2012) confirmed that the most significant impacts in such cultivations are related to the use of materials for building greenhouses and plant growth media.Greenhouse structures and facilities play a key role in determining the environmental impacts of nurseries.Similar results are obtained by Khoshnevisan et al. (2013) comparing open field togreenhouse strawberry cultivation.

Early studies on the impact ofgreenhouses began in the 1990s. Apioneer study, although not specifically focused on nursery but more on protected crops, is Wada (1993), which developed the calculation of the ecological footprint (EF) by applying this method to the cultivation of tomato in hydroponic greenhouses. Analysis of the EF was used to compare the productivity of hydroponic and traditional, open field, agriculture. Wada takes as reference the tomato crop for several reasons; for example, thisvegetable plant appeared to be the most widely grown in greenhouses at the time of the study, accounting for 44% of all greenhouse crops in North America by sales volume in 1991, so the discussion on the production of tomatoes in greenhouses appeared to be a significant contribution to the debate on greenhouses in general (Wada, 1993). The analysis has shown that hydroponic farming is an example of an only apparent energetic high-performance system and it is, on the contrary, ecologically unsustainable: hydroponic techniques require a 20times higher surface area than traditional agriculture in open field to produce the same output.

After the study of Wada, the role of structures and facilities for protected crops has been deeply investigated, from the impact of plastic greenhouses on ecosystem services (Chang et al., 2011) to the capacity of these structures to perform primary energy saving (Bronchart et al., 2013).

MATERIALS & METHODS

Modelling the nursery system

For the application of an impact assessment method, it is necessary to model the system to be studied. This requires three steps: 1) modelling the studied system;2) defining the boundaries of the system; and 3) quantifying the involved resources (Russo et al., 2008; Ingram, 2012).

The nursery employs several inputs, which are used and are exhausted, totally or partially, during the production processes. The acquisition of data was made through a direct interview with the producer. The owner of the company responded to a questionnaire prepared for the present study, taking into account the observations made in the first phase of the research. This questionnaire consistedofseveral sections.There was an introductory section on general aspects of the company concerning the quantities of production, marketing, extension of the surface, subdivision, and the presence of areas within the nursery. The second and third partswererelated to detailed description of the greenhouse and the methods of propagation that were commonly used. The fourth section included questions related to the company's annual energy consumption, used for machines, irrigation, and equipment that required electricity. The fifth part assessed the presence of machinery for working the land or to facilitate the manufacturing process, such as conveyor belts and machinery for potting. The sixth section analysedwhich materials wereused, such as substrates and containers, pallets, cover materials, fertilisers, and crop protection products. The last part concerned water: sources;method of irrigation;quantity; and the materials used for the plants.

System boundaries

Looking at the production system, whether agricultural or industrial, it is possible to see how its inputs are systems themselves. For example, the production of fertilisers is a stand-alone system with certain inputs and outputs (Latimer et al., 1996).Going even further back, we could say that the machinery used for the production of fertilisers can be considered outputs of an industrial system, and so on. It is evident that to make the application of a method of environmental assessment possible, it is necessary to set limits to the virtual process that we intend to study (Khoshnevisanet al., 2013). These limits are called 'system boundaries' and they separate the internal components from external entities that need not be included in the system studied.

In this case study, as can be observed in **Figure 1**, the production of fuel, fertiliser, crop protection products and other resourceswere included in the nurserysystem.Within the boundaries, there werealso the structures used and the electricity used in the production processes (Russo et al., 2008). The processes of production of tractors and machinery used in the nursery were notincluded in this study.

Resources used by the nursery

For analytical purposes, it is good to define resources as being assets used in the production process to which it is possible to assign a numerical value. The conversion of these inputs through coefficients of equivalence will be the core of the footprint calculation.

As there is no reference in the literature of specific works for the nursery, it was necessary to conduct a preliminary study on the modelling of employed resources. Following the reference bibliography for the application of the EFA in agriculture (Cerutti et al., 2010), the considered resources were broken up into stock and flow (**Figure 1**). The first werethe resources that werecapitalised in the production processes;the other circulated into the system, ranout, and needed to be renewed from year to year.

Stock resources

The stockresources of the nursery are shown below.

- Agricultural surface: the area of the farm destined to plant production, expressed in hectares.
- Deposit surface: the area occupied by the warehouse, the loading and unloading area, and the workshop, in hectares.
- Metal: used in the construction of the frame of the tunnel, under which the plants werebred in pots, and as a carrier material of the irrigation system,expressed in tonnes.
- Cement: a key component in the construction of buildings in the nursery centre, measured in tonnes.
- Plastic: calculated in tonnes, can be considered as stock or flow depending on the system under study. In the nursery, most of the plastic wasimmobilised in the roofing material of the tunnel, in the wing of the dripping irrigation system, and in the shading and mulching sheets. However, a certain amount of plastic

must be considered as a part of the flow system because it passedthroughthe system in the form of pots and containers for plants intended for sale.

Flow resources

Flow resources are included in the production process annually;they circulate and are exhausted once they have accomplished theirusefulness.

