Influence of management practices on economic and environmental performance of crops. A case study in Spanish horticulture.

Abstract

This paper assesses the effect of management practices on the environmental and economic performance of tigernut production in Spain. Tigernut is a horticultural crop grown in a very limited area with homogenous climate and soil; thus the influence of these surrounding factors on the agricultural practices and their subsequent impact can be overlooked. From an environmental perspective, the variability among farms was much greater than the one of the costs. A principal component analysis showed that keeping some impacts low would also decrease the costs. Results highlight how proper management leads to both relatively low environmental impacts and costs.

Keywords: crop management, Life Cycle Assessment, Life Cycle Costing, tigernut, variability.

Running head: Management influence on overall impact of crops

1. Introduction

Sustainable agriculture implies the ability of agro-ecosystems to remain productive in the long term, i.e. to be economically competitive, to produce high quality food in sufficient quantities at affordable prices, and to be environmentally benign (UN-DSD, 2000). To attain a sustainable agriculture, a combination of strong economic performance together with a sustainable use of nature is needed. For this reason, farmers need information about the production costs and also about the causes of environmental impacts in order to promote profitable and environmentally sound agricultural production.

Life Cycle Assessment (LCA) is a compilation and evaluation of the inputs and outputs and of the environmental impacts of a product system (Guineé et al., 2002). LCA methodology has proved to be a valuable tool for the environmental evaluation of farming systems. Some agricultural LCA studies have assessed specific agricultural production systems (Sanjuán et al., 2005; Blengini and Busto, 2009; McDevitt and Milà i Canals, 2011); others have compared systems, such as conventional versus organic farming (Meisterling et al, 2008; Backer et al., 2009; Van der Werf et al., 2009; Venkat, 2012). Every one of those studies has addressed the differences between the farming systems regarding environmental impacts. However, the results from LCA studies are affected by different sorts of variations. In fact, some studies (Mouron et al., 2006a; da Silva et al., 2010; Thomassen et al., 2009) have highlighted the variations that exist between the farms or scenarios within the same type of production system, even within the same region. A way to tackle this variability is to define representative systems and to quantify the uncertainty linked to the variability by using Monte-Carlo analysis (Basset-Mens et al., 2006; Basset-Mens et al., 2009). Another option is to study each farm separately, since it can help us not only to differentiate the results obtained from the farms but also to define the potential of an individual farm in order to improve their environmental management. As Mouron et al. (2006a) state, the promotion of environmentally sound farming is not only a question of choosing a farming system (e.g. organic vs. integrated farming), but also of knowing that it is crucial to understand the influence of system specific management.

The estimation of the economic results implies the quantification of costs and revenues. According to Carlsson Reich (2005), the right tool is a financial Life Cycle Costing. But, as Norris (2001) already stated, the separation of environmental assessment from economic analysis limits the influence and relevance of LCA for decision-making, and does not characterize the important relationships and trade-offs between the economic and life cycle environmental performance of alternative product design decision scenarios. Since then, several studies have examined the relationship between environmental efficiency and profits in agricultural production (Tzilivakis et al., 2005; Thomassen et al., 2009; Jan et al., 2012).

In this paper, an environmental and economic assessment has been carried out on a horticultural crop, specifically tigernut (*Cyperus Sculentus L.*). Tigernut is grown as a crop in some African countries and in Spain, specifically in the Comunidad Valenciana (Pascual et al., 2000), in an area called *L'horta Nord*. In this region, the tubers are mostly used to make tigernut milk (*orxata* or *horchata*), a traditional soft drink. Most of the tigernut producers of this area belong to the the Apellation of Origin *Chufa de Valencia* (B.O.E, 1997), which supervises the production techniques and the quality of the product. Although tigernut is not a product which is commonly found in the markets, it is a good example of a crop that is grown in a very limited area with homogenous climate and soil type. As stated before, both the environmental impact and economic benefit of a farm depend to a large extent on the farmer's management practices. However, the link between farmer management and impacts is indirect, as other factors (soil characteristics, weather) affect the causal chain linking these management practices to emissions of pollutants (Basset-Mens et al., 2006). In this study, the influence that these surrounding factors can have on the agricultural practices and their subsequent impact can be overlooked, since all the farms are in a limited area.

The goal of this study is to examine the effect of management practices on the environmental impacts and economic results of horticultural crops under a life-cycle perspective and, furthermore, to simultaneously assess how these practices influence the inter-farm variability.

