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Abstract

Ecological Footprint Analysis (EFA) is an environmental accounting system, in physical unit, able to quantify the total amount of ecosystem resources required by a region or by a production process. This methodology is both scientifically robust and widely diffused for territorial and productive analysis. The application of EFA to agricultural systems are still uncommon and examples in the fruit sector rare.

In this work a detailed application of EFA to an experimental trial in a commercial nectarine orchard in Piedmont (Italy) is presented. The field trial is focused on the evaluation of agronomical benefit of various kinds of swine manure for fertilizing orchards. Four productive systems were established from 2008: liquid slurry (LS), covered slurry (CS), solid fraction (SF), mineral nutrition (MN). All the environmental impacts of the four systems were quantified both directly on field and with extrapolations from farmer knowledge. As previous studies suggested, we considered not only the one-year field operations, but also the whole lifetime of the orchard. The environmental costs of each system are presented and related to each other on the basis of their relative footprint value.

Results highlight almost the same ecological footprint for the three manure fertilized systems (LS, CS and SF) with average of 0.96 gha t^{-1}) and the highest ecological footprint can be found in the MN system (1.14 gha t^{-1}). Interesting remarks can be done comparing the contributions to the ecological footprint of the field operations related to fertilization in the four systems. In the manure fertilized systems the fertilizer contribution goes from 0.9% to 1.2% of the total ecological footprint; but in the MN system the fertilizer contribution is 6.6% of the total ecological footprint. Results support the hypothesis that internal recycle and connections among different systems increasingly resulted in high system benefit and sustainability.

Keywords

Fruit production, Sustainable farming, Environmental accounting, Slurry management

1. INTRODUCTION

1.1 Sustainable farming

Minimizing use of chemical fertilizers in fruit growing is not a goal just for integrated fruit productions (Reganold et al., 2001), but also for an environmental friendly development. Different strategies have been investigated and various technical solutions have been proposed. Researches are increasing on the reuse of agricultural and urban wastes in substitution of fertilizers (e.g. Ruggieri *et al*. 2009). Swine manure as fertilizer is used mainly in open field crops and only few works can be found where the use of different kinds of manures are compared in fruit orchards (Chatzitheodoru *et al.* 2004; Amiri and Fallahi, 2009). These works compare just the agronomical benefit of such application but do not consider sustainability aspects.

On the other hand the evaluation of sustainability is becoming an important issue in studying agricultural systems although there are no commonly accepted standards for sustainable food production (e.g. Gerbens-Leenes, 2003). Rather than giving an absolute indication for the sustainability of an agricultural system, it is preferable to compare various scenarios, or possibly real systems, with specific assessment or environmental tools. At present, a variety of methods are used to estimate the environmental burden of different agricultural production systems at farm level (e.g. Thomassen and de Boer, 2005). Many studies have outlined that indicators and accounting systems considering several aspects simultaneously are more useful in addressing the complexity of the agricultural systems (Bastianoni, 2001).

The objectives of this work are (i) to evaluate the sustainability of swine manure fertilization in orchard through one of the most used environmental accounting tool; (ii) to verify the application of the Ecological Footprint Analysis modified by Cerutti *et al.*

(2010a) to an experimental trial; (iii) to compare the incidence of fertilizing technique on the whole production system.

1.2 Pig manure as fertilizers

Livestock production is considered as one of the most significant contributors to environmental problems (Ilea, 2009). From an environmental point of view, intensive livestock production heavily contributes to the pollution of all the ecological spheres: air, soil, water and biosphere by decreasing biodiversity and ecosystem resilience properties (FAO, 2006). The environmental impacts of meat are mainly due to two aspects: the feed required (Elferink *et al.*, 2008) and the waste produced (Hatfield *et al.*, 1999) by livestock. Furthermore livestock production is estimated to duplicate within 2050 (FAO, 2006), therefore new environmentally management strategies have to be found. A relevant problem, often pointed out, is that the intensification of livestock production in the last decades has been accompanied by its dissociation from crop production (e.g. Halberg *et al.*, 2005; Lopez-Ridaura *et al.*, 2009). The dissociation of the two systems brings out the problem of the allocation and translocation of the relative inputs and outputs. Several studies underline the efficiency of integrated productive systems (e.g. Wei *et al.*, 2009; Cederberg, 2003) and the problems generated when the separation occurs (Lopez-Ridaura *et al.*, 2009). These works emphasize the importance of closing the productive cycles and transforming manure from a pollutant source to a nutrient resource.

