Application of Ecological Footprint Analysis on nectarine production: methodological issues and results from a case study in Italy

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Abstract

Ecological Footprint Analysis (EFA) is an environmental accounting system that provides an aggregate indicator which is both scientifically robust and easy to understand by non-experts. Although based on the lifestyle consumption of natural resources, recent improvements in the methodology now allow the application of EFA to a final product. Thus the resulting footprint value represents the environmental cost of all of the activities required to create, use and/or dispose of a particular product. 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 a commercial nectarine orchard in Piedmont (Italy) is presented. In contrast to previous studies, we considered not only the one-year field operations, but also the whole lifetime of the orchard. The calculation was conducted for six different orchard stages: (ST1) nursery propagation of the young plants; (ST2) orchard establishment, (ST3) young trees producing low yields, (ST4) mature trees at full production, (ST5) declining trees with low yields, and finally (ST6) orchard removal. The environmental costs at each stage are presented and related to each other on the basis of the relative footprint value. Results highlight the importance of applying EFA to the entire lifecycle of orchard production: ST4 accounted for the majority of costs at 65% followed by ST2, ST3 and ST5 at or near 10%, whilst the costs of ST1 and ST6 were negotiable. Thus it is the type of ST4 production used which can have the greatest impact on EFA values

Keywords

Orchard management, Fruit production, Sustainable farming, Environmental accounting

1. INTRODUCTION

1.1 Sustainable farming

The evaluation of sustainability is becoming an important aspect in the study of agricultural systems although there are no widely accepted standards for sustainable food production (e.g. Gerbens-Leenes, 2003). There are also different concepts of sustainability: in agriculture a common definition may be that a sustainable farm must produce adequate yields of high quality, be profitable, protect the environment, conserve resources and be socially responsible in the long term (Reganold et al., 2001). Furthermore, sustainability research in food production depends on the scale, the market channels, and the geographic context of location (Granatstein and Kupferman, 2008).

Thus rather than giving an absolute indication for the sustainability of an agricultural system, it is preferable to compare various scenarios with specific assessment or environmental tools. At present, a variety of methods are used to assess the environmental burden (or cost) of contrasting agricultural production systems at farm level (e.g. Thomassen and de Boer, 2005; Mila i Canals et al., 2006). Many studies point out that indicators which consider a lot of aspects simultaneously are more useful in addressing the complexity of the agricultural systems (Bastianoni, 2007).

The objectives of this work are (i) to quantify the environmental burden of each stage of nectarine production, especially the impact of the one-year cultural practices versus the whole orchard lifetime, and (ii) to verify the application of the Ecological Footprint Analysis to fruit production.

1.2 Ecological Footprint Analysis

Ecological Footprint Analysis (EFA) is an environmental accounting system that

provides an aggregate indicator that is both scientifically robust and easy to understand by non-experts. Introduced by Rees (1992) and further developed by Rees and Wackernagel (1996), the ecological footprint quantifies the total area of the terrestrial and aquatic ecosystems necessary to supply all resources utilized and to absorb all resultant emissions involved in the production of particular products. 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 easy comparison of results arising from different scenarios.

Nowadays, the studies that utilize EFA for scientific, political and didactical purposes are extremely numerous and cover very different geographical regions and spatial scales (Bagliani et al., 2008). The continuous development of the analytical methods by various research groups around the world led to Wackernagel and collaborators to create in 2004, the Global Footprint Network (GFN). The GFN is a network of research institutions, scientists and users of EFA which aims improve the calculation methods (Bagliani et al., 2008).

Although EFA was initially formulated to account for the use of natural resources through lifestyle consumption, recent improvements of the methodology enable the application of EFA to productive systems where the resulting footprint value represents the environmental burdens of all of the activities required to create, use and/or dispose of the final product (Global Footprint Network, 2009).