2. Materials and methods

2.1. Study location

Tigernuts are grown in sixteen municipalities located on the northern outskirts of the city of Valencia, in an area known as *l'Horta Nord*. This area has suitable climatic and soil type conditions for this crop. Tigernuts are usually part of a crop rotation and are seeded between April and May and harvested between November and December. This crop demands loose soils, sandy loam, not only because of the quality of the tubers, but also because it increases the yield and makes the harvesting of the tubers easier, inasmuch as harvesting must be done by sieving the first 15-20 cm depth of the soil where the tuber is located. Furthermore, the soil must have a good drainage, must be levelled, clean of plant residues and stones and rich in organic matter. A warm climate is required, with a high average temperature (13 to 25 ºC), high relative humidity and from 4 to 5 months without frost. Although the precipitations are low in Valencia (around 450 mm annual), the proximity to the sea gives the humidity needed. To keep a high moisture content in the soil, watering must be frequent and abundant during the summer (600-700 m^3/ha and week). Watering is mainly done by means of an irrigation channel network with water from rivers and also with ground water.

2.2. Data recording

The farm data used in this study contains detailed information about the usual practices of each farmer. In order to obtain these data, the farmers had to answer a survey. These surveys enable the data to be standardized and easily processed and, in addition, make it possible to carry out partial studies (segmentation, farm typology, etc) (Grande and Abascal, 2005). The survey was arranged in the following sections: farmer data; general characteristics of the farm; management practices (agricultural practices, watering system and well depth, fertilizers and pesticide treatments, and crop yield); and machinery used.

First, 10 farmers were polled, and from the results the initial survey was modified for a better understanding and the definitive survey was defined. To check the sincerity of the answers, some control questions were included. The sampling of farmers surveyed was based on the election of individuals by means of information provided by the Apellation of Origin *Xufa de*

Vàlencia (AO). Finally, 31 farmers belonging to the AO were polled on their own farms between September, 2007 and October, 2008. They account for 10.6% of the crop area in the AO. From these, 27 farms practised conventional agriculture, whereas 4 practised organic farming. Although it could be thought that the farm sample is unbalanced, there are actually only 4 organic farms in the AO.

2.3. Environmental performance

The environmental performance of the farms was based on the results of an LCA carried out for each farm in the sample, taking the ISO standards into account.

2.3.1 Goal and scope definition.

A functional unit (FU) was defined in order to achieve the previously defined goal of the study, and to enable the different farms to be compared. The FU is related to the function of the system under study and the results of the environmental impacts are related to the FU. Taking into account that agricultural systems are multifunctional, two different FU were used in this study. On the one hand, considering that farms produce marketable goods, 1 kg of tigernuts has been the FU used. On the other hand, 1 ha of cultivated land has been chosen as the second FU unit. This FU was chosen according to another important agricultural function which is providing environmental services.

This study focuses on the agricultural production of tigernuts, without taking into account the subsequent processing of the tubers (i.e. cleaning and drying) or their distribution. For this reason, the stages considered within the system boundaries were: the production of fertilizers, the production of pesticides, watering (that is, the production of electricity to be directly used for watering), machinery use (implying diesel production and combustion) and the agricultural stage, which includes those practices performed on the farm (that is, the application of fertilizers and pesticides and their subsequent emissions). The transport of fertilizers and pesticides has not been included, due to lack of data. The production of agricultural machinery has not been included, because although the use of machinery is seasonal, most of the surveyed farmers stated that they rented the machinery. Thus, a greater use is made of the machinery than if it was used by only one farmer. Furthermore, a study carried out by Frischknecht et al. (2007) shows that the production of capital goods contributes to a cumulative energy demand, whereas the contribution to other impact categories is not significant.

As regards the temporary system boundaries, one farming season has been taken into account, corresponding to the years in which the survey data were gathered.

2.3.2. Inventory data

Input manufacturing. All the data about the type and dose of inputs applied come from the surveys (section 2.2). The emissions originated during manure production were not included because they were allocated to the manure producer (Nemecek *et al*., 2003). Data on fertilizer manufacturing come from GaBi database (PE international, Germany), except potassium nitrate and diammonium phosphate from Davis and Haglund (1999). To estimate the energy needed for pesticide production, the method proposed by Green (1987) was used and, when the active ingredient was not available, the extrapolation methods proposed by Audsley et al. (1997) and Audsley et al. (2009) were applied.

