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Life cycle assessment of bean production in the Prespa National Park, Greece

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ABSTRACT

The aim of this cradle-to-farm-gate LCA study is the comparison of the impacts generated by different modes of cultivation of beans in the Prespa National Park in Greece. More specifically, three different bean varieties have been assessed based on three different cultivation practices: conventional, integrated and organic. Moreover, the cultivation practices of the three bean varieties are compared based on two different functional units, namely a mass and an area unit. The bean cultivation inventory is compiled from raw agricultural data for the year 2008, extracted from multiple producers involved in a pilot labelling programme. Impact assessment was performed using the CML baseline 2000 method.

The results of our analysis indicate that the high input high yield bean varieties are environmentally preferable if we base our assessment on a mass-based functional unit, while the lower input lower yielding variety is preferable if we base our assessment on land use. The integrated agricultural practice is the preferable among the three, in terms of the regional acidification and eutrophication impacts and the global warming potential. On the other hand, organic cultivation of beans leads to protection of the global abiotic resources. Electricity required for irrigation is the major input that affects the environmental impacts followed by the application of sheep manure.

1. Introduction

The most environmentally damaging form of human consumption is eating (Ehrlich, 2011). Thus, the study of sustainability of agricultural products is gaining increasing attention. Life Cycle Assessment (LCA) is one, among others, environmental impact assessment methods (Cerutti et al., 2011; van der Werf et al., 2007) used in the study of various stages of the food supply chain. LCA has been applied for more than 15 years to agricultural systems, i.e., primary food production, in a variety of geographical regimes, aiming at improving their environmental performance (Brentrup et al., 2004). Recently, Ingwersen (2012) studied the fresh pineapple from Costa Rica via LCA; Beccali et al. (2009) initially examined six Italian citrus-based products by use of the LCA while later the same research group (Beccali et al., 2010) presented a sensitivity analysis and improvement scenarios on the same case study. In Italy again, Cellura et al. (2012) presented an LCA of five protected crops; Romero-Gámez et al. (2011) study green bean production in Spain; Roy et al. (2007) present an LCA of rice production in Bangladesh; Charles et al. (2006) present an LCA in wheat crop production while Mila i Canals et al. (2006) assessed the production of apples in New Zealand. LCA can have practical applications, such as its use as a support tool for Environmental Food Product Declarations (Schau and Fet, 2008) or by developing alternative scenarios to establish pathways of environmental performance improvement (Beccali et al., 2010).

To achieve the aforementioned goals LCA relies on expressing environmental impacts of a process or product per an appropriate functional unit. A very interesting aspect with agricultural systems is that the use of different functional units can improve the interpretation of the environmental results (van der Werf et al., 2007). Multiple functional units have been used: product yield, land area use, and product quality properties such as nutritional constituents or energy content (Schau and Fet, 2008). van der Werf et al. (2007) strongly recommend the expression of impacts of agricultural production systems both per unit area and per unit product, since these two modes of expression are complementary.

LCA has also been used to differentially assess the environmental performance of differing types of agricultural production (Nemecek et al., 2011). Due to environmental concerns a number of approaches towards a more environmentally benign way of cultivation have been exceedingly gaining importance. While conventional farming can be described as the "business as usual" situation, organic farming restrains from the use of synthetic fertilisers and pesticides relying more on the suitability of cultivars and

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cultivation practices for the local environment to attain the desired production levels. On the other hand integrated management allows itself a greater flexibility resorting to synthetic fertilisers, if needed, and, while seeking to address plant protection by means of cultivation practices and low toxicity selective pesticides, it may resort to more drastic means if economically acceptable limits of infection are breached. The way that agriculture is performed has received considerable attention within protected areas as it may enhance or jeopardise conservation efforts. Labelling schemes that might add value to environmentally friendly modes of agricultural production in protected areas have been proposed in order to provide an incentive for their uptake by farmers (FAO, 2003).

In the present study we seek to test the following assumptions: a) types of agricultural production developed as alternatives to the conventional one exhibit an improved environmental performance and b) cultivation of varieties requiring more intensive practices exhibit a decreased environmental performance. We pursue these goals by conducting an environmental assessment in terms of LCA of three different bean varieties, namely gigantes, elefantes and plake (P.G.I. designation: Commission Regulation (EC) 1549/98) produced by three different cultivation practices: conventional, integrated and organic. The cultivation practices of the three bean varieties were compared based on two different functional units, namely a mass and an area unit. The number of studies aiming to assess environmental performance of Greek agricultural systems is very small and focused exclusively on energy inputs (Kaltsas et al., 2007; Kavargiris et al., 2009; Michos et al., 2012; Strapatsa et al., 2006). Thus, to the best of our knowledge, this is the first attempt to perform a cradle-to-farm gate LCA on an agricultural product, namely the production of beans, in Greece. At the same time, while there have been efforts to assess the environmental performance of grain legume cultivation for use in animal husbandry, there is a lack of studies treating the issue of grain legumes for human consumption (Gaillard et al., 2006). As a final task of this research the CO_2 equivalents of the three bean varieties per cultivation practice will be calculated and reported. Modelling of the system took place in SimaPro 5.1 (PRé Consultants, 2003). SimaPro is a generic LCA tool that is flexible enough to model agricultural systems.