Despite its uptake and the analytical properties of the method, specific applications to agricultural systems are still rare. Some works can be found in the dairy sector (Thomassen and de Boer, 2005; Van der Werf et al., 2007; Bagliani et al., 2009), the horticultural sector (Wada, 1993; Deumling et al., 2003) and, recently, the energy-crop sector (Stoeglehner and Narodoslawsky, 2009). To date, only one paper uses the

application of EFA in the arboricultural sector (Niccolucci et al., 2008), however this work refers only to the wine industry. Thus no application of EFA has been undertaken on major fruit-tree species, such as nectarine.

Typically the EFA of fruit crops for the National Footprint Accounts (the analysis of the ecological footprint of each single nation of the world made by the Global Footprint Network) are evaluated on the basis of the average yield of a species and the national consumption (Chambers et al., 2000). National Footprint Accounts' footprint for fruits is considered to be 0.5-0.6 ha per ton of product on the basis of average global yield, embodied energy of the cultivation and estimation of the impacts of post-harvest management (Chambers et al., 2000). Although for example, the IIED report (1995), provides qualitative remarks on the social-environmental burdens of the production of bananas in Costa Rica such as the likely loss of biodiversity and agrochemical pollution, the footprint of imported bananas accounts simply for the average soil required for the production and the energy for transportation to the UK.

For 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 land required to produce the non renewable energy used on the farm and for the production of the farm inputs. This land component is called "energy land" and it is a fundamental requirement for almost all the resources used. Another land type, less used in agricultural EFA, is build-up land. This component considers the land occupied by infrastructure, e.g. deposit, garages, silos and other structures. In order to make these lands comparable, 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).

1.3 Environmental burdens in orchard

Fruit production is considered an agricultural sector with low environmental impacts in comparison to the herbaceous crops sector (Granatstein, 2007) and other food sectors (Carlsson-Kanyama et al., 2003; Frey and Barrett, 2007). Fruit production requires less bioproductive land compared to all animal and some horticultural products (Gerbens-Leenes et al., 1999). Nevertheless quantification of the sustainability of fruit production is required to make specific considerations and comparisons.

In order to apply the EFA it is necessary to identify what processes and resources are involved to determine the environmental consumption (Wackernagel and Yount, 2000). Some studies present the typical environmental burdens which may arise for general fruit production (Mila i Canals and Polo, 2003), (e.g. use of fertilizers, irrigation or pest and disease managements) or when applying a life cycle assessment analysis to a specific fruit production (Mouron et al, 2006).

When evaluating the environmental burdens in fruit production it is very important to remember the differences between the open field crop systems (where assessment tools are mainly applied) and the perennial crops (Mila i Canals and Polo, 2003). A key difference is understorey management as this can impact significantly soil quality (Glover et al., 2000; Granatstein and Kupferman, 2008) and management requirements such as fertilizer inputs and mechanical operations.

Another important aspect to be considered is that some resources are used annually whilst others are present during the whole lifetime of the orchard. Mila i Canals and Polo, (2003) identify 6 different stages in the overall orchard production (nursery

through to orchard removal) and point out that usually only the high yield stage is analyzed, even though all the stages contribute to the environmental burden per mass of fruit. Therefore in this paper we distinguish and evaluate the impacts of each of the 6 categories.

2 METHODS

2.1 Nectarine Production System

All one-year field operations were studied directly in a commercial nectarine (*Prunus persica* var. laevis Gray) orchard in Cuneo province, Northen Italy, managed according to the Italian Integrated Fruit Production (IFP) protocol. Using information provided by the farmer and considering local pedoclimatic conditions, agrotechniques and cultivar, the entire lifetime of the orchard was estimated to be 20 years. The specific duration of each of 6 stages (ST) proposed by Mila i Canals and Polo (2003) is as follows : 2 years for the propagation of the plants in the nursery (ST1), 1 year for the establishment of the orchard (ST2), 2 years of low yield due to young plants (ST3), 13 years of full production (ST4), 2 years of low yield due to declining plants (ST5), and then the destruction of the orchard (ST6).

SN1. The nursery stage was evaluated as the average processes and resources needed to obtain rootstocks, scions and finally young plants. All the environmental burdens needed to support 1 ha of the final commercial orchard have been considered; in particular the soil surface for mother-plants and for growing rootstocks, the plastic for the tunnel, water, fertilizers and pesticides.