Another recent aspect that has to be considered is that production of phosphate fertilizers will not be possible forever because phosphorous rocks are not a renewable resource and current global reserves may be depleted in 50–100 years (Cordell *et al.*, 2009).

For all of these reasons, a field trial on the evaluation of the agronomic benefits of utilizing liquid manure to fertilize orchards is carrying on (Cerutti *et al.*, 2010b). Preliminary results show that three years of swine manure applications instead of mineral fertilizers do not affects productivity and fruit quality.

1.3 Ecological Footprint Analysis

Ecological Footprint Analysis (EFA) is an environmental accounting system, in physical unit, able to quantify the total amount of ecosystem resources required by a region or by a production process. This methodology has several positive aspects: it is scientifically robust, widely used for territorial and productive analysis and easy to understand by non-experts. The concept of ecological footprint was firstly introduced by Rees (1992) and further developed by Wackernagel and Rees (1996). The methodology quantifies the total area of the terrestrial and aquatic ecosystems necessary to supply all resources utilized and to absorb all resultant emissions involved for a certain productive process. EFA provides a single value (hectares or global hectares) that comprises of various environmental burdens and which can be disaggregate down to the most detailed level of the single consumption. The aggregation capability of the EFA thus enables comparison of results arising from different scenarios.

The areas of application cover very different geographical regions and spatial scales (Bagliani et al., 2008). Recent extensions of the methodology enable the application of EFA to productive systems: the resulting footprint value quantifies the environmental burdens of all the activities required to produce, use and/or dispose of the final product (Global Footprint Network, 2009).

When applied to the agricultural sector, three land types are considered sufficient to describe the land composition of farms (Thomassen and de Boer, 2005; Van der Werf et al., 2007). The first component is cropland, which accounts for the effective land surface where the farm is assessed and for production of animal feeds which were not produced on-farm. The second is forest, which accounts for production of forest resources. The third component is the forest extension required to sequestrate all the CO2 emissions deriving from the non renewable energy used directly on the farm and, indirectly, for the production of the farm inputs and machineries. This land type is called "energy land" and it is a fundamental component for almost all the resources used. Another land type, less used in agricultural EFA, is build-up land. This component takes into account the surface occupied by infrastructure, e.g. deposit, garages, silos and other structures. In order to compare and add these different land types, equivalence factors have been introduced (Wackernagel and Rees, 1996) to convert effective land surface into global hectares (gha). These equivalence factors (EQF) are corrections of the land components based on the different productivities of each land type, therefore the gha unit gives a standardized and productivity-weighted value of the EFA results (Global Footprint Network, 2009).

EFA can give precious information when applied as a tool for scenarios comparison. Thus several works present the EFA structured in such way (e.g. Wada, 1993; Niccolucci *et al.*, 2008) and consider that foods (or goods in general) with lower EF are more sustainable (Deumling et al., 2003).

1.4 EFA in orchard

Fruit production is considered an agricultural sector with low environmental impacts in comparison to other food sectors when considering the energy in the life cycle per kg of product (Carlsson-Kanyama et al., 2003). On the other hand the use of pesticides is an important key-issue that may increase heavily environmental impacts. As a consequence quantification of the sustainability of fruit production is required to make specific considerations. Applications of EFA to agricultural systems are still rare: to date, only two papers uses the application of EFA in the arboricultural sector: Niccolucci *et al.* (2008) and Cerutti *et al.* (2010a), the first refers only to the wine industry and the second on major fruit-tree species, particularly nectarine.