2. Bean farming description

The Prespa Park is the first transboundary protected area in the Balkans shared by Greece, Albania and FYROM. Prespa is a globally unique natural area due to its geomorphology, rich ecology, and biodiversity. In Greek Prespa, the Prespa bean, a Product of Protected Geographical Indication, is the main crop and source of income. This section presents the common agricultural practices associated with bean farming in the Prespa Park. These practices include: field preparation, seeding, post-seeding agricultural practices, fertilisation, irrigation, plant protection and harvesting. The following paragraphs describe the practices per step. The equipment used and the inputs applied are summarised per field practice in Table 1. Qualitative differences between organic and conventional/integrated farming are indicated in this table as well. The detailed quantitative data upon which the analysis was based can be found in the Results section, Tables 2 and 3.

Ploughing takes place during autumn or winter. In early spring disk harrowing is applied in order to destroy the early spring weeds, incorporate the manure (which is applied every third year) into the soil and prepare the field for the incorporation of the herbicides. The herbicides are applied before seeding (except from organic farming) and are then incorporated to the soil by disk harrowing. The seeds, with the exception of the organic farming case, prior to seeding are treated with fungicide. Seeding takes place from mid- to late spring. After germination disk harrowing takes place again in order to account for the weeds and improve soil aeration. In addition soil gets warmer and it retains its humidity. The next step is the creation of the irrigation ditches. Digging is carried out by means of a tractor digging implement. A small protective soil bank is also created in order to protect the plants form direct contact with irrigation water. In the middle of June supporting takes place using four reeds in the form of a pyramid. 20,000 reeds per hectare are required every three years.

Table 1
Summary of field practices and inputs for bean cultivation.

Field practice	Equipment	Input	Management practice
Field preparation	60 kW tractor[a]	Diesel	All
		Herbicides	Conventional/ Integrated
Seeding	60 kW tractor[a]	Diesel	All
		Seeds	All
Post seeding weed control Creation of irrigation ditches	60 kW tractor[a]	Diesel	All
Supporting with reeds	16-ton truck[a]	Diesel	All
Fertilisation	60 kW tractor[a]	Diesel	All
		Chemical fertilisers	Conventional/ Integrated
		Sea weeds	Organic
		Manure	All
Irrigation	Four pumping stations of 1000 l/s capacity and four of 500 l/s.	Water Electricity	All
Plant protection	60 kW tractor[a]	Diesel	All
		Herbicides	Conventional/ Integrated
		Insecticides	Conventional/ Integrated
		Fungicides (excl. Sulphur)	Conventional/ Integrated
		Sulphur	Organic
Harvest	60 kW tractor[a]	Diesel	All

[a] Assumption reflecting the average types of tractors and trucks in use.

Bean is a plant with high requirements in phosphorus and potassium and fair requirements in nitrogen. These needs are covered mostly by inorganic fertilisers in conventional and integrated management types. In the case of organic farming, sea weeds are also utilised as fertilisers. In addition, the application of manure is a common practice for all types of cultivation (i.e., conventional, integrated, organic) that takes place every 2–3 years. Irrigation of the beans starts in June and ends in middle or late September. Most of the area is surface irrigated. The irrigation frequency depends on the soil type and the ambient temperature. During the summer period, beans require an equivalent of 5 mm of water daily. The water required for the whole biological cycle of the plant is 300–450 mm, which is provided by approximately 25 irrigations per cultivation cycle. Water for irrigation is pumped from the Large and Small Prespa lakes. There are four pumping stations of 1000 l/s capacity and four of 500 l/s. All the pumps run on electricity. A variety of herbicides, insecticides and fungicides are applied for the protection of the plants in the conventional and integrated cultivation. On the other hand, only sulphur is utilised in organic farming. Harvesting starts in the middle of September and ends in late September or early October.

3. Life cycle assessment

There are four steps in an LCA study: the goal and scope definition, the inventory analysis, the impact assessment and the interpretation (ISO14044, 2006).

Table 2
Life cycle inventory data for the 7 scenarios (per 1 t of beans produced).

Inputs	Units	Gigantes conventional	Gigantes integrated	Gigantes organic	Plake conventional	Plake integrated	Plake organic	Elefantes integrated
N fertiliser	kg	18.22	3.65	–	33.30	2.13	–	1.31
P_2O_5	kg	–	39.01	–	–	51.03	–	5.11
K_2O	kg	66.36	36.88	24.91	97.18	34	74.40	3
Water	ton	1423	1474	1594	1733	1626.5	1811	1371
Manure cattle	ton	–	1.51	1.88	–	–	2.62	0.037
Manure sheep	ton	4.06	–	4.13	4.98	0.58	7.1	0.138
Sea weeds	ton	–	–	1.38	–	–	4.69	–
Fungicides	g	66.5	75.6	–	278.8	72.3	–	–
Herbicides	g	406.3	31.5	–	263.2	30.7	–	14.8
Insecticides	g	146.4	84.6	–	296.6	107.9	–	–
Sulphur	g	–	–	127.8	–	–	266.9	–
Electricity	kWh	76	78	85	92	86	96	73
Diesel	kg	24.9	25.8	28	30.3	28.4	32	24
Land occupation	$m^2\ a^{-1}$	3571.4	3703.7	3194.9	8695.7	4081.6	6578.9	3448.3

