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Abstract

Sustainable farming in the fruit production systems of the Piemonte Region of Northern Italy was examined using a multifunctional Ecological Footprint based method. The analysis is based on the quantification of four different ecological footprint applications related to different functional units: tons of product, nutrient content in the fruit produced, hectare of crop and 1000 € of revenue. Of the major fruit production in the region, apricot and nectarine show the best overall performance from an ecological and economic point of view. This result is mainly due to the low input requirements of the cultivation processes, combined with a good product mass and the high market value of the fruit. Kiwifruit production had the worst overall ranking due to the high requirement of agronomical inputs and a low market value of the final product. The problems and the key aspects of a multifunctional assessment are discussed from a methodological point of view. Results highlight that standard Ecological Footprint Analysis alone would not allowed to evaluate the complete environmental profile of the different production systems.

Keywords

Environmental accounting, Economic profitability, Efficiency, Orchard management, Sustainable farming

1. Introduction

Food production is recognized as one of the main sources of environmental pollution and resource depletion (MA, 2006). The study of environmental indicators able to highlight ecologically suitable options is a key factor in sustainable development. There are a number of frameworks for sustainability assessment that evaluate the performance of food companies, farms, or even the entire agricultural sector of a country. Reviews of the application of environmental assessment methods at various levels, such as at country level (Singh et al., 2012), at corporate level (Herva et al., 2011) and of fruit production systems (Cerutti et al., 2011), show that indicators which consider several aspects of the environmental impact at the same time are more useful for addressing the complexity of anthropic systems. One of the most important features of an indicator is its ability to summarise, focus and condense extensive datasets (obtained from complex environmental parameters) into a manageable quantity of meaningful information. Thus, tools which combine economic and multiple environmental indicators may give a more complete picture of a system, and can help organizing the information in order to guide appropriate decisions about specific policies (e.g. Cuadra and Björklund, 2007).

The objectives of this work are: (1) to evaluate usefulness and problematic issues of four different Ecological Footprint (EF) based methods to assess environmental impact in production systems; (2) to evaluate the integration of the economic aspects in the use of environmental assessment methods because of their importance in the evaluation of the sustainability of a system; (3) to assess the environmental key-aspects of the fruit production systems in Piemonte (Northern Italy) as a basis of discussion among growers, field technicians and stakeholders.

1.1 Ecological Footprint Analysis

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 utilized and to absorb CO_2 emissions of a particular production process. EFA can be used at several geographical scales: from World and Nations (WWF, 2010) to Regions or districts (Bagliani et al., 2008).

Although the original formulation of EFA (Rees, 1992; Wackernagel and Rees, 1997) focused on 5 different land types (cropland, built-up land, forest, pasture and land used for energy production), several studies indicate that it can be used for investigating the contribution of direct and indirect land occupation. The first reflects the actual land required directly for the production process and the latter is the required land for production of process inputs. Recent studies (Erb, 2004; Kissinger and Gottlieb, 2010; Lenzen and Murray, 2001) have investigated the importance of focusing on the 'real land use' and its geographical location around the world.

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 it is a fundamental component of almost all the used resources.

EFA can provide information if used as a basis for comparison with different systems or management strategies (e.g. Niccolucci et al., 2008; Wada, 1993) especially since end products with a lower EF can be considered more environmentally sustainable (Deumling, 2003).

1.2 EFA in orchards

Although many aspects of environmental accounting methodologies in food production have already been investigated, the application of environmental indicators to the fruit sector is still rare and no consensus can be found regarding a preferred method. Widely diverging approaches have been adopted in several aspects of the analyses, such as data collection, handling of scaling issues, and goal and scope definition (Schau and Fet, 2008).

Traditionally, environmental burdens in orchards have been studied in terms of consumption of resources (e.g. water, soil, air, energy, etc) or direct impact (e.g. pollution, human and ecosystem health risks, decreasing biodiversity, etc). A few recent studies have attempted to assess the total environmental burden of specific fruit production systems through their entire life cycle by applying aggregate assessment methods.

When quantifying the environmental pressures of fruit production it is important to take into account difference between open field crop systems and perennial crops (Milà i Canals et al., 2006). One basic aspect to be considered is that some resources are used annually while others are utilized during the whole lifetime of the orchard. Calculating the impact of just one standard production year and not of the whole orchard system, may result in underestimating the real ecological footprint by up to 35%, depending on the production system (Cerutti et al., 2010).

1.3 Description of the area and of the crops

The cultivation of fresh fruits and nuts in 2008 in Piemonte Region involved more than 42˙000 hectares and yielded over 440˙000 tons of product. Since the beginning of the decade, land occupied by orchards increased significantly (+12.6%) in contrast to a decrease at a national level (-9.3%) (INEA, 2010). Fruit production was primarily for fresh consumption. Hazelnut production was mainly absorbed by the local food industry.

Although widespread throughout the region in both flat and hilly areas, fruit production systems are mainly located in the province of Cuneo, which accounts for about 75% of total production. Apple is the

most cultivated fruit with approximately 5˙200 hectares, followed by peach and nectarine (3˙800 and 3˙400 hectares, respectively). The kiwifruit is a more recent introduction in Piemonte and the area under cultivation (including new investment) since 2000 shows an increasing trend that has begun to stabilize in recent years, with about 4˙600 hectares. Overall, the fruit sector for fresh consumption had a net production value in 2010 in excess of 225 million € (6.4% of the total agricultural production income of the region). This value is mainly due to kiwifruit (about 66 million €), apple (54 million) and peach (in 2008 peach and nectarine production amounted to about 33 and 36 million € respectively).