Emissions from fertilizers use. Tigernut crop is part of a rotation and thus each crop is strongly related to one and another. Taking into account that farmers apply nitrogen fertilizers separately for each crop its emissions to air and ground water can be fully allocated to the crop of application (van Zeijts et al. 1999).

In order to obtain the nitrogen losses on the farms under analysis, LEACHN, the nitrogen module of the LEACHM model (Wagenet and Hutson, 1989), has been used. This model is a process-based, one dimensional model that simulates water and solute movement, and related chemical and biological processes, in the unsaturated soil. Transient field conditions, in which the movement of both water and solute vary with depth and time, are resolved by the numerical integration of the Richards' equation for one-dimensional water flow and the convection-dispersion equation for solute transport. For nitrogen cycling, the model considers three organic pools (manure, litter and a relatively stable humus fraction) and three mineral pools (urea, ammonium and nitrate). LEACHN also requires the nitrogen input by rainwater and irrigation, fertilization and organic amendments.

Soil, climate, irrigation and crop data necessary to run the LEACHN model were experimentally obtained from one selected, conventionally managed plot during the 2008 crop season. In this plot, soil samples were taken at 20 cm intervals down to 60 cm at three moments: before planting, at the end of an irrigation period, and at harvest in order to determine the water, chloride and mineral N content in the soil profile. On each irrigation date, the water applied was determined by measuring the flow rate of surface water, the wet section of the channel and the time of irrigation, and two water samples were collected at the beginning and the end of irrigation for nitrate, ammonium and chloride analysis. Meteorological data were taken at the "Valencia-Viveros" station (ca. 5 km from the experimental plot). The hydraulic parameters of the model were estimated from the SPAW software (Saxton et al., 1986) using soil texture data and organic carbon content. Parameters related to the nitrogen cycle in the Valencia region (rates of mineralization, nitrification, volatilization and denitrification) were taken from Contreras et al. (2009).The model was calibrated by adjusting the infiltration of water and drainage outputs using chloride and water balance methods (Lidón et al, 1999). The calibrated model has been applied to the other plots with the same climatic data and irrigation frequency, varying only the fertilization rate used by each farmer in order to obtain nitrogen losses in function of the fertilization rate. The nitrogen content of organic manures was obtained from Labrador (2006).

Emissions from pesticide use. Fate, effect and finally characterization factors of the pesticide applied during cultivation were calculated for both freshwater ecotoxicity and human toxicity, following the USEtox model (Rosenbaum et al., 2008). A leaf area index (LAI) of 7.06 was calculated based on an average of 50 leaves per plant and 8.5 cm^2 $leaf^{-1}$. Physicochemical pesticide parameters, needed as input in the model, were obtained from the FOOTPRINT (2010) pesticide properties database. Site specific input parameters used in the fate model are: land area of 23,225 km^2, sea area of 17,400 km^2, area fraction of fresh water of 0.01, temperature of 18ºC, and annual rainfall rate of 450 mm per $year^-$.

Energy and water consumption. Data on energy consumption of agricultural machinery have been obtained from an agricultural machinery rental firm. Irrigation using surface water implies no energy consumption. However, in the case of watering with groundwater, the power needed for watering has been computed from the pressure, the volume of water and the depth of aquifer. Due to lack of data, we have directly measured the irrigation water applied on one of the farms during the 2008 crop season, in which a total of 8 irrigation episodes occurred; thus, the dose of water is 6,830 m^3/ha·year. The dose of water applied can vary, depending on the year's rainfall. Data on energy production and on emissions of agricultural machinery have been obtained from GaBi databases 2006 (GaBi software, PE International, Germany).

The emissions produced when the plant is burnt previous to harvesting were obtained from IPCC (2006).

2.3.3. Impact assessment

The following impact categories and category indicators (in brackets) were chosen following the CLM 2001 methodology (Guinee *et al.*, 2003): air acidification (expressed as kg SO_2 equivalents), eutrophication (kg PO_4^{-3} eq.), photochemical oxidant formation (kg ethylene eq.), depletion of non-renewable resource elements (kg Sb eq.), depletion of non-renewable resource fossil (MJ), global warming (kg CO_2 eq.) and ozone depletion (kg CFC-11 eq.).

The toxicity impacts caused by pesticides, both on aquatic ecosystems and humans, have been computed by following the USEtox model (Rosenbaum et al., 2008) and expressed as kg DCB eq. The toxicity caused by the pesticides used in organic agriculture was not assessed due to lack of data. The toxicity impacts caused by other off-farm emissions (e.g. those linked to energy production) have been neglected.