When quantifying the environmental pressures of fruit production it is important to differentiates between open field crop systems (where assessment tools are mainly applied) and perennial crops (Mila i Canals and Polo, 2003). A key difference is soil management as this can impact significantly soil quality (Granatstein and Kupferman, 2008) and requirements such as fertilizer inputs and mechanical operations. Another important aspect to be considered is that some resources are used annually while others are present during the whole lifetime of the orchard. Previous studies (Cerutti *et al*., 2010a) demonstrated that applying the EFA only to the high yield production years and not to the whole orchard system, may underestimating the real ecological footprint up to 35%, depending on the production protocol.

2 METHODS

2.1 Experimental productive systems

The field trial has been conducted in a commercial orchard nectarine (*Prunus persica* var. laevis Gray) located in Villafalletto (44° 32' N, 07° 32' E) in Cuneo Province, North-Western Italy. Trees of cultivar ‘Spring Bright’ were planted in 2004, in a medium-density orchard (distance between the trees is 1.8 m along the row and 3.9 m among the rows). A randomized block design with three replications of five treatments has been applied: liquid slurry (LS), covered slurry (CS), solid fraction (SF), mineral nutrition (MN). The MN treatment considers the standard fertilizing techniques for nectarine production in Piedmont without recycling process. In the trial also a not fertilized (NF) treatment has been added. This control allows to quantify the effect of the different fertilizations above the field nutrients content (Chatzitheodoru *et al.* 2004), but do not reflect a real possible treatment (farmers rarely don't fertilize at all), so it is not considered as a possible case in the EFA.

Soil classification, rootstock, varietas, plant age, and agrotechniques (except fertilization) were the same on all the plots. The quantity of fertilizing materials was obtained reaching the same nutrients value for all the treatments (except for the not fertilized trial). Nutrients content in the pig slurry and in the solid fraction was sampled 5 days before the application and the quantity of such materials needed to reach the optimal fertilization values was calculated.

From a sustainability point of view, each fertilizer treatment corresponds to a possible system and has to be evaluated separately with the chosen assessment tool. A schematic representation of the four systems is shown in figure 1.

A number of researches focused on the application of an ecological accounting tool to animal product underline the problem of manure data allocation. This problem occurred because the manure is at the same time an output of a system (livestock) and an input of another one (open field crop) in a open-loop recycling (Cederberg, 2003; Basset-Mens and van der Werf, 2005). Different methods of manure allocation are accepted on the basis of the study case (Audsley *et al.*, 1997, Bagliani et al. 2009). The present work is focus on orchard perspective, thus manures can be considered just as byproducts of the pig production system. From a ecological accounting point of view, environmental impacts of byproducts are not related to their production process, but rather to their disposal procedures (Baumann and Tillman, 2004). This allocation strategy is common in manure or field residues management researches (Lopez-Ridaura *et al.*, 2009). As a consequence, in the present research we do not consider the environmental impacts of pig production but the impacts of disposal and land application procedures (figure 1).

Furthermore, most part of the orchard operations and field resources uses are common to all the systems, only nourishment procedure changes. A brief description of the environmental impacts of the fertilizing procedures for each studied systems is hereafter reported.

LS System. In this system the footprint value of the nectarine production with pig slurry fertilization is evaluated. Liquid manure was distributed to the field through a tractor with tanker, therefore manure storage, transportation and distribution have to be added to the footprint value of all the other field operation and resources use.

CS System. This system is similar to the previous one, but it considers a further stage that is the manure partial burying by the passage of a tractor with soil harrow use for other understorey management operations. This procedure is done in order to limit the loss of N through ammonia emission and runoff (Langevin *et al.*, 2010).

SF System. This system considers a frequent procedure in pig slurry management (Lopez-Ridaura *et al.,* 2009): the extraction of the solid fraction from the row slurry. The solid fraction obtained after composting is considered a better quality fertilizer than the liquid manure (e.g. Sanchez and Gonzalez, 2005). This operation allow an easier transportation and distribution in field and also limit the losses of nutrient from emission and leaching due to the slower release of nutrients than from the liquid manure. Besides the elaboration of liquid manure allow the recovery of a high quantity of water for irrigation, nevertheless this transformation has energetic cost and ammonia emission during the processes that have to be considered.