Nut cultivation (hazelnut, chestnut, walnut) is of particular relevance to the agricultural economy in Piemonte because it gives income opportunities in hilly and mountainous areas, in which other agricultural activities are difficult due to the adverse environmental conditions. Hazelnut cultivation in particular covers more than 10˙000 hectares and shows strong growth: orchards have increased by 27% in the period 2000-2008 and production currently amounts to an average of 14˙000 tonnes/year. Recently, hazelnut orchards have also been established in lowland areas, providing a viable alternative to other permanent and open field crops. In 2008, the net production value of hazelnuts from Piemonte was estimated at 16.4 million €, corresponding to approximately 12% of the national total. It must be noted that, in economic terms, the annual production value of hazelnuts is quite variable and competition from products of foreign origin influences the prices paid to producers.

2. Materials and methods

2.1 Data collection

All the data collected and evaluated for this investigation were gathered from questionnaires completed following direct interviews with farm owners or field technicians. The major fruit productions in the Region were investigated: apple, pear, peach, nectarine, apricot, plum, kiwifruit and hazelnut, with data

collected from 15 different farms for each during the years 2009-2010. The data collection was structured in a four-step process. Step one was profiling the farm, asking question of the farm owner about organization and finance, such as number of employees, machinery costs and revenues per hectare. Step two was profiling each plantation of the farm as conventional, integrated, or organic, and the orchard design (e.g. number of plants per hectare, cultivars, and expected lifetime of the orchard). Data collected in the first two steps are shown in table 1. Step three was the quantification of the resources used in the cultivation. This step was done by consulting the "field book" of each farm. In such registries, each single field operation in the orchard (e.g. the distribution of fertilizers, pesticides, and water) is recorded in terms of time of application and quantity of materials. In the fourth step, the data obtained in previous steps were compared to the Italian guidelines for agricultural production (Regione Piemonte, 2006, 2011) and Regional statistics (INEA, 2010) in order to identify inconsistant values. Even when most of the farm data and the statistical data were in accordance, values far outside the regional average were double-checked by means of further investigations directly on the farms. The matrix of the resources used was the basis for the evaluation of the environmental demand (table 2).

2.2 System boundaries

As advised by other authors (Cerutti et al., 2010; Milà i Canals et al., 2006) in addition to one-year field operations all the environmental impacts related to the entire lifetime of the orchard were also taken into account. The production system was modelled in 4 stages: (ST1) the nursery stage: the average processes and resources needed to obtain rootstocks, scions and young plants for the quantity of plants per hectare of the given orchard design; (ST2) the establishment stage: the common practice of removing previous installations and preparing the field for the orchard. Plastic, steel, and wood resources, and energy for the orchard installation, were added in proportion to the lifetime of the orchard; (ST3) the farming and harvesting stage, (divided in ST3a - low yield production sub-stage due to young or declining plants and ST3b - full production sub-stage) which includes all one-year field operations and in particular:

tree management, pest and disease management, under-storey management, irrigation, and weather damage prevention, and harvesting; (ST4) the destruction of the orchard, mainly relating to machinery and fuel.

2.3 Ecological Footprint methods

Despite the general uniformity of the analyses, a few differences in methodologies can be found in the case study. The most significant difference was between the application of the EFA for individuals, groups of people such as a nation (in which case the method is called National Footprint account) or a production system (Kitzes and Wackernagel, 2009). In the first case the method can describe and quantify the resource flow of a region. In the latter case, the object of the study is the production of goods, thus a kind of life cycle perspective is adopted. As a consequence, some authors are beginning to consider the EFA of a product as actually being a Life Cycle Impact Assessment (LCIA) method (de Alvarenga et al., 2011) with its own specific impact assessment method, almost comparable with the Ecoindicator 99 (Huijbregts et al., 2008). The main features of these two methods and the proposed multifunctional EFA are summarized in table 3.

Using a life cycle perspective, EF can be defined as the sum of time-integrated real and virtual land occupation related directly and indirectly to the production of goods, disposal of materials and emissions of CO_2 during the whole production cycle:

$$\mathrm{EF} = \mathrm{EF}_{\mathrm{real}} + \mathrm{EF}_{\mathrm{CO2}} \quad (1)$$

where EF_{real} represents land occupation over time by cropland, built-up land, pasture and forest. This value is counted as the sum of the area occupied by each land type, multiplied by the specific land-related Equivalence factor (EQF). These factors are land specific coefficients that correct the land components on the basis of the different productivities of each land type, taking into consideration the

average productivity of all the bioproductive areas on Earth. The second component of the footprint (EF_{CO2}) is the virtual bioproductive land required to sequester, through forestation, the atmospheric fossil CO_2 emissions related to the produced goods. This value is obtained by multiplying the product-specific emission of CO_2 by the EQF of forests and the mass of CO_2 sequestered in biomass with a correction of the CO_2 absorbed by oceans (Monfreda et al., 2004).

The consequence of the use of EQFs instead of real hectares alone, is that EFA results are expressed in global hectares (gha), which identify the standardized and productivity-weighted values of the EFA results (Global Footprint Network, 2009).

Another key aspect in considering EFA from a product life cycle point of view is the possibility of using different functional units for the same system. The most commonly used functional units are 1 kg of fruit, packed and delivered to the customer, or 1 tonne of fruit at the farm gate (Cerutti et al., 2011). However the choice of functional unit may represent a critical issue of the research (Martínez-Blanco et al., 2010) because different functional units may lead to different environmental impact results and, consequently, to a different evaluation of the sustainability of products. Thus In this research a multifunctional EFA is proposed. This methodology adopted in the research is summarized in figure 1. Stock resources (material used for the orchard lifetime duration) and flow resources (materials and energy used for process that cross the system, e.g. fuel or electricity) collected were listed (table 2) and converted into bioproductive area by specific conversion factors available from the Global Footprint Network database (Global Footprint Network, 2006). Using such conversion factors, all resources were converted in the required amount of real and virtual land. When conversion factors for the real land components were not available (e.g. for plastics or electricity), just the carbon land has been accounted using the embodied energy coefficients to convert data into the equivalent emission of CO_2. The CO_2 produced was then converted into the energy land-category needed for sequestration. A world-average carbon sequestration of 0.277 gha/tCO_2 was used (Global Footprint Network, 2006). To convert diesel

consumption from fuel consumption to gha the following assumption was considered: 1 gha could absorb the CO_2 released by burning approximately 1450 litres of gasoline (WWF, 2010).