Impacts have been considered as "direct" environmental impacts, those that take place on the farm site, and "indirect", that is, those associated with production and supply of inputs used on farm: fertilizer and pesticide production, diesel production for machinery and electricity for watering. Van der Werf et al. (2009) distinguished between these two kinds of impacts because when the evaluation method is used, it is useful to find the ways in which to decrease a farm's impact, as it will reveal the relative importance of the two components for each impact; consequently, it will help to identify improvement strategies.

2.4. Economic performance

To assess the economic performance of the farms, the costs and the income were quantified. In this study, we have divided the total costs according to the cultural practices and according to the inputs applied.

According to the sequence of cultural practices, the tigernut cultivation costs are: soil preparation, watering, pesticides, fertilizers and harvesting. And the production-dependent costs are the following: labour, pesticide treatments (before sowing and after sowing), fertilizers (before sowing and after sowing), seeds, water and machinery.

A cost sheet database was built using the data gathered by the survey. This database reflects both the cultural practices and the products and services used in the aforementioned practices. Prices of inputs were gathered from suppliers.

For each farm, the income was calculated as the tigernut yield multiplied by the market price. The profits obtained by the farmer were calculated as the difference between the income and the total cost. Results were referred to the two FU; that is, 1 kg tigernut and 1 ha cultivated land area.

3. Results

3.1. General characteristics of the farms

Table 1 summarizes the different agricultural practices of tigernut cultivation found on the conventional and organic farms in the studied area. The main differences between the two systems lie in the fact that neither chemical fertilizers, nor pesticides are used in organic farming. As a consequence, another difference is that, in organic farming, the plant is dried before harvesting without the help of herbicides.

Means and standard deviations of the characteristics of the studied farms are presented in table 2, together with the maximum and minimum values of each characteristic. Although the organic farms studied are smaller than the conventional ones, the average area of both reflects the smallholding typical of the region. The average yield in conventional farms is slightly higher than in organic farms, although no significant differences were found. As regards the use of chemical pesticides, as stated before, they are not applied in organic farming, and the amount used in conventional farming is highly variable. Only one organic farm used Neem oil and *Bacilus Thuringiensis*, which explains the great standard deviation observed in this input in table 2. With respect to the chemical fertilizers, the applied dose is also observed to vary greatly. In fact, chemical fertilizers are only applied before seeding on eleven farms and no chemical fertilizers at all are used on three conventional farms during the whole cultivation period. Thus, if the farms on which chemical fertilizers are not applied are not taken into account, the average dose increases to 116 ± 97 kg N/ha. A significantly higher amount of manure is applied in organic farming, whereas there are six conventional farms on which no manure is applied at all. Poultry manure is used in conventional farming (except in one scenario in which sheep manure is used) while on three of the organic farms, sheep manure is used and on the fourth one cattle manure is applied. The amount of diesel used for field operations with a tractor is higher on conventional farms than on organic ones, which also points to a greater degree of variability in the former. Electricity is used when watering with ground water (all conventional farms and one organic farm) and the consumption depends on the percentage of water provided from the well and on the well depth, since the same water dose has been considered on all farms as previously explained. As can be observed in table 2, the depth of the well varies greatly, as does the percentage of water that comes from it. It must be highlighted that only one of the organic farms uses water from a well: 50% with a well depth of 150 m.

The results shown in table 2 confirm that it is difficult to define standardized practices even within a farming system. The farmer's choices with respect to the inputs will affect the costs and impacts, as the economic and environmental results show in the following sections.

3.2. Results of the environmental assessment.

Table 3 and Table 4 present the average values obtained for each impact category referred to the two functional units used in the study, 1 kg tigernuts and 1 ha, respectively. Unlike the results of previous studies (Backer et al., 2009; Martinez Blanco et al., 2010), no differences can be detected between the average results referred to the two functional units. This is due to the fact that the differences in the yield obtained by the two farming systems are not significant, as commented on section 3.1.

Expressed per 1 kg of tigernut, the **aquatic ecotoxicity** and **human toxicity** levels caused by pesticides are higher in conventional farming ($6.03 \cdot 10^{-4}$ and $1.15 \cdot 10^{-4}$ kg 1.4 DCB-eq., respectively), since only one organic farm uses natural pesticides and the toxicity was not assessed. Nevertheless, based on the results of analysis of variance, no significant differences were found between either production system ($p<0.05$). The coefficients of variation (CV) for these impact categories were very high on conventional farms, 109.9% and 108.6%, as were the maximum to minimum ratios, 32.9 and 26.0 for aquatic ecotoxicity and human toxicity, respectively.