MN System. This system considers the common nourishment procedures for nectarine producers in Italy, therefore represent the agricultural protocol of Italian Integrated

Fruit Production. The footprint of this system comprehends the impacts of mineral fertilizer production, transportation and distribution in the orchard.

The options for manure utilization, as well as offering a fertilizing product, provide a way of organic wastes management, while the utilization of mineral fertilizers only provide nutrients without organic matter. The unbalanced functions of products involved in the productive systems generates problems in comparisons (Finnveden, 1999; Ruggieri *et al*. 2009) but can be overcome expanding the boundaries of the systems to consider an alternative type of managing swine manure that is not fertilization. In order to quantify correctly the contribution of the alternative disposal method we decided to separate the MN system in two scenario: MN1 do not considers an alternative disposal method, MN2 considers both agricultural practices and a common disposal method. The most common way to dispose pig manure in the Cuneo province is the field application in a subservience land (that can be or not an agronomic used land). Therefore land use, fuel for tractor transportation and disposal were added in the quantification of the footprint of the MN system. We decided to add the disposal impacts to system MN2 instead of subtract those impacts to all the others systems as suggested by Ruggieri *et al.* (2009), due to cleanliness in reading the results. This method permits to understand better the situation because all environmental burdens that are not avoided using a productive process have to be accounted.

Another important aspect that has to be considered in the analysis are the restrictions of livestock effluent for land distribution. The European Water Directive (91/271/EEC) forbids the slurry field distribution for more than 170 kg per hectare in the vulnerable zone. The Cuneo province is constituted by almost all vulnerable zones, therefore subservience lands are very limited. The availability of land for production (or for disposal in this case) can be an important parameter for fit the EFA to the regional context in which is carried on (Stoeglehner and Narodoslawsky, 2009).

2.2 Nectarine Production System

The present study is focused on the comparison of different agrotechniques in which most of the field operations are common to all the systems. In such case a lot of authors concentrate only on the differences between systems and do not consider the common environmental impacts (e.g. Lopez-Ridaura *et al.*, 2009). Instead of that, we preferred to consider all the environmental impacts in order to compare the incidence of the fertilizing method on the whole production system. Thus the system boundary of the analysis comprehend all the field operations carried out in the orchard (figure 2).

As other authors (Mila i Canals and Polo, 2003; Mila i Canals *et al.*, 2006) suggest, not only the one-year field operations were considered, but also all the environmental impacts related to the entire lifetime of the orchard. The one-year field operations were studied directly on the field in years 2008-2009, and the life-time operations were provided by the farmer. Particularly, the orchard life time was estimated to be 20 years, subdivided as follow: 2 years for the propagation of the plants in the nursery, 1 year for the establishment of the orchard, 2 years of low yield due to young plants, 13 years of full production, 2 years of low yield due to declining plants, and then the destruction of the orchard. For detailed description of the impacts related to each production stage see Cerutti et al. (2010a).

2.3 Ecological footprint methodology

During 2008 and 2009 all materials and energy used for process crossing system, e.g. fuel or electricity (flow resources), were collected directly on field. Data for accounting materials used for the whole orchard lifetime duration (stock resources) were collected thorough a survey of all farm installations and equipments. Flow and stock resources were listed (table 1) and converted into bioproductive area using the specific conversion factors calculate by the Global Footprint Network database (Global Footprint Network, 2006). When conversion factors were not available, embodied energy coefficients were used to estimate the equivalent emission of CO_2 and the area of energy land-category needed for its sequestration. A world-average carbon sequestration of 0.277 gha tCO_2^{-1} was used (Global Footprint Network, 2006). To convert diesel consumption to gha the following assumption was considered: 1 gha could absorb the CO_2 released by burning approximately 1450 liters of gasoline (WWF, 2008).

In accord with other papers (Mila i Canals and Polo, 2003) machinery and resources (like steel, plastic and glass from tractors, hydra-ladders and equipments) were added as a proportion of the predicted useful life-time of the machinery. E.g. the tractor environmental burdens were converted in kg of steel, plastics and electrical materials, than divided for the predicted lifetime of the tractor. Following this methodology the footprint of a single working hour was obtained; this value was then multiplied for the effective working hours in each system.