- Water: one of the most important resources of the production process, used for irrigation of crops, both in open field and in greenhouses. This resource, however, wasdifficult to quantify since the impact generated from its consumption was strongly linked to the ecosystem in which the production system was located. For example, it is clear that the environmental impact of water use in temperate or semi-arid conditions can be very different. Although the importance of water use in agricultural systems, as today, in the EFA, water is only counted as energy consumed by the irrigation.Because of this lack some studies suggest to couple EFA with other specific water use methods, such as the Water Footprint (Galli et al., 2012; Ridoutt & Pfister, 2013), nevertheless as this kind of studies are at preliminary stage of developments they were not considered for the current research.
- Fertilisers: distributed on crops and essential for the growth and development of plants, thanks to the supply of nutrients. Once they enter the system, they can be either absorbed by plants or run down the system and they have to be evaluatedannually. These substances weremeasured in tonnes and their impact wasquantified in the analysis according to the impacts they generated in their production phase. The use of fertilisers generated impacts also during their distribution, but in this case the fuel consumption wasincluded.
- Pesticides: consumed annually during the production phase,expressedin tonnes of products. From a methodological point of view, they wereassessed in the same way as fertilisers.
- Diesel: the fuel used for the operation of machinery in the agronomic practices carried out both in open field and under cover, expressed in litres.Diesel wasalso used for the heating of greenhouses. It was accountedforin the EF as both energy needed in the supply chainand land required in the re-absorption of CO_2 emitted from the combustion of units of volume.

- Lubricating oils: used for the proper functioning of the agricultural machineries,evaluated in kilograms.The total amount wasderived by taking into account the quantity of diesel used and the tables that bind the consumption of lubricating oil per unit of fuel consumed.

- Electricity: it is used for multiple operations such as for irrigation, for the conveyor belts, and the potting, for the fog system of the tunnel, and for the lighting system. This resource wascounted in gigajoules and its impact waslinked to the energy production of the country in which the analysis wasconducted.

- Substrates: involved in the production cycle as flow resources, because they are exploited for the growth of plants and are subsequently moved away from the nursery within containers that are marketed together with the plant material. However, the substrates are not currently considered a resource in the standards for the calculation of the footprint; therefore, coefficients for the calculation are still not available. In this research, the substrates were studied for the purposes of a realistic nursery model;however, they were not considered in the calculation phase of the footprint.

- Wood: used in pallets for storage, loading, and unloading of the product. It is considered a flow resource because the utility of this material runs out during the course of a production process. It wascounted in tonnes.

Description of the case study

The nursery used for thiswaslocated in the Biella area (Piemonte region), in a typical agricultural area of Northern Italy. The nursery was founded in 1991 and its production wasprimarily concerned with the cultivation of chestnut (*Castanea* spp.) and ornamental plants such as maple trees (*Acer* spp.) and shrubs (*Prunus laurocerasus*, *Photinia* spp., and others).

In order to validate this model and to investigate the relative impact of the nursery in a whole fruit production system, a real chestnut orchard, to which young chestnut plants weresold, was included in the assessment. Chestnut cultivation was chosen for the present study case as it represents a very important agroforestry keyspecies in many temperate fruit-growing regions worldwide(Mellano et al., 2012). The reference orchard system wasthe Tettogarrone farm, located near Cuneo (a different province of the same region). This farm growschestnuts, walnuts, and hazelnuts mainly for fresh consumption and the confectioneryindustries of the area.

The chosen environmental assessment method: ecological footprint analysis

EFA is an environmental accounting method, resulting in a single unit, to quantify the total amount of ecosystem resources required by a region or by a production process. EFA has several advantages: it is scientifically robust, widely used for territorial and production analysis, and easily understandable by non-experts. It quantifies the total area of the terrestrial and aquatic ecosystems necessary to supply all of the resources utilised and to absorb CO_2 emissions of a particular production process. EFA can be used at several geographical scales: from global (WWF, 2010) to regional(Bagliani et al., 2008).

Although the original formulation of EFA (Rees, 1992; Wackernagel and Rees, 1997) focused on five different land types (cropland, built-up land, forest, pasture, and land used for energy production), several studies have indicated that it can be used for investigating the contribution of direct and indirect land occupation. In the agricultural sector, the real land can be: (I) cropland, the actual land surface on which the farm is located and taking into account the production of animal feed not produced on-farm; (II) forest land; and (III) built-up land, occupied by buildings and storage facilities. The real land differs from the virtual land used in the EF calculation, which includes the forest land required to sequester all the CO_2 emissions from non-renewable energy used directly on the farm and, indirectly, for the production of farm input and machinery. This virtual land is also called 'carbon land' and is a fundamental component of almost all the used resources.

EFA can beused as a basis for comparison ofdifferent production systems (Cerutti et al., 2013 b), since end products with a lower EF can be considered to have a lowerimpact on the environment (Deumling et al., 2003;van der Werf et al., 2007). A review of application of EFA on fruit production systems has been presented by Cerutti et al. (2011).

When applying EFA at the product level, it is important to highlight that the use of a single aggregated impact category (such as the global hectare – measure unit of the Ecological Footprint) is seen a major disadvantage compared to a standard LCA which included several impact categories (Finkbeiner, 2009).