The obtained value of gha per each system investigated was divided by the total amount of commercial output of the system (figure 1). Instead of considering just the mass of fruit as the commercial output of the orchard, multiple outputs were considered as functional unit to be correlated to the natural demand in gha. In order to achieve a more systemic evaluation of natural demand of the cultivation, we propose four different functional units for agricultural products:

(I) product based EFA ($EF_{product}$): the environmental impact is related to a specific amount of product produced in the investigated system. This is the common process based EFA and several researchers applied this approach (e.g. Niccolucci et al., 2008; Thomassen et al., 2009; van der Werf et al., 2007; Wada, 1993). In agricultural systems, mass units are most commonly used, such as 1 tonne of produced food at the farm gate or 1 kg of produced food at the beginning of the consumer phase. In this method, the whole EF of the productive system is divided by the amount of production:

$$\mathrm{EF_{product}}\left(\frac{\mathrm{gha}}{\mathrm{t}}\right) = \frac{(\mathrm{EF_{real}}+\mathrm{EF_{CO2}})}{\mathrm{Yield}} \qquad (2)$$

(II) nutritional-value based EFA ($EF_{nutrient}$): the environmental impact is related to a specific chemical parameter used in the evaluation of the quality of the product. This is a quite specific functional unit for food production systems, e.g. Martínez–Blanco *et al.* (2010) evaluated the environmental impact of cauliflower production on the basis of the concentration of bioactive compounds in cauliflower samples (among other functional units). A parameter commonly used as a nutrient functional unit is the direct protein content in different food (e.g. Thomassen et al., 2009) or in the case of feed substitution (e.g. Lehuger et al., 2009) Nevertheless, protein content may not be a good functional unit for fruit

products, due to the diversity of protein type in various kinds of fruit. A more general nutrient based functional unit for food, which is also meaningful for fruit, is the energetic content (Cuadra and Björklund, 2007). In the present study the whole EF of the production system is divided by the amount of energy content in the total yield of the farm, thus $EF_{nutrient}$ indicates the EF per crop to produce the quantity of food related to 1GJ per farm system:

$$\mathrm{EF_{nutrient}}\left(\frac{\mathrm{gha}}{\mathrm{GJ}}\right) = \frac{(\mathrm{EF_{real}}+\mathrm{EF_{CO2}})}{\mathrm{GJ}\times\mathrm{Yield}} \quad (3)$$

(III) economy-value based EFA ($EF_{revenue}$): the environmental impact is related to the economic value of the products. This functional unit is useful when the economic eco-efficiency of the systems can be optimised (Mouron et al., 2006). Economic value-based functional units can be used for the comparison of different fruit production and commercialisation systems on a common basis, and can also be used to resolve quality issues. However, the results can be strongly influenced by the economic context of the farm locations; as market prices change the results of environmental indicators as well. The economy-value based EFA applied in this study was proposed by Cuadra and Björklund (2007) in order to relate the ecological footprint to the economic profitability. The method was called $EF_{revenue}$ and indicates the area needed for every crop to obtain a given revenue (calculated simply as money received by farmers after all costs have been paid); in this study we use 1000€. The modified formula is:

$$\mathrm{EF_{revenue}}\left(\frac{\mathrm{gha}}{1000€}\right) = \frac{(\mathrm{EF_{real}}+\mathrm{EF_{CO2}})\cdot 1000}{\mathrm{Revenues}} \quad (4)$$

(IV) land based EFA (EF_{land}): the environmental impact is related to a specific amount of occupied land. This functional unit is not commonly used in LCA and EFA, partly because land use is not directly a service and does not provide a productive function, but it can give interesting results. In general, converting

resource consumption or environmental impact to units of land use allows evaluation of the impact of cultivating a certain area. This parameter is also called the impact intensity of a farm (Mouron et al., 2006).

Ecological footprint values per hectare of crop allow visualisation of the difference between the area occupied by the orchard and the total area used, considering all upstream processes (Niccolucci et al., 2008) expressed in global hectares (gha). In the present study the whole EF of the production system is divided by the biological carrying capacity of the farm, calculated by multiplying the real hectares of the farm (including productive land and built-up land) by the EQF of cropland:

$$\mathrm{EF_{land}}\left(\frac{\mathrm{gha}}{\mathrm{gha_{farm}}}\right) = \frac{(\mathrm{EF_{real}}+\mathrm{EF_{CO2}})}{\mathrm{Area_{farm}}\times\mathrm{EqF_{cropland}}} \quad (5)$$

Furthermore, capital goods (e.g. machinery) are considered on the basis of the machine time used as a proportion of the predicted useful lifetime. E.g. the environmental burden of tractors was converted into kg of steel, plastics and electrical materials, then divided by the predicted lifetime of the tractor. Data on both material components and expected lifetime of machineries have been obtained from original product descriptions by the manufacturers. This approach, although not common in environmental assessments in the food sector (Schau and Fet, 2008), can be important when comparing different crops or the environmental performance of different farms (Mouron et al., 2006). The environmental burden of storage materials (soil, cement, plastic and glass) was added as a proportion of the estimated lifetime of the farm. The soil occupied by structures was counted as a built-up land component and thus considered as occupied cropland unusable for food production. The water consumed was counted as the energy necessary for irrigation (according to the specific irrigation system of the farm), because the valorisation

of water as a resource is not taken into account by EFA methodology, but rather through the use of other specific methods, such as the Water Footprint Analysis.