3.1. Goal and scope definition

The aim of this study is the comparative environmental assessment of 3 varieties of beans (namely gigantes, elefantes, plake) grown by 3 different cultivation techniques (conventional, integrated, organic) utilising the LCA methodology. The scope of the study includes the agricultural practices and inputs required for the farming and harvesting. Biogenic carbon balance, i.e. the equilibrium between net CO_2 uptake by plants (net primary production) and CO_2 released by soil respiration is not taken into account. The assessment of the environmental impacts is calculated per kg of products and per m^2 of land area. More specifically, the goals of the study were:

- To assess the mass and energy inputs and outputs in the bean cultivation, including indirect environmental impact related to energy source generation and water and raw materials production; and
- To evaluate the environmental impact of bean cultivation, in order to identify the most significant issues and to suggest suitable options that reduce the environmental impacts of the bean cultivation system.

The impact assessment method used was CML 2000 developed by the Centre of Environmental Science of Leiden University (PRé Consultants, 2003). The impact category indicators considered in our assessment, were: abiotic depletion factor, stratospheric ozone depletion potential, global warming potential for time horizon 100 years, Marine aquatic ecotoxicity potential, fresh water aquatic ecotoxicity potential, terrestrial ecotoxicity potential, human toxicity potential, photochemical ozone creation potential, acidification potential, and eutrophication potential.

3.1.1. Functional unit

The concept of the functional unit is a key one in LCA, facilitating the comparison of alternative products and services (ISO 14044, 2006). The present study will be based on the assessment of impacts calculated for two different functional units for comparative purposes. This is a common practice in LCAs of agricultural products (Beccali et al., 2009; Cerutti et al., 2011; Charles et al., 2006; van der Werf et al., 2007). The use of multiple functional units can improve the interpretation of the environmental results obtained in LCA studies (van der Werf et al., 2007). The first functional unit for this study will be mass-based and is defined as: the production of 1 kg of each one of the three different varieties of beans (gigantes, elefantes and plake) during one annual farming period. Three different cultivation practices are examined (conventional, integrated, organic) for the production of beans. The same bean varieties and agricultural practices will be assessed based on the second functional unit which is land-based, defined as the annual cultivation of 1 m^2 of land ($m^2\ a^{-1}$).

3.1.2. System boundary

In LCA, the system boundary should ideally be set where nature ends and the technological system proceeds. However, with food production, the inclusion of biological processes renders the distinction between technological systems and nature unclear (Berlin, 2002). Bean production is by far the major activity taking place in the protected area of Prespa, covering an area of approx. 1000–1200 ha. Thus, the focus of our study was bean production

Table 3
Life cycle inventory data for the 7 scenarios (per 1 ha cultivated).

Inputs	Units	Gigantes conventional	Gigantes integrated	Gigantes organic	Plake conventional	Plake integrated	Plake organic	Elefantes integrated
N fertiliser	kg	51.03	9.67	–	38.3	5.22	–	37.99
P_2O_5	kg	–	105.32	–	–	125	–	148.05
K_2O	kg	185.80	99.58	77.96	111.75	83.29	113.08	87.08
Water	ton	3984	3981	4989	1992.5	3985	2753	3975
Manure cattle	ton	–	4.08	5.88	–		3.98	1.06
Manure sheep	ton	11.37	–	12.94	5.73	1.42	10.79	3.99
Sea weeds	ton	–	–	4.31	–		7.13	–
Fungicides	g	186.3	204.1	–	320.6	177.2	–	43.1
Herbicides	g	1137.5	85.2	–	302.7	75.1	–	–
Insecticides	g	409.8	228.5	–	341.1	257.2	–	–
Sulphur	g	–	–	400	–		405.6	–
Electricity	kWh	205.2	218.4	266	105.8	210.7	145.9	211.7
Diesel	kg	67.2	72.2	87.6	34.8	69.7	48.6	69.5

rather than their storage, distribution or consumption. Consequently, the system boundary included all the life cycle stages from the cradle (fertiliser and pesticide production from raw materials) to the farm gate (harvested beans), as shown in Fig. 1. The boundary of the foreground system includes the following agricultural practices: field preparation, herbicide application, seeding, agricultural practices post-seeding (disk-harrowing, formation of irrigation ditches, supporting and vine training), fertilisation, irrigation, plant protection and harvesting. Moreover, the construction phase of the infrastructure (e.g. tractors and pumps) was not taken into account. Transportation, market phase, use, and end of life (disposal of organic residues and packaging) were also omitted from the analysis. Fig. 2 presents a detailed outline of the various field operations of bean production in the protected area of Prespa and their timing.