Ecological footprint calculation

Quantification of the EFis composed ofa series of calculations thattransform the input data supplied to the production system, each with their own specific unit, into an area value. The production and use of every good and service depend on various types of ecological productivity. Thisecological productivity can be expressed as an equivalent area of land. It is possible to obtain the total EF of the system by summing up the land required for all categories of consumption and waste (Wackernagel and Rees, 1997).

We can identify five methods of calculation based on the typology of input:

a) Input surface

Inputs of this type are those of the land that affect the nursery (cropland and built-up land). Because this type of input is already expressed in terms of area, itsimply needsto be converted from hectares toglobal hectares. Therefore,it is necessary to multiply the values of those inputs to the equivalence factor specific for the type of surface used (Global Footprint Network, 2009). The result will therefore be a value in global hectares thatrefersto the land belonging to the provided input, as can be seen inthe following equation:

(1) $$EF\ (gha) = R\ (ha) \times Eq\ (gha\ ha^{-1})$$

where EF indicates the ecological footprint, measured in global hectares, R is the input as supplied resource, valued in hectares, and Eq identifies the coefficients of equivalence, depending on the category of the area examined.

For example, the agricultural area corresponds to the type cropland, so it is calculatedas hectares of used land multiplied by the equivalence factor of cropland.

b) Input of industrial production

This measures the surface of the area used to produce the energy needed for realisation of the input. For this reason, the variables of the formula are:

(2) $$EF\ (gha) = R\ (t) \times EE\ (GJ\ t^{-1}) \times Eq\ (gha\ GJ^{-1})$$

where EF indicates the ecological footprint, measured in global hectares; R is the resource input provided, evaluated in tonnes (t); EE indicates the embodied energy, a performance factor that measures the energy supplied for production of the input and calculated in GJ per tonne, and Eq refers to the equivalence coefficients.In this case Eq is composed of two energy parameters,*energy 1*, whichtransforms GJ intotheamount of CO_2 produced, and *energy 2*, which translates the amount of CO_2 produced intothearea required for itsabsorption, measured in gha.

c) Input of agricultural/forestry production

With this methodology, it is possible to calculate the areas used for the production of agricultural and forestry inputs, such as wood. For quantification of agricultural/forestry resources, it is necessary to take into account the efficiency factor of the crop (Global Footprint Network, 2009). These resources therefore havea 'double' footprint, which isvalued both as ecologically productive areas, pasture, fisheries, and forest, and as energy lands. The formula for the first type of calculation is:

(3) $$EF\ (gha) = R\ (t) \times Y\ (ha\ t^{-1}) \times Eq\ (gha\ ha^{-1})$$

where EF is the ecological footprint; R the resource expressed in tonnes; Y is the yield factor that corresponds to the ecologically productive area, referringto the used resource,for example, in the case of wood, the value referring to forest land is used (Stoeglehner et al., 2009). This parameter is expressed in hectares for each tonne produced. Eq, however, is the coefficient of equivalence, which refers specificallyto the land type to which calculated hectares belong.

In the second case, calculation of the energy exploited for the production of this type of input, the formula is the one referring to the resources of industrial production (point b). In our case study, this calculation wasapplied to the wood resource.

d) Electricity Input

This calculation method is different from the previously seenformulas, because the resource is already expressed in GJ. Consequently,the calculation does not need to pass through the embodied energy and directly applies the conversion via the equivalence factor on energy:

(4) $$EF\ (gha) = R\ (GJ) \times Eq\ (gha\ GJ^{-1})$$

e) Input of fuels

For the calculationof the oil footprint, the quantity of the resource, expressed in litres (l),is multiplied bya constant value of 1450 gha l^{-1}, provided by WWF's Living Planet Report (2010),and representingthe global average of the Earth's surface needed to absorb the emissions of 1 l of fuel:

(5)EF (gha) = R (l) / 1450 (gha l^{-1})

Once the footprint of each of the resources used is found, subdivided by the area of use, it is possible to proceed with the total sum of all surfaces, in order to obtaina global footprint to be studied related to the output referred to the system under study.

Reference output

The total value of the EF for an entire production system is a useful outcome, but it is not always possible to use it directly to make comparisons with other systems, as these can be very different in size, type of product, and production. The results of this analysis are, however, significant if they are expressed as compared to areference unit. For example, in most studies about EFA applications, results were expressed in global hectares per tonne of product;nevertheless, the use of more than a single reference unit is advised in order to obtain more complete results (Cerutti et al., 2013 b). In this case study, two types of output can be considered significant: the output of production, related to growing plants for themarket; and output of surface, related to exploitation of the soil for the production process.

Production output

Knowing the quantity of output, in this case the total number of plants (manufactured and sold), it was possible to make different considerations on the results obtained.A method mightbe the quantification of the footprint for a hundred pieces, both produced and sold by the farm. In this case, the overall EF calculated above wascompared withthe total quantity of plants from the nursery, divided byone hundred, as can be seen in equation 6.

(6) EF (gha/100 pieces) = EF tot (gha) / (total n° of plants / 100)

Another significant result mightbe evaluation of the EF for each produced plant: it wasnecessary to compare the overall footprint with the number of plants produced and sold (equation 7).To facilitate the reading of the result, it was necessary to transform the unit of measurement gha into total square metres (gm^2).