2.4 Economic analysis

The results of the ecological efficiency of processes alone may not be sufficient to investigate the sustainability of a productive system, taking into consideration the complexity of socio-economic systems. In order to obtain more relevant results some authors group together ecological and economic results (Wackernagel and Rees, 1997). In these cases ecological efficiency is compared to economic profitability so that the systems or products with the best performance in both parameters can easily be identified. Nevertheless in this kind of comparisons it has to be clear that economic profitability indicators are quite different from the other environmental indicators. These latter bound together ecological damage and performance results (which can be product- related or economic), while the profitability indicators have to be only referred to the economic dimension of the studied system.
Here a simple indicator of economic profitability at farm level has been carried out, considering profitability as the economic benefit received by the farmer and expressed as a percentage of total costs:

$$\text{Profitability (\%)} = \frac{\text{Revenues}}{\text{Total costs}} \times 100 \qquad (6)$$

2.5 Statistical and summary analyses

The use of statistical analysis to measure the results of an environmental assessment method is not a common procedure. For example Soler-Rovira and Soler-Rovira, 2008) used a Principal Component Analysis (PCA) on EF results (and other environmental indicators) in order to set appropriate weights among different indicators for an aggregated assessment of apple trade in Spain. Niccolucci et al. (2008)

used the Analysis of Variance (ANOVA) to investigate the distribution of inputs in the evaluation of the EF of different farms. Cerutti et al. (2011) used the ANOVA in order to highlight statistically significant differences in the EF of different agrotechniques in orchards.

In the present study statistical analysis was necessary to evaluate whether differences in EF values from all the fruit cultivations were significant. As data were collected mainly from questionnaires filled-in by farmers, it was possible to calculate the EF of each cultivation system. These values have been considered as repetitions for a one-way ANOVA. The Tukey post-hoc test was used when the ANOVA presented significant differences ($P < 0.05$). The statistical software package SPSS 17.0 was used for this analysis.

The average EF value for each fruit system (within the same EF method) was calculated with a weighted average of the EF results of each farm. More detailing for each fruit system the sum of the EF of all farms was divided by the sum of the functional unit of the same farms. For example in the case of the average $EF_{product}$ the following formula was applied:

$$\text{Average } \mathrm{EF}_{\mathrm{product}} \left(\frac{\mathrm{gha}}{\mathrm{t}}\right) = \frac{\sum_{\mathrm{farms}}(\mathrm{EF}_{\mathrm{real}} + \mathrm{EF}_{\mathrm{CO2}})}{\sum_{\mathrm{farms}} \mathrm{Yield}} \quad (7)$$

Using formula (7) instead of a mathematical average of the EF results of each farm, different farm sizes and different yield efficiencies of the considered farms is taking in to account.

Furthermore, in order to have an aggregated index that takes into account all the EF methods and the economic profitability a ranking method was proposed. EF results for each method were ranked, with the top value being 100, and the remainder a proportion thereof, a summary ranking evaluation was then obtained by adding rank values from each EF method, subtracting rank values of profitability, and relating the results to a new ranking scale. In this way fruit systems with a lower summary ranking represent more sustainable systems from an environmental and economical short term perspective.

3. Results

A summary of the results for the different EF methods is presented in table 4. Standard EFA results ($EF_{product}$) show high variability: from 0.93 gha/t in nectarine production systems, to 8.04 gha/t in hazelnut production systems. Results from the ANOVA and Post Hoc tests highlight the presence of five groups that are slightly different, with the exception of kiwifruit and hazelnut production systems, which show an average $EF_{product}$ which is significantly higher than other systems (table 4). For $EF_{product}$ a hot-spot analysis in stage contribution was also conducted and the results are shown in figure 2. The environmental impact of full production years (ST3b) on the whole lifetime of the orchard is fairly similar for all the production systems and varies from 57.41% for the apple, to 65.58% for the apricot.

The results of the environmental impact of producing 1 GJ ($EF_{nutrient}$) show that the hazelnut is the most favourable crop (0.27 gha/GJ) with a statistically significant difference compared to other productions (table 4). The $EF_{nutrient}$ of other fruit varies from 0.50 gha/GJ for the nectarine to 1.38 gha/GJ for the kiwifruit with a well defined segregation in statistical significant groups by the Post Hoc analysis (table 4).

The results of the EF per productive hectare of the orchard (EF_{land}) are clearly defined by the post hoc test into 5 statistically different groups (table 4). The hazelnut is the crop which requires the smallest additional land per area of cultivation (4.22 gha/gha_{farm}) and the kiwifruit is the crop requiring the highest additional area (20.57 gha/gha_{farm}). The $EF_{revenue}$ method shows that the apricot requires fewer environmental resources in order to generate a unit of income (1.66 gha/1000€). Kiwifruit and pear have the highest requirement of natural resources per unit of income (6.77 gha/1000€ and 6.75 gha/1000€ respectively). Other fruit systems show intermediate values not well defined by the Post Hoc test (table 4).

Considering the contribution of EF_{real} and EF_{CO2} in the evaluation of each system, all the four methods were used (figures 3-6) because there are different results depending on the EF method applied. EF_{CO2} is

the principal component in all the cases, contributing to the total EF from 75.08% in hazelnut and 95.01% in kiwifruit, with an average of 87.32% for all systems and for all methods. In absolute terms the EF_{CO2} ranges from 0.74 gha/t in nectarine to 5.73 gha/t in hazelnut (figure 3); 0.19 gha/GJ in hazelnut to 1.27 gha/GJ in kiwifruit (figure 4); 1.35 gha/1000€ in apricot to 6.27 gha/1000€ in kiwifruit (figure 5). Considering just the land based method, the EF_{real} is almost constant for each system (and almost equal to 1 gha/gha_{farm}) and EF_{CO2} can be compared among different fruit (figure 6). Virtual land occupation (EF_{CO2}), evaluated thorough the EF_{land} method, ranges from 3.01 gha/gha_{farm} for the hazelnut to 19.05 gha/gha_{farm} for the kiwifruit.