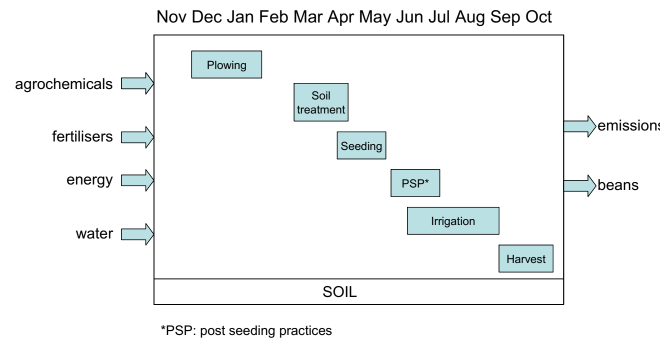

Fig. 2. Outline of the field operations during bean cultivation in Prespa National Park.

3.1.3. Main modelling assumptions

Mass and energy inputs that cumulatively contribute more than 99% to the mass and energy input of the product system respectively are included in our analysis. The main modelling assumptions of the present study are the following: The numerous commercially available plant-protection products that are utilised by the bean producers in Prespa have been classified as either, (i) herbicides, (ii) insecticides or (iii) fungicides. Thus, all plant protection products have been modelled as just three major inputs. Data for their life cycle inventories have been compiled from Sutter (2010), i.e., all the inventory data (e.g. raw materials, active ingredients, emissions to air, water and soil) have been taken from Sutter (2010) and have been introduced in the SimaPro 5.1 database as three new raw materials, namely “Herbicides”, “Insecticides”, and “Fungicides”.

Regarding fertilisation, all chemical fertilisers used have been modelled as nitrogen, P_2O_5, and K_2O equivalents. Both the sheep and cattle manure have been modelled twofold: their impacts resulting from N_2O, NO_x and ammonia emissions in addition to phosphorus leachate were calculated based on the equations suggested by Nemecek et al. (2007). On the other hand, their utilisation is replacing chemical fertilisers, thus an environmental credit has been given to both of those agricultural inputs. Likewise, seaweeds have been modelled to contain 0.3% nitrogen, 0.1% phosphorous and 1% potassium per weight, substituting thus respective amounts of synthetic chemical fertilisers. Regarding the carbon balance of the plants, its biogenic part has not been accounted for, since this was out of the scope of this study.

Regarding irrigation, the main assumption is that the capacity of the pumps is 20 m^3 of water per kWh of electricity. The environmental impacts of electricity consumption depend on the mixture of fuels utilised to generate electricity. Based on data by the Public Power Corporation, the electricity mix in Greece for 2008 was the following: lignite 51.52%, diesel oil 11.70%, natural gas 15.50%, hydro power 7.70%, other renewables 5.81% and imports 7.77%. Imports were modelled as the average medium voltage UCPTE electricity mix, from the SimaPro 5.1 database.

In all cases were a tractor is needed a 60 kW tractor is assumed, which corresponds to an average tractor commonly used in the area. The amount of diesel used was calculated as the sum of the fuel consumption of a 60 kW tractor needed to accomplish the necessary field operations. Reeds used in supporting bean plants are being transported from a distance of 500 km. 16-ton trucks are assumed to be used for this operation, while each truck load includes 25,000–30,000 reeds. The fuel needed by this truck loaded with the reeds to cover 500 km from the source of the reeds to the study area was added to the previous amount. Data for the diesel life cycle were taken directly from the SimaPro 5.1 database.

The final modelling assumption is on allocation, i.e., the partitioning of the inputs and outputs of a unit process to the product system under study (ISO 14044, 2006). As it is clearly stated in the goal and scope definition, the current research examines the cultivation of three varieties of beans by three cultivation techniques. So, we examine the production of seven bean products by seven independent processes carried out by seven independent farmers' groups and we compare the final results of the impact categories. It is evident that we are not modelling the production of beans as a multi output process; thus there is no need for allocation.

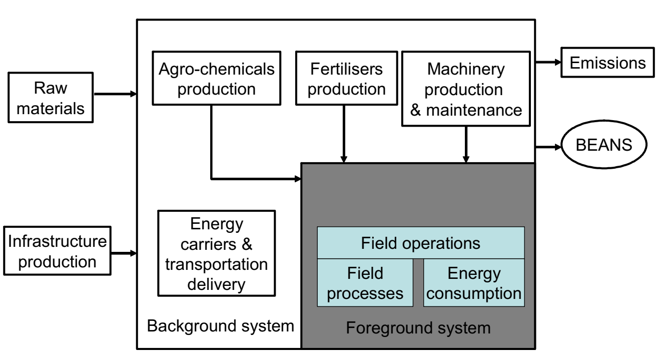

Fig. 1. Sub-systems included in the LCA study of the bean production (adapted from Mila i Canals et al., 2006).

3.2. Life cycle inventory

For the assembly of the inventory, the foreground system considered was based on the actual field operations for the production of the beans. Data associated with the effects produced by the inputs in the background system (agro-chemicals production, fertilisers production, electricity generation and transportation) were derived from the SimaPro 5.1 database and literature sources.