(7) $$EF\ (gm^2/piece) = EF\ tot\ (gm^2)\ /\ total\ n°\ of\ plants$$

Finally, the result could be expressed as EF per tonne of produced and sold biomass. The calculation method differed from the previous procedure, because it gaveeach species of plant a mass. Taking into account the weight of each plant produced, it was possible to proceed by dividing the total EF bythe global biomass produced and sold (equation 8).

(8) $$EF\ (gha\ t^{-1}) = EF\ tot\ (gha)\ /\ total\ mass\ (t)$$

Surface output

Evaluation of the surface output is a type of expression of the results for analysis of the EF of the nursery underexamination. The result of EF is the ratio between the total footprint of the surfaces and the sum of the footprints of cropland and built-up land of the areas of the nursery, as shown in formula 9.

(9) $$EF\ (gha\ EF\ ha\ nursery) = EF\ tot\ (gha)\ /\ \Sigma\ cropland - built\text{-}up\ land\ (gha)$$

In this way, it waspossible to assess the impact of the footprints of the nursery compared withthe total agricultural land use and built surfaces, taking into account the crops and buildings.

Integration of the nursery results into the orchard system

The results of the present study were used to integrate the output of a previous study by Cerutti et al. (2010). In that case, the same EFA method as previously described was applied to a chestnut orchard, but system boundaries were defined without considering the impacts of the plant production in the nursery. As shown in **Figure 2**, environmental impacts of the nursery were added later in the full orchard EFA evaluation in relation to the number of grafted plants that constituted the plantation. In practical terms, a modular approach

(Jungbluth et al., 2000; Buxmann et al., 2009) has been considered in order to better evaluate the relative impact of the nursery phase.

RESULTS

Life cycle inventory

The first result of this research is the quantification of the resources used in the nursery under study. Accordingly, this section presents the quantities of each resource and their exploitation in components of EF.

Cropland and built-up land: the total area used as a nursery was 7 ha, divided into 1.6 ha of plants in containers kept outdoors, 0.4 ha of cultivated plants in containers under cover, 4.86 ha of surface used for growing plants outdoors, and 0.14 ha used as a warehouse, workshop, and the apron for loading and unloading of goods. Theextension data wereenhanced using formula 1. For the areas of work the coefficient of equivalence of cropland was applied, with the following footprint results: 4.23 gha for growing plants in containers outdoors;1.05 gha for plants in containers undercover; and12.84 gha for the cultivation of plants outdoors.For the nursery buildings, the coefficient of equivalence of built-up land was applied, with the result of 0.37 gha.

Plastic: exploited in all four areas ofthe nursery; in particular, plastic wasused as mulching film, shading net, vases, polyethylene films such as roofing materials, and pipes for irrigation, mounted as drip line (**Table 1**). The annual amounts of plastic were measured in terms of footprint with the method of the inputs of industrial production (equation 2) with the following results: 95.25 gha in the area used for plants grown in containers outdoors; and29.12 gha in the area of cultivation in open field.

Metal: the input of metal wascounted only in the area that included the tunnel, wheretheresource wasused in the support beams of the canvas cover of the structure. To be able to quantify the resource, a model was constructed of a common tunnel based on the ones used in the studied system: for the surface the area of the structure, 4000 m^2, was applied; the length of the structure was666.7 m; the width was6 m; and the height was2.2 m. The metal crossbars werelocated 1.5 m from each other, were8 m long with a diameter of 3 cm, and weighed 4.41 kg each.

The durability of the tunnel wasabout 10years. The total consumption of metal was19.63 t, for a yearly total of 1.96 t in the area of plants grown under cover. Finally, applying equation 2 of the EFA relative to the input of industrial production, the final result was4.55 gha.

Cement: used in the buildings of the nursery. The area occupied by the structure wasabout 400 m^2, with a quantity of cement equal to 1840 m^3, estimated on the basis of the size of the buildings. Considering the density of the cement ratio of 143 kg m^{-3}, this equated to a total of 260 tonnes of cement. Using the estimate fortheaverage duration of concrete structures of 30 years, the annual consumption of virtual cement was8.7 t. Equation 2 was also applied here, giving aresult of 1.69 gha.

Fertilisers: the quantities of fertilisers for crops were provided in terms of total annual quantity. This amount was divided among the areas with agricultural land in proportion to their size and the type of crop. In order to assign a value to each area, a proportion comprising the total area of the section, the total area of the nursery, and the annual consumption was calculated.Fertilisers wereused in the area of plants in containers outdoors, in the areaof plants under cover, and in the area reserved for the growing of plants in open field.The total amount was1.5 t of complex fertilizer.

The impactof fertilisers in terms of footprint wasobtained by using equation 2 and wasequal to: 0.41 gha for the area devoted to outdoor plants in containers; 0.10 gha for the area occupied by the tunnel; and 1.23 gha for the growing area in open field.

Crop protection products: used in areas engaged in the plant cultivation. The calculation procedure wasthe same as that used for fertilisers. The results obtained were0.11 gha for the area devoted to outdoor plants in containers; 0.03 gha for the area occupied by the tunnel; and 0.34 gha for the growing area in open field.