The results of crop profitability (from a short term perspective) are presented in the same table (table 4)with EFA results in order to be able to compare fruit systems from all points of view simultaneously. The hazelnut and the apricot are the most profitable fruit, with a potential profitability of 843% and 714% respectively. The fruit with the lowest profitability is the plum, with a value of 231%. It should be noted that fruit systems – in the Italian context – are high profitability production systems, but a high capital outlay is required to establish the orchard.

4. Discussion

4.1 The environmental burden of the fruit production sector in the Region

Summarising the results of all the EF methods used and economic profitability, the apricot shows the best overall performance from an ecological and economic point of view (table 4). This result is due to the low input requirements of the cultivation (which leads to a relatively low EF_{land}), combined with a good product mass (thus a low $EF_{product}$) and the high economic market value of the fruit (thus low $EF_{revenue}$ and high profitability). Similar results are shown by nectarine, which achieves one of the lowest summary rank, for the similar crop properties.

The other system with a good overall ranking is the hazelnut, because of its very low EF_{land} and $EF_{nutrient}$ values which are statistically different from other crops (table 3). Even though the volume of nut production is not comparable to that of fresh fruits, the hazelnut system shows a high level of sustainability, mainly due to the low input requirements for orchard management.

Kiwifruit is the production with worst overall ranking due to the high values found in the results of all the EF methods. This effect is caused by specific agronomical factors; in particular the higher environmental production costs compared to other fruit systems are due to the low vocation level of kiwifruit in the Piemonte Region; unlike the other investigated fruit systems, which are almost completely adapted to the pedoclimatic conditions of Northern Italy (Baldini, 1988) kiwifruit need warmer temperatures and higher amounts of water in the soil. Optimum climatic conditions for kiwifruit can be found in Central Italy and the lack of some of these conditions necessitates a higher amount of inputs (such as water and energy for irrigation, fertilizers and pesticides). Nevertheless, fruit growers in the Region chose this type of plantation for its relatively high profitability (table 4), despite the consequences in terms of environmental impact on a Regional scale. The apple and the pear are the next systems with a poor overall ranking. Although these two systems show similar results for all the EF methods (with the exception of $EF_{revenue}$ because of the smaller income in pear production), the environmental impact of the apple on the regional scale is almost 4 times higher that of the pear because of the production spread.

At regional level it is possible to evaluate average values of EFA results (table 5) which can then be used in further applications and by evaluation software. Consistent differences between the averages of all the investigated fruit systems, and for fresh fruits alone, can be found for EF_{land} because of the combination of a low EF_{land} for hazelnut production and the wide spread of hazelnut orchards in the Region.

Furthermore, important differences can be found for real and virtual land occupation (figure 3 to 6). EF_{CO2} values per each fruit identify the required amount of virtual land occupation for the absorption of the CO_2 emitted, in addition to the real land occupation. E.g. in order to produce 1 tonne of apples, at the regional pedoclimatic conditions, an average of 0.11 gha of real land occupation and 1.35 gha of virtual

land occupation are required (figure 3). As an average result, to produce 1 tonne of fruit in the Region, 0.37 gha EF_{real} (0.15 gha considering fresh fruits alone) and 1.97 gha of EF_{CO2} (1.43 gha considering fresh fruits alone) are required. According to the Global Footprint Network (Global Footprint Network, 2009) method of EFA evaluation, the EF_{CO2} land type, found virtually everywhere on a global scale, make the fruit systems in Piemonte more than 5 times higher than the biocapacity of those systems in order to produce fruit.

4.2 Discussion of methods

As recent papers suggest (Hanafiah et al., 2010; Huijbregts et al., 2008) when analysing food products the standard EFA of products may underestimate some environmental aspects linked to the production system. A mass-based functional unit is easy to comprehend and widely used, but has difficulty evaluating efficiency within sustainability research. By simply looking at environmental impact per product unit, it is possible to evaluate the eco-efficiency of production, but it is not possible to estimate the sustainability of such production because efficiency does not necessarily lead to sustainability (e.g. Wackernagel and Rees, 1997). In their paper, Wackernagel and Rees (1997) emphasise that the use of mass-based functional units alone may well lead to a preference for high input-high output systems, which, when concentrated at regional level, have been shown to cause major pollution problems (van der Werf et al., 2007). In our case study this problem is highlighted by the EF results for the hazelnut system: the hazelnut has the highest $EF_{product}$, because of the small amount of fruit mass produced in comparison to other fruit systems, but it also has the second best summary ranking. If standard EFA alone had been taken into consideration it would not have been possible to evaluate the complete environmental profile of hazelnut production. The results confirm that the land-based functional unit in fruit production can be considered as complementary to the mass-based functional unit because each gives different results and so both should be used. Indeed, when considering impact per unit area alone, differences in quantity of product per system are not accounted for and while low input-low output systems will have better

rankings for decreased impact at regional level they may create a need for additional land use elsewhere, thereby creating additional impact (van der Werf et al., 2007).

In addition, the nutrient content functional unit changes the results of standard EF, for example the hazelnut moves from the worst ranking in $EF_{product}$ to the best environmental performance in $EF_{nutrient}$, due to the high energy content of nuts. Nevertheless, various authors (Cuadra and Björklund, 2007; Deumling, 2003) have pointed out that this method is inappropriate when the aim is to compare the EF of different crops, because it does not consider differences in crop type. According to this method the hazelnut was evaluated as being the best crop, with a significantly lower $EF_{nutrient}$ than other crops, but nuts and fresh fruits have different chemical compositions, quality traits, nutritional characteristics and consumption patterns, and are thus considered as two different type of foods (Sori, 2002). Applying the ANOVA to fresh fruits alone, three well-defined, statistically different groups result: (I) nectarine, apricot, peach and plum with the lowest $EF_{nutrient}$ (II), pear and apple with intermediate values for $EF_{nutrient}$ and (III) kiwifruit with a higher demand on natural resources to produce nutritional energy.