SN2. The establishment stage was evaluated as the common practice of removing previous installation and preparing the field for the orchard; the stages considered are

soil cultivation including harrowing, basal fertilization, transplanting from nursery. Soil breakage is an operation that moves the soil to facilitate the plantation. This field operation is an extensive practice (about 10 h ha^{-1}) and requires a high power tractor with high fuel cost to provide a soil which is homogeneous and ready for planting. Since the establishment stage considers a phase of soil cultivation and removal of natural elements or previous agricultural structures, the destruction of the orchard (at the end of the previous production cycle) is not accounted prevent double counting.

Other establishment elements include: wooden stakes (one every 8 m) with two steel wires on the tree rows, the hail protection net and irrigation pipework. Therefore plastic, steel, wood resources and energy for the orchard installation have been added in proportion to the lifetime of the orchard.

SN 3 to 5. The young, high and low yield stages categories are described together because processes and resources are the same, only the value of each burden changes on the base of the different average yield (16 t ha^{-1} for the high yield stage and 12 t ha^{-1} for the other stages). These categories include all the field operations adopted in the experimental trial, particularly:

- *tree management*: this category comprises of operations aimed to improve orchard productivity, facilitate harvest and prevent disease proliferation (Mila i Canals and Polo, 2003). Pruning, thinning and harvesting are the most costly field practices in terms of human labor and fuel consumption. The tree management requires globally an amount of five to six field crossings using the hydra-ladder and about 40 working hours per ha. All mulches produced are left in situ and lightly buried in the alley with a mulching mower.

- *pest and diseases management*: pesticide applications are by air-blast spraying 15 times per season using 56 kg ha^{-1} of active ingredients diluted in 16000 l of water per ha.

- *understorey management*: the management of the soil between the rows seeks to prevent competition for water or nutrients with the trees and erosion (Mila i Canals, 2006). Following IFP guidelines, the alley was maintained using natural grass and the tree line kept free of vegetation with the use of non residual herbicides. The alley was mown two to three times per season and in row herbicide applied once per season. The soil was lightly cultivated three times in order to break compacted soil and facilitate the irrigation. In total, understorey management required an average of 6.5 tractor crossings.

- *irrigation*: trees received water through drip pipe irrigation directly under the tree canopy. This system manages water precisely but requires pumping systems that consumes electricity. For nectarine production irrigation it is essential to obtain high fruit quality (Fideghelli and Sansavini, 2005) because the fruit ripening period is very dry and the requirement for water at its maximum. The irrigation rate was 35 to 40 h per season, with a carrying capacity of 8 l h^{-1} $tree^{-1}$, for an average of 455 m^3 ha^{-1}. This information enables both the evaluation of the quantity of water utilized and the electricity consumed for irrigation, given as a quantity of Joules per l of water used.

- *weather damage prevention*: in the commercial field, poplar rows all around the orchard ensured frost events were rare and thus no frost prevention was undertaken. Thus only hail prevention nets were installed, opened and closed once per season, with two field crossings by hydra-ladder.

All the field operations are represented in figure 1 in relation to the period each practice was performed.

Stage 6. The destruction of the orchard was principally accounted for by machinery and fuel. As it is not easy to predict the destination of the resources taken away from agricultural fields because farmers tend to recycle the most useable parts of the orchard, 40% was assumed to be disposed of ex situ and 60% to be recycled in other orchards.

2.2 Ecological footprint methodology

Stock resources (material used for all the orchard lifetime duration) and flow resources (materials and energy used for process that cross the system, e.g. fuel or electricity) collected during the 2008 were listed (Table 1) and converted into bioproductive area by specific conversion factors available from the Global Footprint Network database (Global Footprint Network, 2006). When conversion factors were not available, embodied energy coefficients were used to convert data into the equivalent emission of CO_2. Then the CO_2 produced was converted into the energy land-category needed for sequestration. A world-average carbon sequestration of 0.277 gha tCO_2^{-1} 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 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. In this way the footprint of a single working hour was obtained; this value was multiplied for the effective working hours in each stage.