Diesel: the amount of fuel used in the farm was provided by the owner of the nursery as a matter of total annual consumption. To find the value corresponding to each area, we considered a 'weighted' consumption based on the surface area and the type of machinery that was operated on it. The fuel consumption wasthus divided into: 359 l for the area of the outdoor container plants; 3120 l forthe area undercover;958 l forthe area where plants weregrown in open field; and 958 l forthe nursery buildings. For this type of resource, the methodologyusedwas to calculatethe EF relative to the input fuel (equation 5), so the results were: 0.25 gha for the area occupied by plants in containers outdoors;2.15 gha for diesel fuel used for heating and for the workings in the tunnel; 0.66 gha for the growing area; and 0.66 gha for the business centre.

Lubricant: calculated usingan average mechanical relationship that pairs each litre of consumed fuel with about 0.0045 kg of lubricant. This material wasvalued as a source of industrial production (equation 2) with the following results: 0.002 gha for growing plants in containers outdoors; 0.0008 gha for the tunnel; and 0.006 gha for cultivation in open field.

Electricity: this resource was calculated usingsome economic information and evaluating an average annual consumption, which wasreported to be about 20,000 kWh. This input wasvalued using equation 4 anddivided into the areas of the nursery, resulting in the following values of footprint: 0.41 gha per container in the area of cultivation outdoors; 0.21 gha in the tunnel; and 1.26 gha in the area of cultivation in open field.

Wood: for the total amount of wood used in the company, a model was used forpallets, including aweight of12 kg and a duration of 3years. In the company, there wereabout 250 pallets, with an annual consumption of 1,000 virtual kg of wood. This input must be valued as both an industrial resource (equation 2) andas an agricultural/forest resource (equation 3), resulting ina footprint of 1.16 gha of energy land and 0.99 gha of forest land.

Footprint calculation results

By summing up the footprint of all the bioproductive areas, the value of the EF of the entire nursery was obtained;this value was187.81 gha. **Table 2**showsthepartial and total footprints of the various types of terrain and the partial and total impressions divided by areas of the nursery.The percentages of the bioproductive areas were then processed in a graph (**Figure 3-a**), which shows the percentage of the total EF areas.

However, the value of the EF for an entire production system is not a useful result for the purposes of comparison with other systems and, as such, is almost never presented in international research. Instead, the results are expressed as a ratio of total footprint per unit of production or per unit area.

In this case, it was possible to apply equations 6, 7,and 8 to the production outputs, considering a total of 36,646 sold plants and 86,502 produced plants. Taking into account the functional unit of 100 pieces, the footprint value was equal to 0.512 gha per 100 sold units and 0.217 gha per 100 produced pieces. The footprint for each productwas51.25 gm^2 for a plant already on the market and 21.71 gm^2 per produced unit.In the latter case, as a functional unit the biomass produced was taken into account, resulting in2.60 gha t^{-1} and 1.10 gha t^{-1} for sold and produced units respectively.

Another significant result thatis often used in international items is the EF related to the unit of surface area. To obtain this value, it is necessary to divide the total EF of the entire production system bythe total value of cropland and built-up land affectedbythesystem. In this case study,this value was equal to 10.15 gha of nursery^{-1} (equation 9).

The weight of the use of each resource in determination of the EF of the system is interesting. This is presented in **Table 3**, where the weight (%) of each resource, flow and stock, is divided into the areas of the nursery and given in total.

Moreover, the weight of each area of the nursery on the total footprint is presented in **Figure 3-b.**As can be observed, more than 50% of the footprint wasdominated by the impacts generated in the area of plants in containers outdoors.

Integration of the nursery results in the orchard system

Excluding the nursery system, the total annual bioproductive surface occupied by the orchard was3.63 gha, which led to an EF of 0.81 gha/t of fruit. Considering the plant density of the orchard (444 plants per hectare) and EFA results from the nursery module (51.25 gm^2/plant), the total annual bioproductive surface increased to 4.34 gha. Keeping constant the yield, the EF including the nursery was0.96 gha/t of fruit, with a relative increase of 16.39%.

DISCUSSION

The analysis of EF applied to the production system of this study has provided several interesting observations both in terms of method and results.Environmental impact results, expressed in gha per 100 produced pieces (or gm^2 a piece), are useful in the case in which the analysis is carried out by evaluating the life cycle of a certain amount of plants: in this way it is possible to know the impact generated bythem and make considerations on the actions that could be taken to reduce that impact.On the other hand, the expression of EF in gha per tonne of produced biomass is useful in caseswhere it isnot possible to know the quantities of produced and sold material, whereas this information is often translated into tonnes of biomass for simplification by the manufacturer of the company.

In the comparison ofthe areas that form the nursery (**Figure 3-b**), there was a greater impact in the area with plantsincontainers outdoors, while the impact was lower in the area with open field crops. Comparing these results with the data of surface areas involved (**Table 4**), it is clear that the area with greatest extension had a lowerimpact than the total impact of the nursery (12.53%).This wasdue to the use of different inputs than other areas: for example, the plants grown in open field did not need a container in which to develop, or werenot located under a plastic cover. On the contrary, the area with the greatest impact on the total EF (53.60%) had a higher consumption of plastic, a material that was widely used in the nursery.