The problem of altered $EF_{revenue}$ results, influenced more by profitability than effective environmental load (Cuadra and Björklund, 2007), do not dramatically affect the present study but are noticeable when comparing the apple and the pear. Both systems show similar $EF_{product}$ and EF_{land} values (also within the same statistically homogeneous group) but have different $EF_{revenue}$ (confirmed by different statistical groups), due to the lower income per hectare of the pear than the apple. Nevertheless, this method reflects the socio-economic properties of the investigated system and so we consider it a good complementary method in order to produce a more complete environmental profile of fruit production. Furthermore, the observation that this method is strongly influenced by annual product price variations can be overcome by using the average income per hectare in the same period of the installation, in the same way in which the problem of annual yield variation is overcome (Cerutti et al., 2010).

Other Interesting results arise from the evaluation of virtual land occupation (EF_{CO2}) through the application of the EF_{land} method. On the contrary of the standard EF method ($EF_{product}$), in which results

can be considered as an indicator of land use intensity (Deumling et al., 2003), results of the EF_{CO2} with the land method can be considered as an indicator of energy intensity. As results are given in terms of virtual impact per unit of directly occupied land, the higher the values of EF_{CO2} for a fruit system the more intense the energy consumption of that system is. Our results highlight the fact that intensity of production is mainly influenced by the management strategy: systems with a higher number of plants per hectare require higher inputs, thus a higher use of energy and materials from other systems.

4.3 General conclusions

No single method is adequate to perform a complete environmental impact assessment of a production system (e.g. van der Werf et al., 2007). Our results confirm that a combination of different methods or indices allows us to evaluate the environmental sustainability of a system from different perspectives, giving more significant results. Furthermore, the application of a ranking method allows us to directly compare different assessment methods or to apply a summarizing procedure in order to obtain single aggregated values (Singh et al., 2012) Our results show that a summary ranking would be useful to obtain aggregate and comprehensive EF results, balancing bias and limitations of each EF method.

Although the use of statistical analysis to grade the results of an environmental assessment method is not common in literature, our results highlight the importance of the application of an ANOVA (if allowed by the experimental design) in order to clarify whether variations in EF results are statistically significant or not.

Furthermore, a multifunctional regional EF can be a good matrix of comparison for the environmental load of the fruit production sector in different regions or productive districts, such as Northern Italy in comparison to Southern Italy. When comparing these two areas interesting differences in total and partial values may arise because of the very different pedoclimatic conditions, and therefore very different agrotechniques. In order to investigate larger areas than the Region examined in this study, a more systemic approach may be required, for example taking into account the interaction within sectors

not directly involved in the examined systems (Wiedmann et al., 2006); nevertheless this study can be considered as a first step in the acquisition of the methodologies necessary for the environmental assessment of a productive district using a multifunctional EFA methodology.

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Figures description

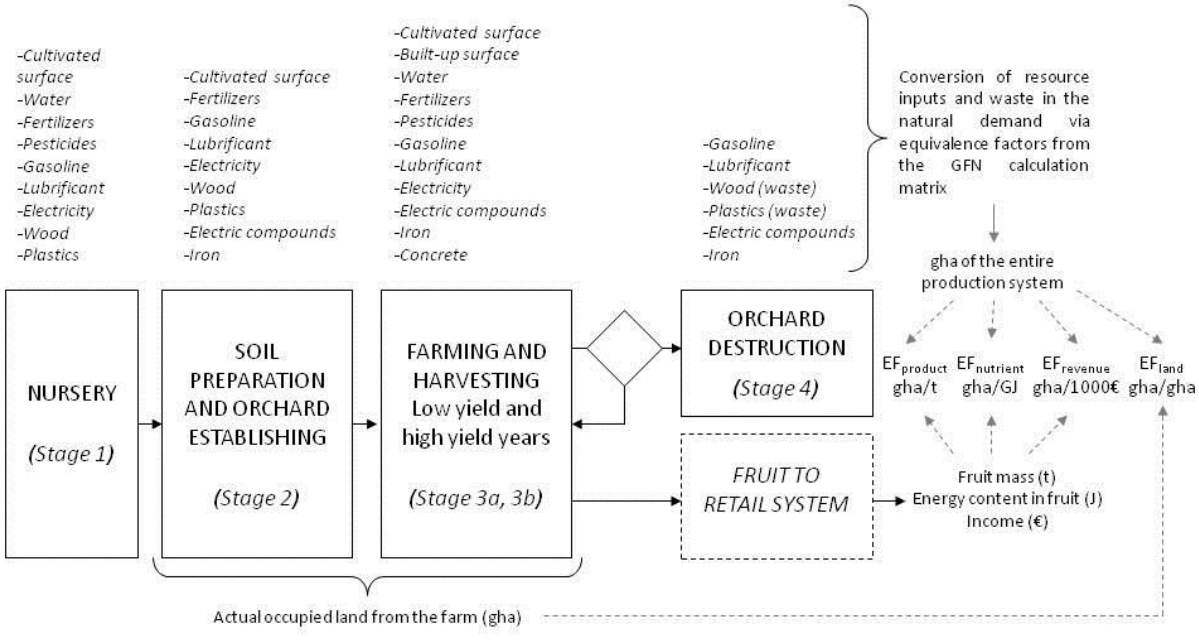

Figure 1. Modeling of the fruit production system and schematic representation of the evaluation method. Each stage of the orchard system consumes specific resources and produce specific waste. Such material were accounted and converted into gha via equivalence factors from the GFN calculation matrix. The EF result was then related to the commercial outputs of the system. Dotted boxes are not considered in the system boundary of the study.