3.2.1. Data collection

Since 2005, the Society for the Protection of Prespa in collaboration with WWF Greece through the programme “One Europe, More Nature (OEMN)” are examining the introduction of an environmental labelling scheme for the agricultural products of the Prespa area, aiming at their labelling/standardisation as «Products of the Prespa Park». These products, beans being the dominant among them, are planed to be produced following standardisation and tracing procedures, i.e. to be certified as produced exclusively within the Prespa National Park according to concrete management obligations.

Primary data for the year 2008 were recorded from a number of producers that were involved in the pilot labelling scheme. The records were organised so as to be based on the distinct cultivated plots. For each plot every cultivation practice and application was documented and kept in a separate file. These data were collected by the Prespa National Park Administration Authority with the participation of WWF Greece. In addition an on-site visit was organised in July 2009 to interview the local producers. A preliminary inspection of the records revealed that, although each producer cultivated all of his/her plots in the same way, there were differences in the cultivation practices among producers that fell under the same broad management category (conventional, integrated, organic). In order to achieve an, as accurate as possible, general assessment of each broad management practice and variety the data corresponding to each case (management practice × variety) were pooled. The input data actually used for the purpose of our modelling are the average values corresponding to the cultivation practice of various producers weighted by the area cultivated by each producer. This way all of the available data were taken into account. For the production of the gigantes variety, the total area cultivated by the participants by conventional means, integrated practice and organic farming amounted respectively to 9.5 ha, 6 ha and 2.6 ha. Data for elefantes correspond to 15 ha cultivated only by integrated means. Finally, the total area cultivated by the participants with the plake variety the conventional way, the integrated way and by organic means amounted to 6 ha, 22 ha and 3.5 ha respectively.

Based on the quality of the records we received and discussions with participants (farmers and agronomists alike) we are confident that the records are accurate for the cultivation period under study. There remains the issue of how representative these data are, with regard to the inevitable year-to-year variability of agricultural operations. Fertiliser application does not vary interannually. Manure application however follows a 3-year cycle. Also application of plant protection substances may vary depending on weather conditions and possible outbreaks. In general our informants did not mention anything unusual taking place in that particular year, so we treated the data as representative.

3.3. Impact assessment

The impact assessment method used was CML 2000 developed by the Centre of Environmental Science of Leiden University (PRé Consultants, 2003). The impact category indicators, included in the CML 2000 ready-made method, considered in our assessment, were: abiotic depletion factor (ADF), stratospheric ozone depletion potential (ODP), global warming potential for time horizon 100 years (GWP100), Marine aquatic ecotoxicity potential (MAETP), fresh water aquatic ecotoxicity potential (FAETP), terrestrial ecotoxicity potential (TEP), human toxicity potential (HTP), photochemical ozone creation potential (POCP), acidification potential (AP), and eutrophication potential (EP). These impact categories have been applied previously by other authors (Charles et al., 2006; Romero-Gámez et al., 2011) in the field of agricultural LCA even though Brentrup et al. (2004) argue that ODP and POCP have been shown to be unimportant for arable crop production.

4. Results

4.1. Main input and output flows

The main input flows per cultivation method are presented in Table 2 (expressed per t of beans produced) and Table 3 (expressed per ha cultivated) respectively. When the inputs are expressed per t of beans produced, land use is included as an input variable. The product yield per ha of each bean variety and cultivation method is presented in Table 4.

Table 4
Yield per hectare of different bean types and agricultural practices.

	Gigantes (t/ha)	Elefantes (t/ha)	Plake (t/ha)
Conventional	2.80	–	1.15
Integrated	2.70	2.90	2.45
Organic	3.13	–	1.52

4.2. Impact assessment per kg of product

The results of impact assessment for the three bean varieties (gigantes, plake, elefantes) for each cultivation method per kg of product are presented in Table 5. If we base our assessment on a mass basis (i.e., impact per kg of product), among the three ways of cultivation for the gigantes variety, the conventional way of cultivation is the most environmentally preferable (i.e., it causes the least environmental impact) in terms of ODP, MAETP and TEP. The integrated way is the most environmentally preferable in term of GWP100, HTP, AP and EP while the organic way is the most environmentally preferable in terms of the ADF, FAETP and POCP. Among the three ways of cultivation for the plake variety, the conventional way is preferable in terms of the FAETP, the integrated way of cultivation is the most environmentally preferable in terms of GWP100, ODP, AP and EP while the organic way of cultivation is preferable in terms of ADF, MAETP, TEP and POCP. The HTP impact indicators for both the integrated and the organic way of bean production are equal.

4.3. Impact assessment per m^2 a^{-1} of cultivation

The results of impact assessment for the three beans varieties (gigantes, plake, elefantes) for each cultivation method per m^2 of annually cultivated land are presented in Table 6. In this case the conventional way of cultivation is the most environmentally preferable in terms of ODP, MAETP and TEP; the integrated way is preferable in terms of GWP100, HTP, EP, AP while the organic cultivation is preferable in terms of ADF, FAETP and POCP. Regarding the plake variety, the conventional cultivation is preferable in terms of ODP, HTP, MAETP and TEP; the integrated is preferable in terms of GWP100, EP and AP while the organic is preferable in terms of ADF, FAETP and POCP.