The environmental burden of the storage (soil, cement, plastic and glass) was added as a proportion of the estimated lifetime of 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 only as the energy necessary for the irrigation, because the valorization of the water as a resource is not already taken into account by EFA methodology.

We used Life Cycle Assessment boundaries (Baldo et al., 2005) for establishing the footprint of workers not directly involved in EFA because firstly inserting human labour in the system boundaries creates a tautology (humans are consumers of the products they are working on), and secondly because the workers' social class is lower than the average Italian, therefore the working hour footprint was not easy to assign. In order to evaluate the effect of human labour on the total footprint, a second EFA was conducted to consider the contribution of this component with the footprint of an average Italian (WWF, 2008) on the basis of the number of work-hours per year.

As the orchard system is not a liner model of production (like an industrial system), the EFA has to follow the orchard stages. Each production stage has specific gha requirement and specific yield (fig. 2). The sum of the gha required for each production stage, counted once for each year of incidence in the production, gives the total land required. The sum of the yield of each stage for each year of incidence is the total yield of the orchard in its lifetime. Total land required (gha) on total yield (expressed as t ha^{-1} y^{-1}) give the footprint of 1 t of nectarine produced.

3. Results

The total footprint for the case study was 1.34 gha t^{-1} nectarines produced. The footprint land-components were distributed as follows: cropland 14.71%, built-up land 0.02%, forest 0.29 %, energy-land 84.97%. Contribution to the whole production system footprint of each stage per each land category is presented in figure 3, in terms of total gha of that stage divided by the total tonnage of nectarines produced from the orchard across all years. Among the stages involved in peach production, ST4 (operations and

resources for production high yield years) has, as expected, the highest footprint value: 65.01% of the overall footprint. The other stages make substantially lower contributions to the overall impact, specifically: ST1=4.34%, ST2=10.59%, ST3=ST5=10.00%, ST6=0.03%.

Another interesting result arises from the comparison between the contribution of each resource used in the overall footprint. The main contribution came from electricity consumption (39.65%), followed by diesel consumption (20.23%), effective soil utilized for the orchard (13.84%) and plastic for the installations (11.53%). Fertilizer use accounted for 5.58% of the total footprint.

The contribution of the flow resources (65.94%) was about double the stock resources (34.06%).

The EFA conducted to consider the human labour hours resulted in a greater footprint of 1.54 gha t^{-1} nectarines produced; a difference of 0.19 gha, corresponding to 12.77% of the footprint. For this component all the land type percentages vary, but the overall proportion is maintained with the exception of pasture land that ranges from 0% to 0.6% of the footprint due to consumption of dairy products as food for workers.

4 Discussion

As this paper presents the first application of EFA to a total orchard system involving six stages both results and methodological issues are discussed.

Mila i Canals and Polo (2003) suggested that gaps can be found in the application of an ecological indicator to orchard systems when common field operations of one standard year (ST4) are used, but this gap was not quantified. This study reveals that this gap, not only exists, but can be significant. In the case study, the ST4 (high yield field operations and resources use) contributes to about 65% of the footprint of the whole system, therefore the other stages (ST1, ST2, ST3, ST5, ST6) in total only contribute to about

35% of the footprint. It is interesting to note that the establishing stage (ST2) that, although having environmental burdens spread over the lifetime of the orchard, makes a similar contribute to the overall footprint (10.59%) as ST3 and ST5.

Our results suggest that applying the EFA only to the high yield production, as presently proposed (e.g. Niccolucci et al, 2008) will probably underestimating the real footprint in some situations, depending on the production protocol. More studies are required to verify the average gap for each fruit species; when these data are available, consideration of all stages in the application of EFA (and other ecological/sustainability indicators) is strongly advised.