Particular attention must be given to the area under cover because whilstitwasassociated with a somewhat small real surface (0.56 ha),it had a significant percentage of impact (19.82%). This effect wasdue to a greater use of resources (plastic, metal, and diesel) in this area than in the others. However, if we evaluate the footprint of the area related to the unit of real surface, so comparing the EFassociated with the real surface (gha ha^{-1}), it can be observed that the area with the highest impact, on the same surface area, wasthe nursery buildings, because of the massive use of inputs, such as plastic, cement, oil, and electricity.

The incidence of the corporate hub on the total in this case waslow, because it didnot occupy a large area in the nursery. The second entry showed that the most impactful area of the nursery per unit of surface area wasthe nursery buildings, with a footprint of 185.85 gha ha^{-1}.

Another aspect to be considered is the relationship between the different components of the footprint (**Figure 3-a**): cropland and other bioproductive areas werepoorly relevant on the total footprint calculated for each soil type. This effect wasdue to the incidence of the energy parameter, described by the embodied energy, which affected the input of industrial production. If thisuse of additional energy was not taken into account, the production system would have a lower efficiency (Cerutti et al., 2010).However,in some specific systems, it is possible to reduce the use of these resourcesby rationalising fertilisers and agrochemicals.

This evaluation wasclosely related to the use, and therefore the weight, that each input possessed inrelationto the total;e.g., plastic presented an overall footprint of 151.15 gha on a total of 187.80 gha, so about 80% of the value of the total footprint. This result wasalso due to the fact that plastic, at the end of use, requires a disposal process that is more complex compared with that forother resources. The data areimportant from the perspective of practical suggestions to the producers to lower the impact of their own company. In particular, a recent study (Cellura et al., 2012) has suggested that more environmentally friendly management of plastic can be achieved with a substitution with biodegradable materials, as plastic is the resource with the greatest impactof the entire system.The use of biodegradable materials, however, is an investment that isusuallyexcessively onerous for nursery activity.

The same reasoning can be applied to diesel fuel, which in the area occupied by the tunnel affected the whole environmental load by1.15%. While thislevel seems modest compared withthe percentages of the other resources, it would be appropriate to consider a reduction in fuel consumption in the heating system, which could be replaced by more sustainable systems, with the use of renewable resources. However, such systems are not very common in the nursery industry.

It would be useful to prepare a fertilisation plan that defines the quantities of fertiliser to be used.It would then be possible to compare these values with actually distributedquantities, to assess theimpact of fertiliser and adjust thedosage.

Furthermore, considering impacts of the nursery on the whole orchard system, it is interesting to highlight that without the adopted model,in the case study almost 17% of the impacts would not have been accounted for. This value is lowerthan what estimated in previous publications (about 30%) (Cerutti et al., 2013 a);nevertheless, it is still a significant share of impacts that should be accounted for and characterised for a proper assessment.

CONCLUSIONS

As nurseries are primary systems, their study is necessary in order to better apply environmental impact methods to the whole production chain in which they are included. The proposed model can be applied to most kinds of European nurseries without excluding any significant components of the system, as most emitting sources are included. Considering the environmental assessment method applied to the nursery model, it is interesting to note that EFA has provided satisfactory results, although there is a level of uncertainty with aggregating all impacts into a single indicator. Despite the lack of material about the EFA applied to agriculture, it was possible to obtain a wealth of information both through adirect interview with the owner andthrough the few papers available in the literature. However, the water consumption and substrates were not evaluated due to the lack of the coefficients of data processing.Consequently, these parameters were processed in bioproductive areas and we could not provide the footprint associated with them.

A more extensive application of EF to all the agricultural production systemswould be desirable, in order to provide a useful tool to makethe operations more environmentally sustainable in the nursery.

Furthermore, three conclusions can be drawn about the share of impacts of the nursery system on the whole fruit production system (almost 17% in the case study):

1. Although the share wassmall, it can be considered significant, especially taking into account that the nursery system can be targeted for technical improvements to reduceoverall emissions from fruit production systems.
2. Despitethe complexity of the modular approach, it could be useful for a more systemic assessment of the system, in particular the use of grafted plants as proxy for the impact of the nursery allows a direct connection of the modules and easy calculation.
3. The share of impacts of the nursery is very case-specific, as it varies according tocultivation techniques, plant types, and geographical zone. Therefore, a database with standardised nursery models and related life cycle inventories could be very useful to ease the calculation for environmental experts.

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Assessing environmental impacts of nursery production: methodological issues and results from a case study in Italy