The environmental burden of the storage (soil, cement, plastic and glass) was added as a proportion of the estimated lifetime (40 years) for multifunctional cultivation equipment used for 30 ha in total of the farm property. The soil occupied by structures was accounted as a built-up land component and thus considered as occupied crop land and unusable for food production.

The water consumed was accounted as the energy necessary for the irrigation, because the valorization of the water as a resource is not taken into account by EFA methodology.

Each experimental system has specific ecological burdens, thus, specific land (gha) requirement, but a common product yield similar to the other systems of the experimental trial (Cerutti *et al.*, 2010b). Total land required (gha) on total yield (expressed as t ha^{-1} y^{-1}) gives the footprint of 1 t of nectarine produced for each system.

As data were collected directly from the orchard were agronomic experiment was carried on it was possible to obtain values for materials and energy use for each repetition. As a consequence, EFA was conducted for each repetition (three repetition for each system) and results were analysed by ANOVA (randomized block design). Tukey´s post hoc test was used when the ANOVA presented significant differences ($P < 0.05$). The statistical software package SPSS 15.0 was used for this analysis.

3. Results

Total ecological footprint and footprint land-components distribution for each productive system presented in table 2. ANOVA result shows that different total ecological footprint values reflects statistical significant differences among systems. Post-hoc test result highlights that three statistical groups can be found: LS, CS, SF systems are the same group and their total ecological footprint is not significant different (average 0.96 gha t^{-1}); MN2 system has the highest ecological footprint (1.14 gha t^{-1}) and MN1 system has middle-value (1.01 gha t^{-1}) but represent significant difference with all other systems.

For all systems the energy-land is the main component (from 75.3% to 84.2%). Results from ANOVA and Tuckey's Test highlight that difference are statistical significant and two discriminate group can be found: LS, CS, SF systems have lower values, M1 and M2 have higher values. High contribution to energy-land component are mainly due to the impacts of electricity consumption: from 29.8% (MN2) to 36.7% (SF) in overall footprint. Second most important resource used is tractor fuel, with a percentage ranging from 22.9% (MN2) to 26.3% (CS). Third most important resource used is the effective soil utilized for the orchard burden upon the overall footprint from 12.1%

(MN2) to 14.4% (LS). Also plastics for installations (orchards, deposit and machines) are resources that weight a lot upon all systems for about 11% of the footprint.

Another interesting result arises from the comparison between the contribution of fertilizers: in LS, CS and SF fertilizer use accounted for about 1% of the footprint, but in the MN2 system it is 6.6%. Detailed values are presented in table 3.

The subservice land is a resource that weight a lot just upon the MN2 system (11.4% of the total footprint). Such incidence makes differences on cropland component values statistical significant; in particular post-hoc test highlights that MN2 system has cropland component statistical different from all others studied systems. No statistical differences can be found of other land components (table 2).

The ratio between the contribution of flow resources and stock resources to the total footprint is about constant in the LS, CS, SF and MN1 systems (about 35% stock resources and 65% flow resources), but changes in the MN2 system (about 42% stock resources and 58% flow resources).

4 Discussion

As this paper presents one of the earlier applications of EFA to a total orchard system involving six stages and four different ways to manage the fertilization, both results and methodological issues are discussed.

First interesting results are that there aren't significant differences within the total ecological footprint of manure fertilization trials (table 2) and that ecological footprint of the fertilization procedures in LS, CS and SF is highly comparable (table 3). That means that, from an environmental point of view, the consumption of a nectarine orchard for one of these three trials have almost the same environmental impact. But the ecological footprint of the two MN systems is higher; in particular MN2 is 19.3%

higher than the average of the three manure systems. MN2 is about 12% bigger than MN1. This percentage correspond to the burden of the alternative disposal. The interesting result is that the MN1 footprint is bigger than the average of the manure systems for a percentage equal to the fertilizer utilize (about 6%).