When looking at the percentage of the different land component it is interesting to point out that about 15% of the footprint is due to the effective land consumption (the cropland and built-up land components), the remaining 85% of the footprint arises from the energy applied to the system in order to amplify the productivity. This energy is applied in various forms: not only electricity and diesel, but also the embodied energy in chemical material (e.g. fertilizers and pesticides) and all the other resources. Without using such additional energy the productive system would have a lower yield (e.g. product lost from pests attacks or from lower fertilization), but would be less esoenergetic (Maturana and Varela, 1987). The built-up land percentage is very low (less than 0.1%), and it is confirmed irrelevant in the EFA of nectarine production. Nevertheless further study is required to extend this remark to other fruit production or to the whole fruit commercial system (production, transformation, packaging and distribution).

Comparing the contribution of each resource used, it is interesting to note that fertilizers represent about 5% of the footprint. This result is concordant to 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.

Diesel consumption accounted about 20% upon the total environmental burden of the case study. This is an important remark in the context of sustainable agriculture: as some authors suggest (Shiva, 2008), a significant way to make fruit production greener is by decreasing the machinery operations (if possible). The impact of the fuel consumption becomes evident when relating to all the resources used, not to a ton of product, but to a single nectarine. For example, for a single fruit of average weight of 140 g, 55.16 ml of diesel are required. In addition, to produce a single nectarine 1.6 MJ of electricity, 4.83 l of water, 8.88 g of fertilizer, 7.36 g of wood, 5.60 g of plastic are also required. This consideration, although little utilized for scientific research due to the low statistical robustness when targeting on a single nectarine, is helpful for a didactical purpose: in order to visualize the material moved (and consumed) for nutrition.

An interesting advance in the research could be the quantification of change in the Ecological Footprint of each productive year based on climatic conditions. Although the annual yield can be considered almost constant, the request of inputs for the orchard production may be strongly affected by the annual climate conditions. For example an increase of the temperature requires an increase of water and pesticide distribution (due to the more aggressive potential of pests) and consequently an increase of the Ecological Footprint.

As a general result of the research and taking into account that any discussion of sustainable agriculture depends on the context (Granatstein and Kupferman, 2008), EFA can easily discriminate the environmental burdens of each component of the system of the specific case study. Therefore, in fruit production, the EFA could help to improve one of the three aspect of sustainability (ecology, economic and social). However, although the ecological footprint is an indicator easy to understand, it is not an indicator easily applied by non-experts; thus the application of EFA directly by field technicians

should only be considered when utilizing a pre-constructed and standardized sheet of calculation.

Although greater validation of the system is still needed before its real application at grower level, we believe that an ecological indicator - based on a realistic and consolidated EFA - may also provide the much required (Meisterling et al., 2009) introduction of an environmental certification system for food production.

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Figures and Table descriptions

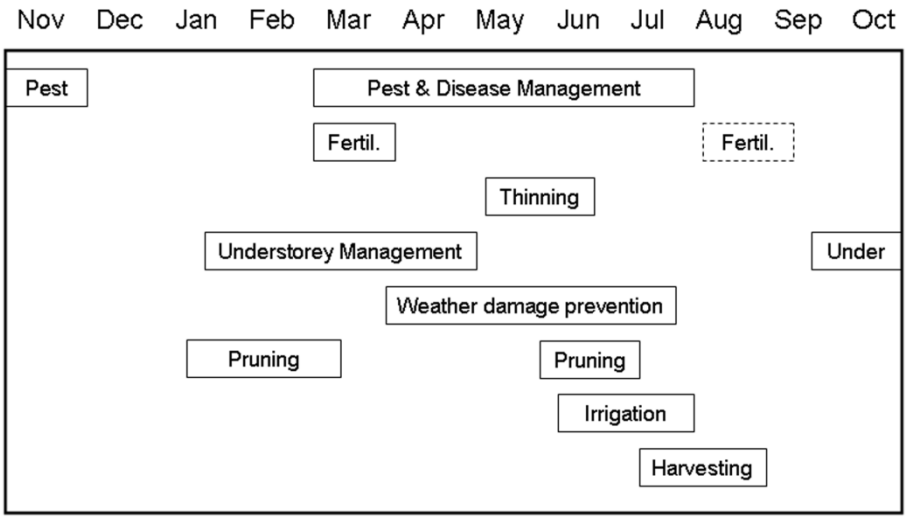

Fig.1. Schematic representation of the one-year field operations in the studied nectarine orchard (Adapted from Mila I Canals and Polo, 2003).