FIGURES

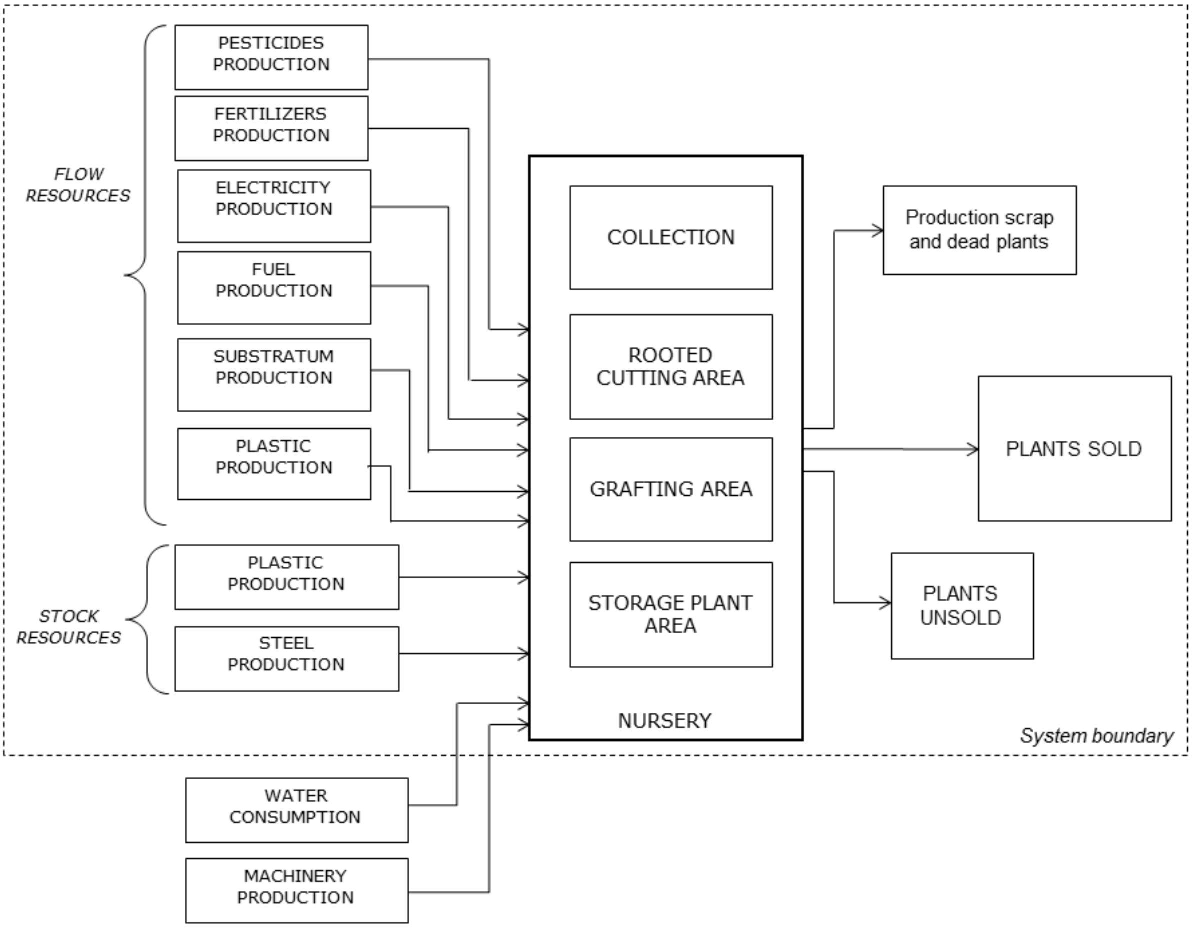

Figure 1.*System boundaries of the case. Environmental impacts related to processes outside the dotted line have not been considered in the analysis.*

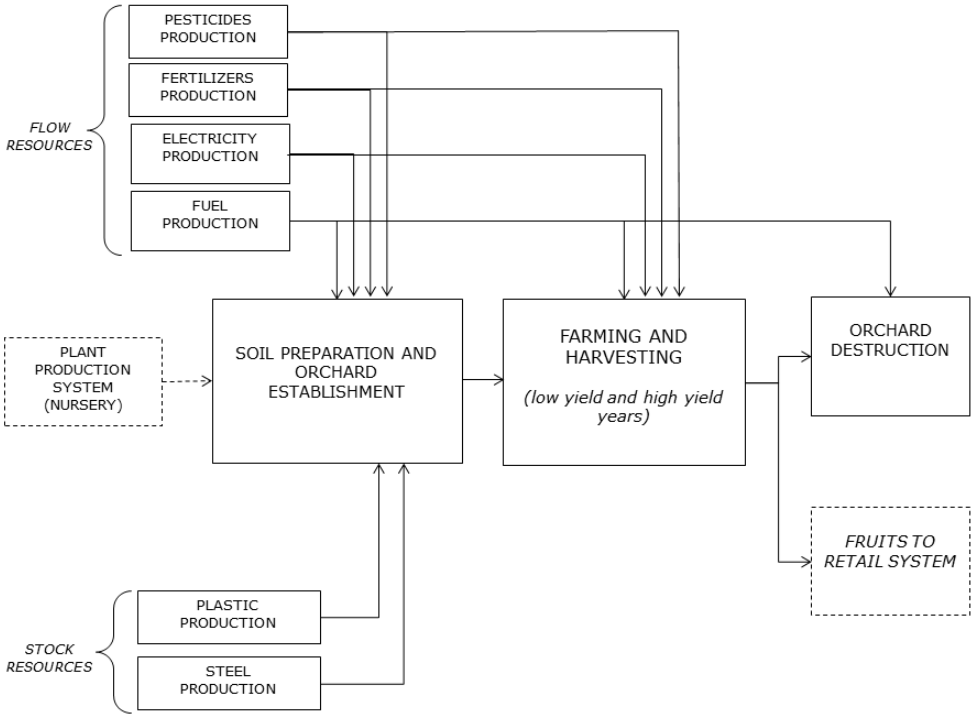

Figure 2.*System boundaries of the chestnut orchard case study. Dotted line boxes indicate processes not included in the assessment.*