4.4. GWP of the bean varieties

Based on the aforementioned assumptions, the CO_2 equivalents per variety and cultivation practice are calculated (see Table 5). For the gigantes variety, the GWP is 0.247 kg CO_2 eq./kg of product, 0.127 kg CO_2 eq./kg, and 0.303 kg CO_2 eq./kg for the conventional, integrated and organic cultivation respectively. For the plake variety the value for conventional farming is 0.302 kg CO_2 eq./kg of product, for integrated 0.118 kg CO_2 eq./kg and for organic 0.438 kg CO_2 eq./kg. Finally, for the integrated production of elefantes the GWP is 0.0865 kg CO_2 eq./kg of product.

5. Discussion

The inputs that cause the major impacts in both the conventional and the organic way of cultivation of gigantes and plake are: the lignite utilised for the generation of electricity which runs the water pumps (which affects in order of importance MAETP, HTP, TEP, and POCP), the sheep manure (which affects AP, EP, GWP100 respectively), and diesel used for tractors (which affects ADF). In the integrated way of cultivation, the main impact is caused by the lignite used for electricity generation (which affects MAETP, HTP,

Table 5
Life cycle impact indicators per kg of product (bold numbers indicate the lowest indicator value per variety).

Impact category	Indicator unit	Gigantes convent.	Gigantes integrated	Gigantes organic	Plake convent.	Plake integrated	Plake organic	Elefantes integrated
Abiotic depletion	kg Sb eq.	0.000732	0.00104	**0.000532**	0.000866	0.00121	**0.000151**	0.00104
Global warming	kg CO_2 eq.	0.247	**0.127**	0.303	0.302	**0.118**	0.438	0.0866
Ozone layer depletion	kg CFC-11 eq.	**4.74E-9**	5.01E-9	5.24E-9	5.74E-9	**5.55E-9**	5.75E-9	4.72E-9
Human toxicity	kg 1,4-DB eq.	0.00994	**0.00957**	0.00979	0.012	**0.0106**	**0.0106**	0.00885
Freshwater aquatic ecotoxicity	kg 1,4-DB eq.	−0.0001	0.000577	**−0.000668**	**−1.17E-5**	0.000751	0.000263	0.000616
Marine aquatic ecotoxicity	kg 1,4-DB eq.	**40**	42.9	44	48.4	47.6	**47.4**	40.6
Terrestrial ecotoxicity	kg 1,4-DB eq.	**12.8E-5**	13.7E-5	13.8E-5	0.000155	0.00152	**0.000147**	0.000129
Photochemical oxidation	kg C_2H_2 eq.	1.25E-5	1.88E-5	**9.03E-6**	1.46E-5	2.17E-5	**9.87E-7**	1.89E-5
Acidification	kg SO_2 eq.	0.0132	**0.00284**	0.0164	0.0162	**0.00235**	0.0269	0.000931
Eutrophication	kg PO_4 eq.	0.0022	**0.000386**	0.00261	0.0027	**0.000137**	0.00417	8.38E-5

TEP, POCP and GWP100) followed by the sheep manure (which affects the EP and AP in order of importance) in the case of plake and elefantes or the cattle manure in the case of gigantes. Note that the use of manures, since they are replacing synthetic fertilisers, has a positive effect on the FAETP and POCP impact indicators.

All in all, our analysis indicates that the main input that causes environmental impacts in bean cultivation is the electricity required to run the irrigation pumps. The generation of electricity affects all the impacts associated to human or ecosystem (both terrestrial and aquatic) toxicity in addition to stratospheric ozone depletion, photochemical ozone formation and global warming. The next major input is the utilisation of manure (both sheep and cattle in order of importance) which affects heavily the acidification and the eutrophication impact categories and partially global warming. Finally, the use of diesel in agricultural machinery affects the depletion of abiotic resources. With the exception of eutrophication and, partially, acidification all other impacts are felt off-site or globally.

The environmental impact of diesel for machinery as well as that of manure application is well established in agricultural impact assessments. However, interestingly enough, our analysis reveals the great environmental burdens that electricity puts on the production of beans, which can be categorised as an indirect effect of irrigation, since electrical pumps are used for water supply from the lakes to the fields. The cultivation of beans is overall a low input activity compared to other agricultural products; thus the relative contribution of electricity, which in the case of Greece is mainly generated from lignite, comes up as a major contributor to the environmental impact categories.