No significant differences ($p<0.05$) were found in the **abiotic depletion of elements** per 1 kg of tigernut. The average values of this impact were $8.0 \cdot 10^{-8}$ on conventional farms and $1.9 \cdot 10^{-9}$ kg Sb-eq. on the organic ones. The CV of conventional farms was slightly higher (99.9 vs. 87.1%) and the maximum to minimum ratio is 252.5 in conventional production and 4.9 in organic. As regards the **abiotic depletion of fossil**, the impact per 1kg tigernut on conventional farms was nearly twice the impact of organic farms (1.22 vs. 0.84 MJ), although no significant differences were found between the average values of this impact category. The CV was slightly lower for organic farms (40.7 vs. 35.6%) and the maximum to minimum ratio is 3.4 in conventional production and 2.2 in organic. Both abiotic depletion of fossil and element were due to indirect resource consumption for both systems, such as those derived from manufacturing agricultural inputs, the production of electricity for watering and diesel production at refineries.

The average **acidification** impact per kg of tigernuts was significantly higher for conventional farming ($4.62 \cdot 10^{-3}$ vs. $2.37 \cdot 10^{-3}$ kg SO2-eq.). For conventional farming, the CV was 46.1% and the maximum to minimum ratio was 9.26. In organic production, the CV was 33.1% and the maximum to minimum ratio, 1.87. This impact was mostly caused by direct emissions on the farm, such as the release of ammonia from the application of chemical fertilizers and manure.

As far as **eutrophication is concerned,** the average value for conventional farming is significantly higher than for organic ($2.10\cdot10^{-3}$ vs. $7.62\cdot10^{-4}$ kg PO_4^{3-}-eq.). The CV of both farming systems is very similar (47.1 vs. 44.5%) and the maximum to minimum ratio is 11 and 2.7 in conventional and organic production, respectively. This impact was also mainly due to in-farm emissions of nitrate from fertilizers.

Global warming per 1 kg tigernuts was significantly higher for conventional farming ($1.71\cdot10^{-1}$ vs. $7.55\cdot10^{-2}$ kg CO_2-eq.) and the CV were 44.3 and 29.6% for conventional and organic farming, respectively. The maximum to minimum ratio is 5.9 for conventional and 1.8 for organic farming. In conventional farming, 57.5% of this impact was caused by direct emissions of nitrous oxides and ammonia from the application of manure and chemical fertilizers and also from machinery-use emissions. The remaining 42.5% of the impact was caused by indirect emissions mainly due to fertilizer production. In organic farming, 74% of the impact was due to direct farm emissions from manure application and machinery use.

The average **ozone layer depletion** of conventional farms was 1.5 times higher than that for organic farms ($4.07\cdot10^{-9}$ vs. $2.70\cdot10^{-9}$ kg R11-eq.) although the CV was lower for conventional farms (78.4 vs. 192.4%). No significant differences were found between the results of this impact on organic and conventional farms. This impact is mainly due to indirect emissions of Halon-1301 linked to the production of electricity for watering, and to the manufacturing of fertilizers and pesticides, since the more electricity is used in these stages, the greater this impact is.

The average **photochemical ozone creation** per 1 kg tigernuts was of the same order of magnitude for both conventional and organic farms ($8.43\cdot10^{-5}$ vs. $6.44\cdot10^{-5}$ kg ethane-eq.), and no significant differences were found. The CV of conventional farms is 1.6 times higher than the CV of organic farms (35.1 vs. 21.4%). As can be observed in table 3, on average 69% of this impact is due to direct emissions on the farms, mainly because of the emissions from machinery use; straw burning emissions of non-methane volatile organic compounds also contribute to this impact. The remaining 31% of this impact is caused by indirect emissions mainly produced in fertilizer manufacturing and, on those farms where a high percentage of well- water is used and the aquifer is very deep, the electricity used for watering also makes an important contribution to this impact.