The alternative disposal scenario weight upon the MN" ecological footprint for 12.2 % (11.4% due to the subservice land, 0.8% due to disposal operations and installations). This result came from the big incidence that land use have in the EFA (Chambers *et al.*, 2000). The subservice land is a parameter difficult to standardize because it can be an unoccupied land or an already cultivated land (e.g. with maize crop) generating allocation problems (e.g. Audsley *et al.*, 1997). In this study the comparison is made considering an unoccupied land because the land availability in the region is not unlimited and it represents one of the strongest environmental limiting factors to livestock production. Thus MN2 can be considered one of the worst possible scenario in order to quantify extreme footprint values. In this way we can assume that recycling manure in orchard can reduce the environmental impacts from about 6%, related to a total ecological alternative disposal scenario (MN1), to about 18%, related to a common alternative disposal scenario (MN2).

The difference between footprint contributions for fertilizing methods (table 3) can be used to quantify precisely the advantage of manure distribution in the orchard. Particularly the distribution of the liquid manure directly on field permits to save 0.20 gha t^{-1} (considering to subtract the alternative disposal impacts and the mineral fertilization impacts, and to add the slurry distribution impacts). Accounting that foods with lower footprint can be considered more sustainable (Deumling *et al.*, 2003), the obtained value of 0.20 gha t^{-1} represents the quantification of the sustainability of such method in comparison to the traditional mineral fertilization. These results suggest also that viable means of increasing sustainability of fruit production could include the decrease of chemicals fertilizer consumption and the increase of organic procedures (such as closing other biological production cycles).

When looking at the percentage of the different land component it is interesting to point out that the footprint due to the effective land consumption (cropland and built-up land components) in the manure fertilized systems is about 15.4% and, in the MN2 system, is 24.3% of the total ecological footprint. The remaining percentage of the footprint (about 84.5% in LS, CS, SF and MN1; 75.6% in MN2) arises from the energy applied to the system in order to amplify the productivity. This energy derives from different factors: not only electricity and diesel, but also the energy embodied in input material (e.g. fertilizers and pesticides) and all the other resources.

Comparing the contribution of each resource used, it is interesting to highlight how the fertilizers contribution differs within the trial. In the manure fertilized systems the contribution of the chemical fertilizer counts only for 0.1% of the total ecological footprint due to the fertilization during the installation of the orchard. In the MN2 system the fertilizers contribution is 4.8% of the footprint. This result agree with other authors (Mila i Canals *et al.*, 2006) which identified fertilizer production and use as responsible for 5 to 11% of the environmental burdens of fruit production.

The diesel consumption result is lower in percentage in the MN2 system (22.9%) compared to the other fertilized systems (average of 25.9%). But considering the contribution to the ecological footprint in unit values, it results that the diesel consumption do not presents significant differences in the four systems (from 81.33 gha t^{-1} in LS, to 85.10 gha t^{-1} in MN2). This is an important remark for the evaluation of the sustainability of the studied systems: the evident decrease in the ecological footprint using manure is not supported by a decrease of fuel consumption which remains almost the same.

Finally, provided results may not identify a single "best system" among LS, CS, SF, but, on one hand clearly highlight the major environmental impact in using fertilizers, on the other hand support the hypothesis that internal recycle and feedback of system increasingly resulted in high system benefit and sustainability (e.g. Cederberg, 2003; Halberg *et al.*, 2005; Ruggieri *et al*. 2009; Wei *et al.*, 2009).