Our assessment results also indicate another important issue: the effect of the functional unit on the decisions supported by LCA. Based on the mass functional unit, the comparison between the gigantes and the plake varieties, yields that the production of gigantes is environmentally preferable over plake in every one of the impact categories considered (see Table 7). The outcome is reversed, if we base our decision on the land use functional unit, i.e., the production of plake is preferable over the gigantes in nine out of the ten impact categories. The same outcome is true if we focus our attention on the organic way of cultivation. With the exception of three impact categories (ADF, FAETP, POCP), gigantes is the preferable variety for cultivation on a mass functional unit, while plake is the preferable variety, for every one of the impact categories, should the decision be based on the land use functional unit. Table 7 presents an overall picture of the environmentally preferable variety for each cultivation method for both functional units. However, moving on to the integrated cultivation practice by which all three bean varieties are produced, elefantes seem to be the variety of environmental choice within seven out of ten impact categories, for both functional units (see Table 7). As a generalised outcome, and taking into account the product yields presented in Table 4, the high yielding varieties (gigantes and elefantes) are preferable if we base our decision on the mass functional unit, while the lower yielding plake is the variety of choice if the decision is based on the land use functional unit. This finding is in good agreement with what Cerutti et al. (2011) state, i.e., that the choice of mass based functional units leads to preference for high input-high output systems while when considering impacts per unit area, low input–low output systems will have better ranking. Low input–low output systems decrease impact at regional level while high input–high output systems, when concentrated at regional level, have been shown to cause major pollution problems (Charles et al., 2006; Tamminga, 2003; van der Werf et al., 2007). Guinée et al. (2002) suggest that in LCA, impacts should be expressed per unit product when the function of the system is the production of commodities, and per unit area for a non-market function (e.g. environmental services). Considering the fact that the production of beans takes place in a protected area, where the key values at stake are environmental, the expression of impacts per unit area seems more fitted.

Table 7 reveals another feature with regard to the suitability of the studied varieties for each production mode. While in the case of

Table 6
Life cycle impact indicators per m^2 a^{-1} (bold numbers indicate the lowest indicator value per variety).

Impact category	Indicator unit	Gigantes convent.	Gigantes integrated	Gigantes organic	Plake convent.	Plake integrated	Plake organic	Elefantes integrated
Abiotic depletion	kg Sb eq.	19.4E-5	29.2E-5	**16.7E-5**	9.95E-5	29.7E-5	**2.3E-5**	25.2E-5
Global warming	kg CO_2 eq.	0.0685	**0.0353**	0.095	0.0348	**0.0289**	0.0666	0.0421
Ozone layer depletion	kg CFC-11 eq.	**1.28E-9**	1.4E-9	1.64E-9	**6.6E-10**	1.36E-9	8.73E-10	1.35E-9
Human toxicity	kg 1,4-DB eq.	0.00269	**0.00268**	0.00307	**0.00138**	0.0026	0.00161	0.00254
Freshwater aquatic ecotoxicity	kg 1,4-DB eq.	−3.49E-5	16.3E-5	**−20.9E-9**	−1.42E-5	18.4E-5	**−26.5E-5**	7.68E-5
Marine aquatic ecotoxicity	kg 1,4-DB eq.	**10.8**	12	13.8	**5.57**	11.7	7.2	11.5
Terrestrial ecotoxicity	kg 1,4-DB eq.	**3.46E-5**	3.83E-5	4.31E-5	**1.78E-5**	3.72E-5	2.23E-5	3.65E-5
Photochemical oxidation	kg C_2H_2 eq.	3.29E-6	5.28E-6	**2.82E-6**	1.68E-6	5.32E-6	**1.51E-7**	4.52E-6
Acidification	kg SO_2 eq.	0.00371	**0.000772**	0.00514	18.7E-4	**5.75E-4**	40.8E-4	15.5E-4
Eutrophication	kg PO_4 eq.	61.5E-5	**10.4E-5**	81.7E-5	31E-5	**7.66E-5**	63.4E-5	24.2E-5

Table 7
The effect of functional unit on the selection of the environmentally preferable variety of bean per cultivation method.

Impact indicator	Conventional		Integrated		Organic	
	per kg	per m^2 a^{-1}	per kg	per m^2 a^{-1}	per kg	per m^2 a^{-1}
ADF	Gigantes	Plake	Gigantes	Elefantes	Plake	Plake
GWP100	Gigantes	Plake	Elefantes	Plake	Gigantes	Plake
ODP	Gigantes	Plake	Elefantes	Elefantes	Gigantes	Plake
HTP	Gigantes	Plake	Elefantes	Elefantes	Gigantes	Plake
FAETP	Gigantes	Gigantes	Gigantes	Elefantes	Plake	Plake
MAETP	Gigantes	Plake	Elefantes	Elefantes	Gigantes	Plake
TEP	Gigantes	Plake	Elefantes	Elefantes	Gigantes	Plake
POCP	Gigantes	Plake	Gigantes	Elefantes	Plake	Plake
AP	Gigantes	Plake	Elefantes	Plake	Gigantes	Plake
EP	Gigantes	Plake	Elefantes	Plake	Gigantes	Plake

impacts being expressed per unit mass high input–high yield varieties are exclusively listed as the best ranking ones in the case of conventional and integrated modes, plake appear (in 3 out of 10 cases) as the best ranking variety in the organic case also when impacts are expressed per unit product. It seems that low input–low yield varieties are better suited for organic farming also in environmental terms, apart from the mere practical ones.