3.3. Economic results

Table 5 shows some descriptive statistics of the cost structure following two cost classifications explained in section 2.4. Results are expressed per 1 kg tigernut since, as commented on in the environmental assessment results, no significant differences in the yield were found. The cost distribution differs between organic and conventional farms, but the average unit cost is quite similar (0.28 €/kg in conventional farming vs. 0.29 in organic farms). Moreover, there are some differences in the range of costs (the maximum and minimum costs). On organic farms, the maximum is 0.40 €/kg and the minimum is 0.20 €/kg (31% CV) whereas on conventional farms the maximum is 0.60 €/kg and the minimum is 0.17 €/kg (39% CV). These differences can be explained because three of the conventional farms present higher costs than the rest. In most cases, the costs of conventional farms are between 0.20 and 0.30 €/kg.

Organic farmers' profits are higher than the conventional ones because both the total cost and the yield are similar but the selling price is significantly different: the organic tigernut price is 1.20 €/kg, whereas the conventional tigernut price is 0.50 €/kg, which, converted into profits, means 0.91 €/kg for organic (10% CV) and 0.23 €/kg for conventional (48% CV).

As regards the **costs of cultural practices**, soil preparation and harvesting costs are higher on organic farms, whereas watering, pesticide and fertilizer costs are higher on conventional farms. The highest share of the cost is due to soil preparation before sowing. This accounts for more than 50% of the total costs on organic farms, and 42% on conventional ones. The CV is 46% and 58% in organic and conventional farming, respectively. The difference between farming systems is to be expected because very little fertilizer is added post-sowing on organic farms (0.03 % of the total cost), whereas, the application of fertilizers after sowing on conventional farms represents more than 6% of the total costs. The second highest share is that of harvesting. On conventional farms this accounts for more than 27% of the total cost, whereas on organic farms it is around 39%, with CV of 37.5% and 9% on conventional and organic farms, respectively. The greatest difference between both systems can be found in the application costs of pesticides and fertilizers. These costs are higher on conventional farms (22%) than organic (2.4%), with a similar degree of variability in both cases. The small difference observed in the watering cost on both kinds of farms (8.6% of the total cost on conventional and 7.6% on organic, respectively) can be explained by the fact that the farms that are the subject of the study are close to one another and the water comes from the same wells or rivers. According to the **cost of inputs** (bottom of table 4), labour costs make up almost 45% (40% CV) of the conventional total costs and 41% (60% CV) of the organic. This workforce is usually not hired but it has been included in the opportunity cost. The machinery cost is the second highest, representing 22.44% (80.6% CV) of conventional farm costs and 42.09% (8.26%) of organic. Therefore, more than 80% of the input costs on organic farms are made up of labour and machinery costs. The remaining costs are mainly caused by fertilizer (manure) and seeds. On conventional farms on the other hand, labour and machinery costs account for less than 70%, but the cost of pesticides and fertilizers is almost 27%, in contrast to 14% on the organic farms.

3.4. Correlations between impact categories and costs

Following Mouron et al (2006a), a principal component analysis (PCA) was performed in order to group the impact categories according to their correlations. A three-component solution turned out to be adequate. The first principal component accounted for 33.6%, the second for 33.11%, and the third for 20.23% of the variance. The principal component loadings after a Varimax rotation are shown in Table 6. The first group is made up of eutrophication, acidification and the abiotic depletion of elements. The abiotic depletion of elements is mostly (95% on average) caused by fertilizer production (except in those scenarios in which only manure is applied), and eutrophication and acidification is mostly caused by nitrate and ammonia emissions from fertilizers, respectively. The close correlation of these three impact categories is of interest in environmental management because if one of these impacts is kept low, the other two will be low as well. As to the second component, the following four impact categories loaded high: the abiotic depletion of fossil fuels, ozone depletion, photochemical ozone formation and global warming. The diesel consumption of the agricultural machinery, followed by fertilizer manufacturing, are the main contributors to the impact categories of the abiotic depletion of fossil fuels (55% and 15.4% on average), and photochemical ozone formation (63.6% and 15.3% on average). Global warming is caused by the emissions from agricultural machinery use (23% on average), fertilizer production (22.8% on average) and the application of fertilizers (18.4%). In the case of ozone depletion, the emissions causing this impact are those related with the production of electricity for watering (36.3% on average), fertilizers (19.5%) and pesticide manufacturing (11.2%). Thus, reducing the diesel consumption and optimizing the dose of fertilizers will decrease these four impact categories. The third group is made up of aquatic ecotoxicity and human toxicity, indicating that these two impact categories have a parallel effect. This is as expected, because both are related to the toxicity caused by pesticides. The Kaiser-Mayer-Olkin test (KMO) assesses the appropriateness of using factor analysis on a sample. It should be greater than 0.5 for a satisfactory factor analysis to proceed; in this case the KMO measure is 0.57.