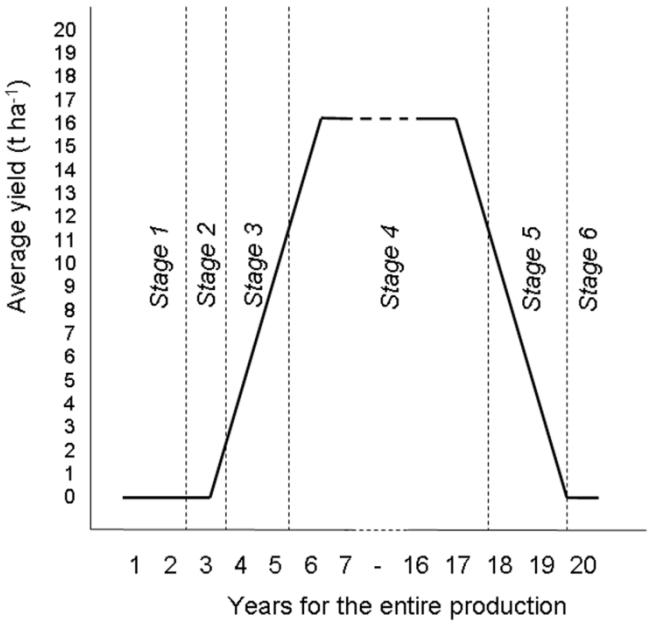

Fig.2. Average yield for each year or the orchard lifetime. Orchard stages are underlined with different average yield.

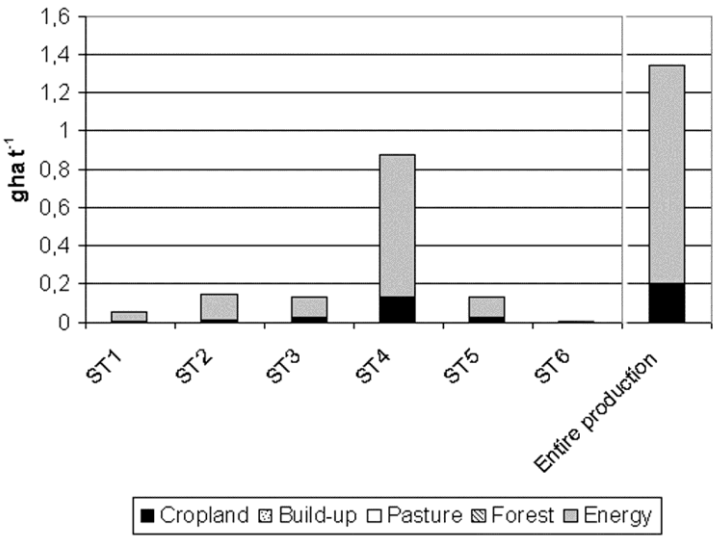

Fig.3. Ecological Footprint of the orchard system for each stage (ST1 to ST6) and for the entire production arranged by land categories. The footprints were accounted as the total gha of that stage divided by the total tonnage of peaches produced from the orchard across all years.

Table 1

Summary of the resources used in the entire orchard lifetime, arranged by stock and flow resources.

Stock resources	Unit	Quantity
Nursery surface	m2	1.14E+04
Orchard surface	m2	1.80E+05
Deposit surface	m2	2.83E+02
Wood	kg	1.35E+04
Plastic	kg	1.02E+04
Electronic compound	kg	3.63E+01
Iron	kg	3.79E+03
Concrete	kg	6.21E+03
Flow resources	Unit	Quantity
Water	l	8.83E+06
Fertilizers	kg	1.62E+04
Pesticides	kg	1.02E+03
Human labour	h	2.13E+04
Gasoline	l	1.01E+05
Lubrificant	kg	5.05E+00
Electricity	J	2.56E+09