Tables 5 and 6 exhibit a remarkable consistency in the hierarchy of the impacts of each cultivation practice for the different varieties. Regardless of plake or gigantes, the rank of the impacts is usually identical between practices. This consistency generates confidence on the validity of the results. Within each variety of beans, our assessment does not reveal a clear advantage of any of the cultivation practices since every practice per bean variety is preferable over the others with respect to different impact categories. Conventional and integrated practices have higher inputs in terms of fertilisers and plant protective substances compared to the organic cultivation practice. On the other hand, organic agriculture had higher manure inputs in 2008. However, the use of plant protective substances may vary considerably depending on weather conditions (De Jong and De Snoo, 2002), and this holds true for both integrated and conventional cultivations. In addition, the use of manures every two to three years is a common practice in the cultivation fields of Prespa, irrespective of the cultivation practice.

The lack of a clear-cut picture is also due to the fact that all three major sources of impacts (electricity, manure application, tractor fuel) are shared between all modes of production. It has to be taken into account however that, unlike all other inputs, manure is a by-product of a distinct production process that would be produced regardless of bean production, while e.g. pesticides and fertilisers are specifically produced for this purpose. Including impacts generated by the use of manure ensures "fairness" in the treatment of the various kinds of production modes. It has to be kept in mind, though, that manure impacts would be realised also in the absence of the production process under study. Another source of bias against use of manure is also the fact that the positive effects of its use, such as the enhancement of water holding and nutrient retention capacity as well as of the physical properties of the soil cannot be modelled within the frame of LCA.

The existing differences between modes of production can be modelled with varying efficiency. Impacts of use of manure are pretty well established and the heavier use of it in organic farming results to more significant impacts. On the other hand pesticide use is less well modelled. Since differences between substances are not taken into account but are rather pooled and modelled in terms of amount of use (European Environment Agency, 2007) differences in the toxicity per unit applied are not taken into account. This is probably introducing a bias against integrated modes that seek the best result with the least toxicity. It is also probably introducing an idiosyncratic effect due to the different amounts of different substances required for the same purpose due to their differing properties.

Despite the aforementioned uncertainties, the results presented in Tables 5 and 6 clearly indicate that the integrated practice of agriculture is the preferable one in terms of regional impacts such as eutrophication and acidification for all bean varieties, while organic agriculture is preferable in terms of the depletion of global abiotic resources (such as minerals and fossil fuels) due to its lower inputs of fertilisers and plant protection substances. Moreover, our analysis indicates that organic agriculture is preferable in terms of the fresh water aquatic toxicity, which is a key ecological indicator for the Prespa protected area.

Regarding the calculated GWPs, for the conventional and organic farming of both the gigantes and plake varieties, more than 75% of the total CO_2 equivalents are attributed to the sheep manure and its associated N_2O emissions. For the integrated production of gigantes, the generation of electricity from lignite and cattle manure contribute almost evenly to its GWP while for the integrated production of elefantes and plake, lignite utilised for electricity generation is the major contributor to the GWP. The integrated agricultural practice is the preferable one for the cultivation of every bean variety in Prespa in terms of its lower GWP.

Due to the fact that only agricultural operations and inputs were taken into account the effect on global warming is always negative. Published results of biogenic carbon balance in agro-ecosystems report in most cases rates of net carbon sequestration that could offset the emissions reported in this study (Lehuger et al., 2010). However these values are highly dependent on pedoclimatic factors as well as the cultivated species and management choices. To the best of our knowledge there is no published study directly relevant to the system we studied. The relatively long growing period (approx. 150 days) and the fact that only grains are harvested enhance the sink effect (Ceschia et al., 2010; Lehuger et al., 2011) whereas the multiple tillage operations the opposite (Mosier et al., 2005).

6. Conclusions

The cradle-to-farm-gate production of three varieties of beans (gigantes, elefantes, plake) by three cultivation methods (conventional, integrated, organic) in a protected area has been analysed via the LCA methodology. Our research indicates that the high input high yield bean varieties (gigantes and elefantes) are environmentally preferable if we base our assessment on a mass-based functional unit, while the lower input lower yielding plake variety is preferable if we base our assessment on land use. For both functional units, the environmental burden posed on the cultivation of beans by the lignite utilised for the generation of the required electricity to run the water pumps is revealed. Overall, electricity is ranked first among the inputs causing environmental impacts, followed by the utilisation of manures (mainly sheep) and the consumption of diesel required for agricultural machinery.

The integrated agricultural practice is the preferable among the three, in terms of the regional acidification and eutrophication impacts and the global warming potential, due mainly to the reduced use of manure compared to the other cases. On the other hand, organic cultivation of beans leads to protection of the global abiotic resources.

The results of any modelling effort of real world systems, such as the agricultural systems, depend strongly on the modelling assumptions. Thus, a shortcoming of the application of LCA for studying agricultural systems in protected areas, is the lack of general impact indices that refer to biodiversity, a key sustainability characteristic of protected areas. Further research and modelling towards this direction is required.

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