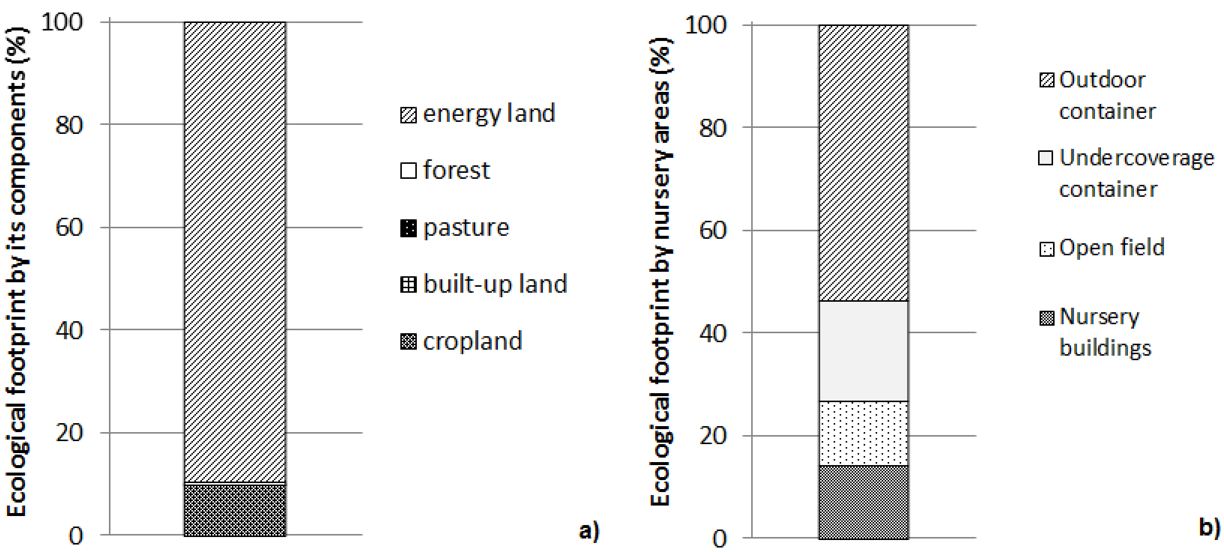

Figure 3.*Breakdown of ecological footprint by land categories (a) and areas of nursery (b).*

TABLES

Plastic material	Calculation parameters	Annual amount
Mulching films	- Average duration estimated from the type of material: 6 years - Average lightness of materials: 110 g m^{-2}	2.36 t
Shading nets	- Average duration estimated from the type of material: 3 years - Average lightness of materials: 90 g m^{-2}	0.12 t
Polyethylene films	- Average duration estimated from the type of material: 2 years - Average lightness of materials: 170 g m^{-2}	0.41 t
Vases	- Annual recovery of the vases: 40%	38.2 t
Irrigation pipeline	- Typology of plastic considered: HDPE polyethylene with a density of 0.9 g cm^{-3}	1.41 t

Table 1 The first column of the table shows the different uses of plastic material, followed by a short note that illustrates the characteristics of the material to be considered in the calculation. Finally, the last column shows the annual quantities, expressed in tonnes.

		Cropland	Built-up	Pasture	Forest	Energy	Surfaces
Outdoor container	gha	4.23	0	0	0	96.43	100.66
Container under cover	gha	1.06	0	0	0	36.16	37.22
Open field growing area	gha	12.86	0	0	0	10.69	23.55
Nursery buildings	gha	0	0.37	0	0.99	25.02	26.38
Total	gha	18.15	0.37	0	0.99	168.30	187.81
Percentages	%	9.66	0.20	0	0.53	89.61	

Table 2 Footprints broken down into different areas of the nursery and total ecological footprint.

	Outdoor container	Container under cover	Open field	Nursery buildings	Entire nursery
Stock resources (%)					
Agricultural area	2.25	0.56	6.84	0.00	9.66
Warehouse area	0.00	0.00	0.00	0.20	0.20
Plastic	50.72	15.50	3.82	10.44	80.48
Metal	0.00	2.43	0.00	0.00	2.43
Cement	0.00	0.00	0.00	0.90	0.90
Flow resources (%)					
Fertilisers	0.22	0.05	0.66	0.00	0.93
Agrochemicals	0.06	0.02	0.18	0.00	0.26
Diesel	0.13	1.15	0.35	0.35	1.98
Lubricant	0.00	0.00	0.00	0.00	0.01
Electricity	0.22	0.11	0.67	1.00	2.01
Wood	0.00	0.00	0.00	1.15	1.15

Table 3 Effect of the single inputs on total ecological footprint

		Outdoor container	Container under cover	Open field	Nursery buildings
Real surface	ha	1.6	0.4	4.858	0.142
Ecological footprint	gha	100.66	37.22	23.53	26.39
Share of area on total footprint	%	53.60	19.82	12.53	14.05
Footprint of the area per unit of real surface	gha ha^{-1}	62.91	93.05	4.84	185.85

Table 4 Comparison between the real surface areas of the nursery, the ecological footprint of each area, the share of the area on total footprint, and the footprint of the area per unit of real surface.