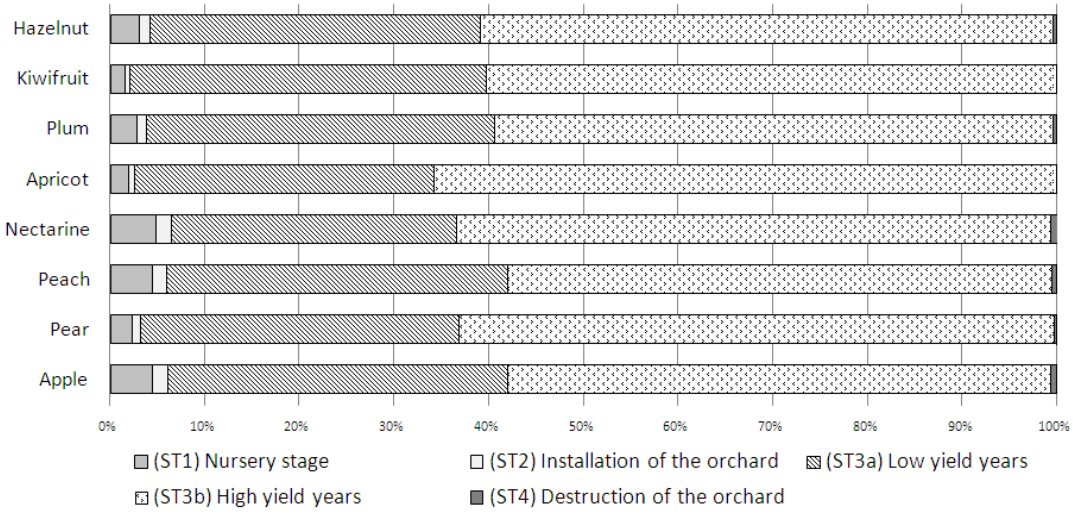

Figure 2. Hot spot analysis for environmental burdens of the considered fruit production systems, considering the contribution to the overall ecological footprint of five production stages.

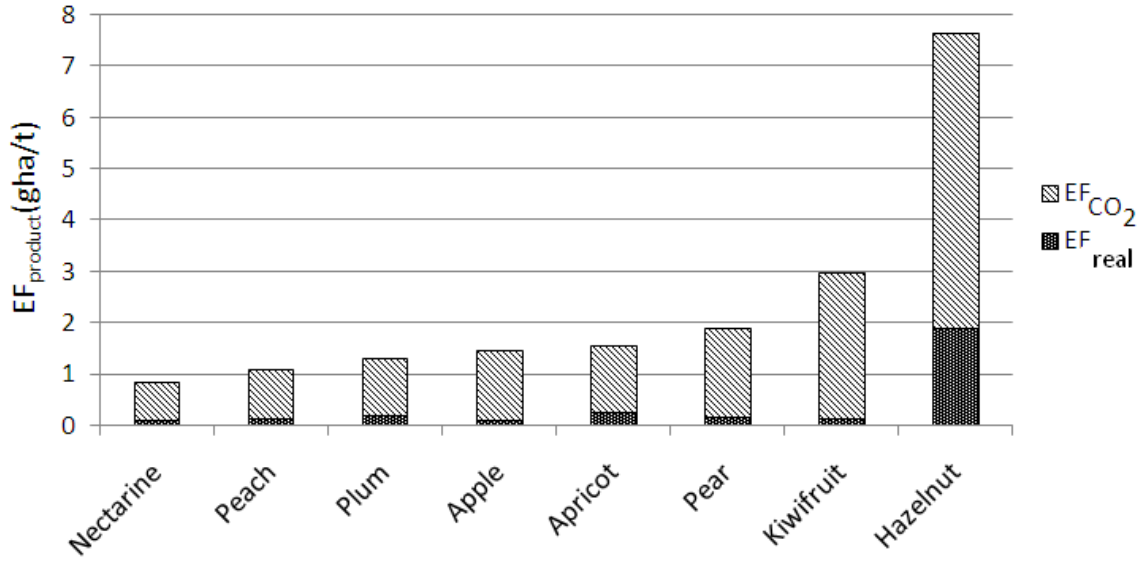

Figure 3. Comparison of the real and virtual contribution of the ecological footprint results accounted by the $EF_{product}$ method.

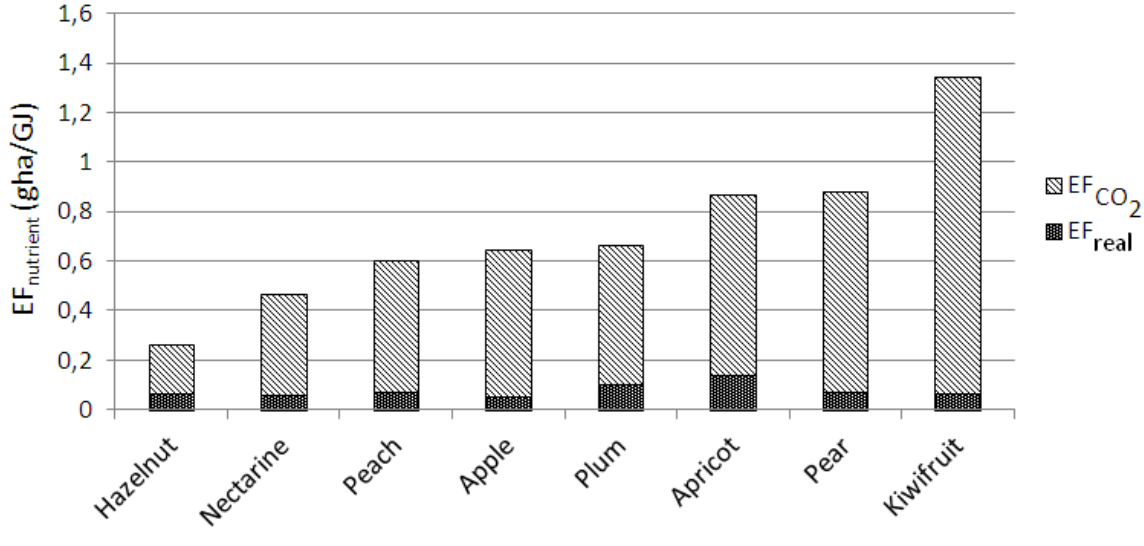

Figure 4. Comparison of the real and virtual contribution of the ecological footprint results accounted by the $EF_{nutrient}$ method.