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Figures and Tables description

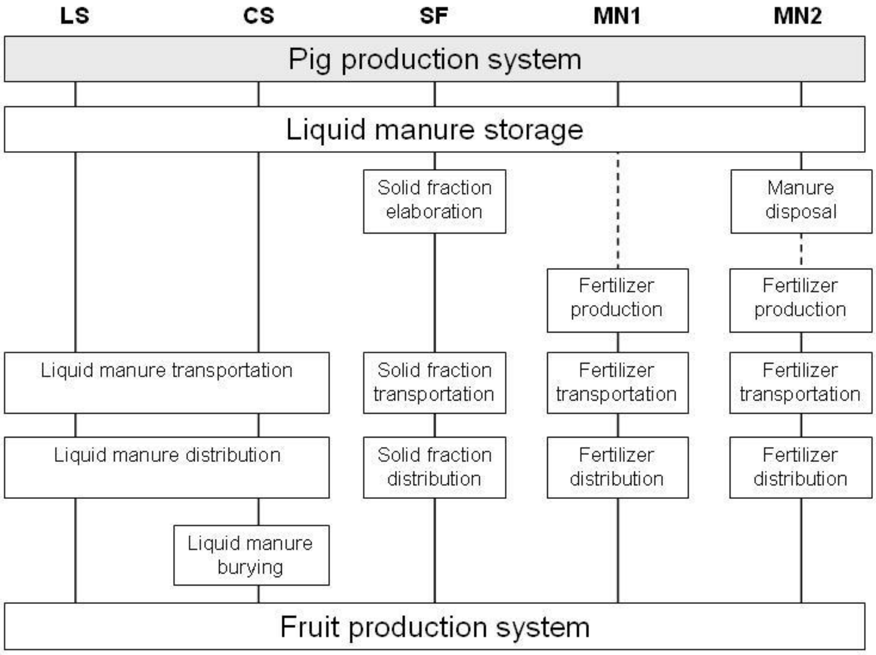

Fig. 1. Schematic representation of the systems streamlines. LS = liquid slurry, CS = covered slurry, SF = solid fraction, MN1 = mineral nutrition without alternative disposal and MN2 = mineral nutrition with alternative disposal. Common steps are identified by common boxes on the system streamline. Shaded boxes are not included in the study.

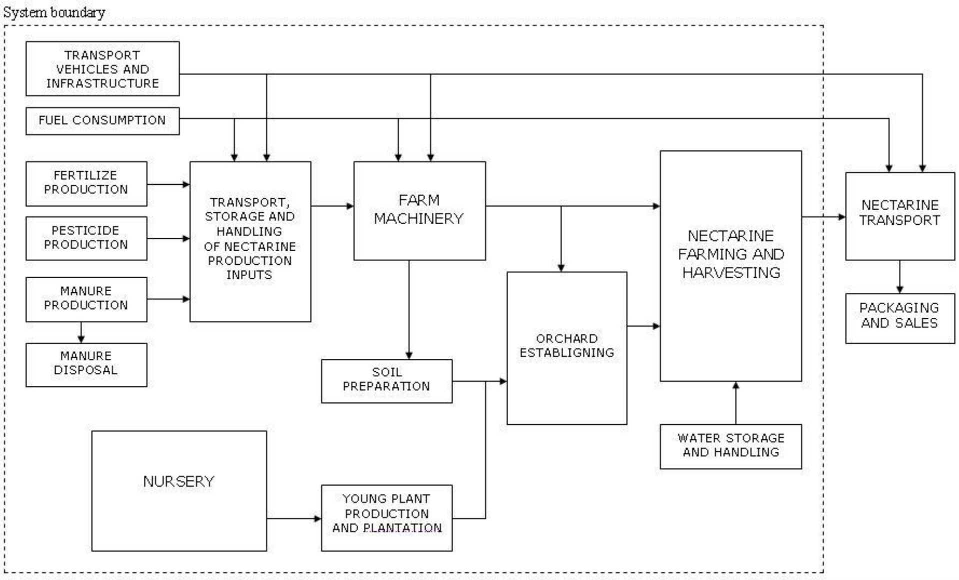

Fig. 2.

Reference case product system boundary for the comparative Ecological Footprint Analysis. (Adapted to the study case from Meisterling *et al.*, 2009).