As previously shown, the principal component analysis of the environmental impacts gave three homogeneous groups. In order to know which group the costs are most closely related to, a new PCA was carried out to include this variable. In this case, the structure of the groups is the same and costs are included in the second group. As stated before, this second group of impact categories is mainly related to input manufacturing and use (fertilizers, pesticides, diesel and electricity); thus, minimizing the use of these inputs will reduce not only the environmental impacts, but also the costs and, consequently, the profits will increase.

4. Discussion

The results point to the variability of both the environmental and the economic impacts, even in a homogenous area such as the one studied. By a careful selection of the management practices, farmers can reduce the environmental impact per kg tigernut by factors 252.5 (abiotic depletion elements), 33 (aquatic ecotoxicity) or 6 (global warming). In the same way, the costs can be reduced by factors of between 2 and 3 on those farms with higher costs.

By analyzing the variability of the environmental assessment through the coefficient of variation, it can be observed that it is greater on the conventional farms than on the organic ones, as was to be expected since the sample size is higher in the former. Furthermore, the management practices are more homogeneous on organic farms; the farmers follow specific regulations, which lead to a lower degree of variability.

The environmental impacts that show the greatest variability are aquatic ecotoxicity, human toxicity and the abiotic depletion of elements. In the case of the toxicity impacts, this is not only due to the fact that the applied dose varied greatly, as can be observed in table 2, but also to the different toxicity characteristics of the pesticides. To illustrate this, Juraske and Sanjuán (2011) assessed the relative toxicity impacts in the integrated and organic production of oranges in Spain and concluded that a careful selection of the pesticides applied can minimize the human toxicity impact by two orders of magnitude and the aquatic freshwater toxicity impact by up to seven. In the present study, in which most of the farmers do not follow any specific farming system, the difference between the scores of the toxicity impacts is higher.

The variability observed in the abiotic depletion of elements is mainly caused by the kind and dose of the fertilizer chosen by the farmer. In the same way, eutrophication and acidification are also related to these aspects, although these two impact categories are less variable. This may be explained by the fact that the variability of the fertilizers' nitrogen content is lower than that of the abiotic elements consumed for its manufacturing.

Other authors have studied the variability of environmental impacts and the influence of management practices. Mouron et al. (2006a) examined integrated apple-growing farms and found a ratio of the maximum and minimum of around 4 for some impact categories on a per hectare basis. The lower degree of variability observed in that study can be attributed to the fact that farmers followed a specific farming system. Van der Werf et al. (2009) also found a high degree of variability on dairy farms in France and, likewise, the highest one corresponded to toxicity related impacts.

As regards the economic assessment, pesticide and fertilizer costs showed the highest variability, which is consistent with the variability observed in the impacts. There are different levels of variability in the partial costs that are compensated for in the unit costs: both kinds of farms showed similar CV. What stands out on organic farms is the variability of labour costs, whereas on conventional farms there is a greater degree of variability in the rest of the costs. In the case of labour costs, organic farmers invest more time in manual weeding out. Other authors, such as Tzilivakis et al. (2005), pointed out that the profitability of organic crops depends heavily on the weed control costs.

If the costs of conventional and organic farms are compared, it can be observed that, although the cost structure is quite different, the average unit cost of both systems is similar. Therefore, in economic terms, the difference in profits is caused by the selling price and not by the costs.

This study also reports the relative importance of the direct and indirect components on overall impacts. Direct impacts (on-farm) exceed the indirect ones, except for ozone layer depletion, the abiotic depletion of elements and fossil which are wholly generated off-farm. In the case of global warming and photochemical ozone formation, the direct impact accounts for 69 and 58% of the overall impact, respectively.

Although the aim of this study is to highlight the importance of farmers' management practices on the overall impact, it must be taken into account that, even in a homogenous area such as the one being studied, there are some aspects that do not depend on the farmer. This is the case of the water source. The use of water from a well or channel is influenced by the volume of water in the channel, which depends on how many farms are being irrigated at the same time. In the case of irrigation with well water, the depth of the well determines the energy consumption, and it is not a farmer's choice.