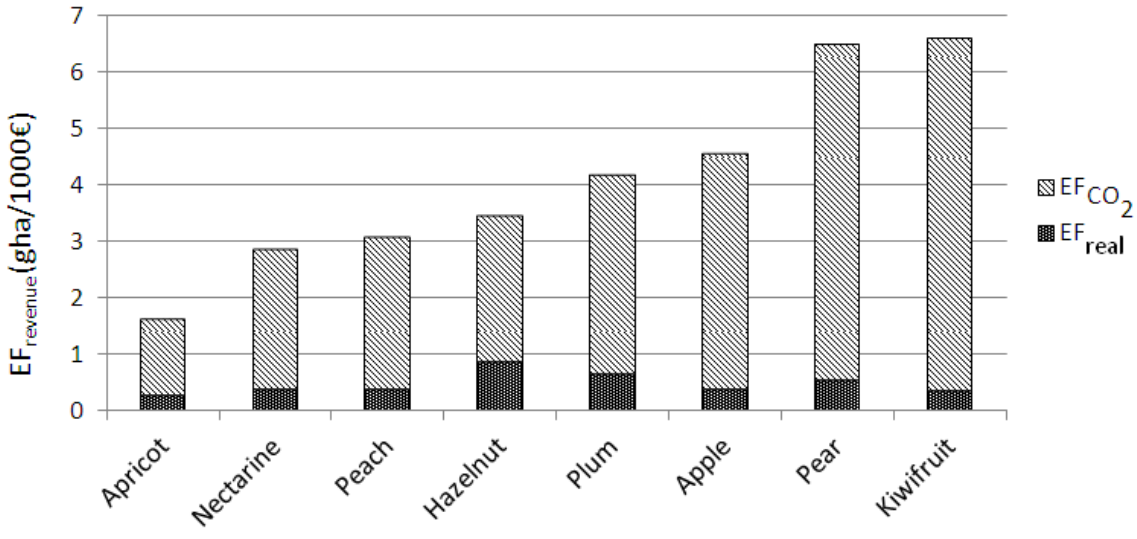

Figure 5. Comparison of the real and virtual contribution of the ecological footprint results accounted by the $EF_{revenue}$ method.

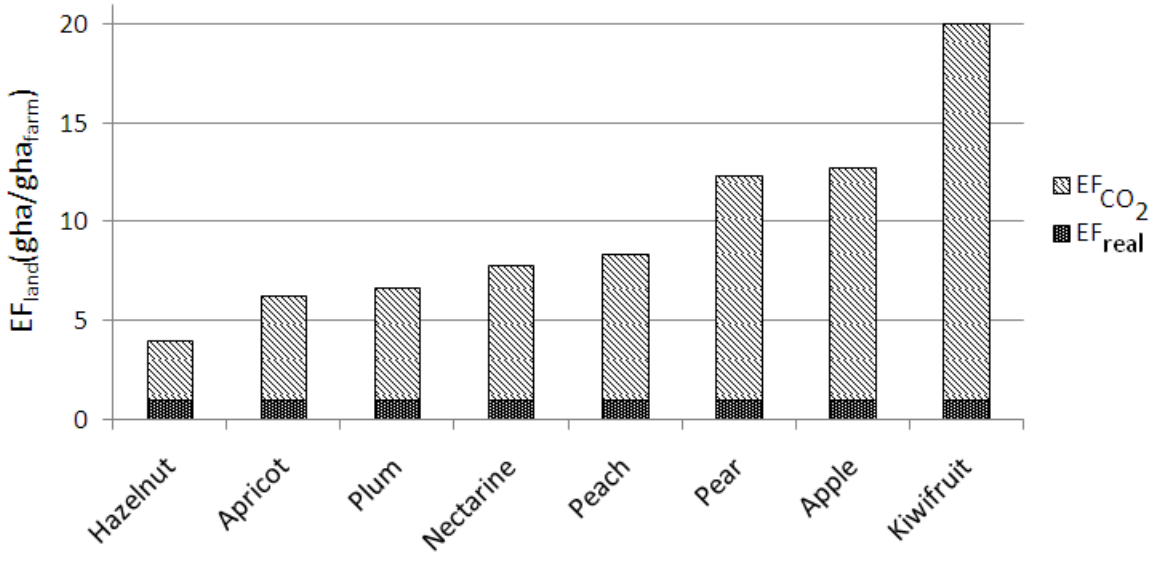

Figure 6. Comparison of the real and virtual contribution of the ecological footprint results accounted by the EF_{land} method

Formulas

$$EF = EF_{real} + EF_{CO2} \quad (1)$$

$$EF_{product}\left(\frac{gha}{t}\right) = \frac{(EF_{real} + EF_{CO2})}{Yield} \quad (2)$$

$$EF_{nutrient}\left(\frac{gha}{GJ}\right) = \frac{(EF_{real} + EF_{CO2})}{GJ \times Yield} \quad (3)$$

$$EF_{revenue}\left(\frac{gha}{1000€}\right) = \frac{(EF_{real} + EF_{CO2}) \cdot 1000}{Revenues} \quad (4)$$

$$EF_{land}\left(\frac{gha}{gha_{farm}}\right) = \frac{(EF_{real} + EF_{CO2})}{Area_{farm} \times EqF_{cropland}} \quad (5)$$

$$\text{Profitability (\%)} = \frac{\text{Revenues}}{\text{Total costs}} \times 100 \quad (6)$$

$$\text{Average } EF_{product}\left(\frac{gha}{t}\right) = \frac{\sum_{farms}(EF_{real} + EF_{CO2})}{\sum_{farms} Yield} \quad (7)$$