Stock resource	**Unit**	**LS**	**CS**	**SF**	**MN1**	**MN2**
Nursery surface	ha	1.13E+00	1.13E+00	1.13E+00	1.13E+00	1.13E+00
Orchard surface	ha	1.70E+01	1.70E+01	1.70E+01	1.70E+01	1.70E+01
Deposit surface	ha	2.66E-02	2.66E-02	2.66E-02	2.66E-02	2.66E-02
Subservice land	ha	0	0	0	0	1.60E+01
Lagoon surface	ha	3.11E-02	3.11E-02	3.11E-02	3.11E-02	3.11E-02
Wood	t	1.34E+01	1.34E+01	1.34E+01	1.34E+01	1.34E+01
Plastic	t	9.25E+00	9.25E+00	9.25E+00	9.98E+00	9.98E+00
Electronic compound	t	3.61E-02	3.61E-02	3.61E-02	3.61E-02	3.61E-02
Iron	t	3.66E+00	3.66E+00	3.66E+00	3.66E+00	3.66E+00
Concrete	t	6.29E+00	6.29E+00	6.29E+00	6.29E+00	6.29E+00
Flow resource	**Unit**	**LS**	**CS**	**SF**	**MN2**	**MN2**
Water	l	8.36E+06	8.36E+06	8.36E+06	8.36E+06	8.36E+06
Fertilizers	t	2.63E+00	2.63E+00	2.63E+00	1.54E+01	1.54E+01
Pesticides	t	9.59E-01	9.59E-01	9.59E-01	9.59E-01	9.59E-01
Gasoline	l	1.17E+05	1.18E+05	1.18E+05	1.18E+05	1.23E+05
Lubrificant	t	1.15E-02	1.60E-02	1.15E-02	1.15E-02	1.15E-02
Electricity	J	2.13E+09	2.13E+09	2.14E+09	2.12E+09	2.13E+09

Table 1
Summary of the resources used in the entire orchard lifetime for the four systems, arranged by stock and flow resources. LS = liquid slurry, CS = covered slurry, SF = solid fraction, MN1 = mineral nutrition without alternative disposal and MN2 = mineral nutrition with alternative disposal.

	LS (gha t^{-1})	CS (gha t^{-1})	SF (gha t^{-1})	MN1 (gha t^{-1})	MN2 (gha t^{-1})	***F***	***P(F)***
Cropland	0,138 *a*	0,138 *a*	0,138 *a*	0,138 *a*	0,269 *b*	303,60	2,17 E^{-12}
Build-up	0,009	0,009	0,009	0,009	0,009	0,917	0,515
Pasture	0	0	0	0	0	--	--
Forest	0,003	0,003	0,003	0,003	0,003	1,305	0,325
Energy	0,806 *a*	0,808 *a*	0,809 *a*	0,860 *b*	0,863 *b*	9,809	4,82 E^{-4}
Total EF	0,958 *a*	0,960 *a*	0,960 *a*	1,011 *ab*	1,145 *b*	34,398	6,99 E^{-7}

Table 2.
Summary of average land components and total EF for each system. Values are expressed in gha per ton of nectarine. Results of ANOVA are shown in the last two columns. For P(F) values higher than 0.05 there are no statistical significant differences within the treatments. Letters *a*, *ab* and *b* identify three separate statistical groups from the Tukey post hoc test. LS = liquid slurry, CS = covered slurry, SF = solid fraction, MN1 = mineral nutrition without alternative disposal and MN2 = mineral nutrition with alternative disposal.

Field operation	**Reference system**	**EF** (gha t^{-1})	**EF** (%)
Liquid slurry distribution in 1 ha for the entire orchard life time	LS	0.009	0.93
Liquid slurry distribution and burying in 1 ha for the entire orchard life time	CS	0.010	1.04
Solid fraction distribution in 1 ha for the entire orchard life time	SF	0.012	1.25
Mineral fertilization in 1 ha for the entire orchard life time	MN2	0.076	6.63
Alternative disposal scenario for the same liquid slurry volume	MN2	0.140	12.22

Table 3.
Summary of contributions to the ecological footprint of the field operations related to fertilization in the four systems. The EF contribution is expressed in gha t-1 and % is referred to the reference system entire EF. LS = liquid slurry, CS = covered slurry, SF = solid fraction, MN1 = mineral nutrition without alternative disposal and MN2 = mineral nutrition with alternative disposal.