By controlling three key impact categories, a total of nine impact categories and the costs will be under control. Nevertheless, it must be taken into account that PCA group 2 is related with energy consumption and, therefore, high consumption involves high impact. On the other hand, groups 1 and 3 are related with the kind of fertilizers and pesticides, respectively. From a cost management point of view, groups 1 and 3 are linked to variable production factors, whereas group 2 is linked to fixed production factors, since the energy consumption is linked to an investment in equipment. This fact has sound implications on the possibilities of reducing the environmental impacts, since variable production factors can be easily changed while fixed production factors cannot be easily varied in the short term.

Specifically, farm managers should carry out a thorough selection of the fertilizers and the dose to be applied and should also perform nitrogen balances. In this way, the first group of impacts would be controlled, decreasing eutrophication, acidification and the abiotic depletion of elements. In the same way, it is also necessary to carry out a careful selection of the pesticides and dose in order to control the toxicity impacts (group 3). To control group 2, a decrease in the consumption of fossil fuels should be encouraged. To this end, Mouron et al. (2006a) recommend using small and efficient engines and increasing machinery life span as much as possible. However, changing machinery involves a high investment.

Another interesting result is the correlation between environmental impacts and costs. This means that controlling the second group of PCA impact categories not only decreases the impacts of four categories, but also the costs, consequently affecting the profits. Therefore, a positive relationship has been found between economic and environmental performance. This finding falls into line with previous studies searching for possible trade-offs between environmental and economic performance (Mouron et al., 2006b; Thomassen et al., 2009; Jan et al., 2012).

This correlation between some impact categories and the costs explains why policy interventions or regulations, such as raising taxes on pesticides, fertilizers or energy, can be effective, because minimising the cost might decrease the environmental impact. Nevertheless, some farms show impacts and costs that are noticeably higher than the average values, which demonstrates that farmers' decisions, even those concerning the costs, are not always rational. Therefore, what is needed is an approach which is more firmly based on education and training.

The difference between the profits produced by both kinds of farms leads to the question of why every farmer does not adopt organic production. There are many factors influencing this, the main ones being a lack of information about this farming system, mistrust of the restrictions set by regulations and less accessibility to the distribution channels.

In order to obtain joint information from the economic and environmental results of this study, it would be interesting to integrate them. Data Envelopment Analysis (DEA) has been successfully used for this purpose (Ribal et al., 2009; Sanjuán et al., 2011; Jan et al., 2012). In this way, the eco-efficiency of the farms is measured and benchmark values can be defined.

Limitations of the present work

The main limitation of the present study is how representative the sample is, mainly due to the low sample size of organic farms. Another restriction was the lack of some specific farm data. This is the case of the weight represented by the aerial part to be burnt, where an average value was used. As regards the amount of irrigation water, and as pointed out in the methods section, the amount of water applied was only measured on one farm.

An additional limitation is that impact categories such as water and soil quality or biodiversity loss have not been taken into account.

Profits were chosen as the measurement of economic performance and they represent a business point of view. Nevertheless, other variables could have been chosen, such as Economic Value Added so as to express the contribution of each farm to the Gross Domestic Product (GDP) or the Work Income per Family Work Unit, which means the remuneration of the family labour force after the rest of the production factors have been remunerated.

There is scope to undertake a more holistic study, taking into account the social aspects of this kind of farming such as its contribution to maintain peri-urban agriculture.

Conclusions

In this study, the importance of the variability of management practices has been analyzed. The homogeneous conditions of the cropping area have enabled the variability caused by farmers' decisions to be highlighted. The results show how, regardless of the farming system, a proper management leads to the generation of both relatively low environmental impacts and costs, contributing to achieve sustainability.

In the case of pesticide selection, the wide range of available commercial products causes an even wider range of toxicity. In the case of fertilizers, the farmer mainly bases the selection on the macronutrient content and price. Nevertheless, the variability in those impact categories with a greater contribution from fertilizers is much greater in the abiotic depletion (off-farm) of elements than in eutrophication and acidification (on-farm). Therefore, the recommendations as to input selection should take into account the variability that the available options (e.g. commercial products) can transfer to other life cycle stages.

The case study highlights the effect that smallholdings have on the results. The group of farms surveyed is made up of smallholdings, which means there are many decision makers in a limited area. This favours the presence of outliers, whose impacts increase the average of some impact values. This finding can be extended to other horticultural crops.

Finally, an important conclusion reached by this study is that, as far as the profits of some farms are concerned, a good environmental performance could be achieved within the constraints of economic viability, contributing in this way to attain more sustainable farming systems.

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