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Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis

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Abstract

Agricultural researchers widely recognise the importance of sustainable agricultural production systems and the need to develop appropriate methods to measure sustainability. The principal purpose of this paper is to evaluate the financial and environmental aspects of sustainability of organic, integrated and conventional farming systems (OFS, IFS and CFS, respectively) at farm level and on more detailed spatial scales. This was achieved by applying an integrated economic-environmental accounting framework to three case study farms in Tuscany (Italy) covering different farming systems (FSs) and different spatial scales. The environmental performances of the FSs were measured through the application of an environmental accounting information system (EAIS) at field, site and farm level. The EAIS indicators were then integrated with: (1) a set of financial indicators to evaluate the economic and environmental trade-offs between different FSs and (2) with information on the regional and site-specific soil and climate conditions to study the impact of different pedo-climates on the environmental performances of the FSs. The gross margins of steady-state OFSs were found to be higher than the corresponding CFS gross margins. The OFSs perform better than IFSs and CFSs with respect to nitrogen losses, pesticide risk, herbaceous plant biodiversity and most of the other environmental indicators. However, on hilly soils, erosion was found to be higher in OFSs than in CFSs. The pesticide and the nitrogen indicators in this study showed a similar environmental impact caused by integrated and conventional farming practices. Regional pedo-climatic factors were found to have a considerable impact on nutrient losses, soil erosion, pesticide risk and herbaceous plant biodiversity, site-specific factors on nutrient losses and soil erosion. Results at field level suggest that herbaceous plant biodiversity and crop production are not always conflicting variables. Results of the case study farms are discussed and compared with environmental sustainability thresholds reported from EU Directives on nitrate and pesticides in groundwater and the literature.

Keywords: Sustainability; Farming systems; Organic agriculture; Pedo-climatic impact; Tuscany

1. Introduction

Agricultural researchers widely recognise the importance of sustainable agricultural production systems and the need to develop appropriate methods to measure sustainability. Modern society increasingly values sustainable farming systems (FSs) for their potential to enhance wildlife and the landscape and to decrease environmental harm caused by farming practices. Against this background an increasing body of literature has developed on the quantification of the sustainability of agricultural production.

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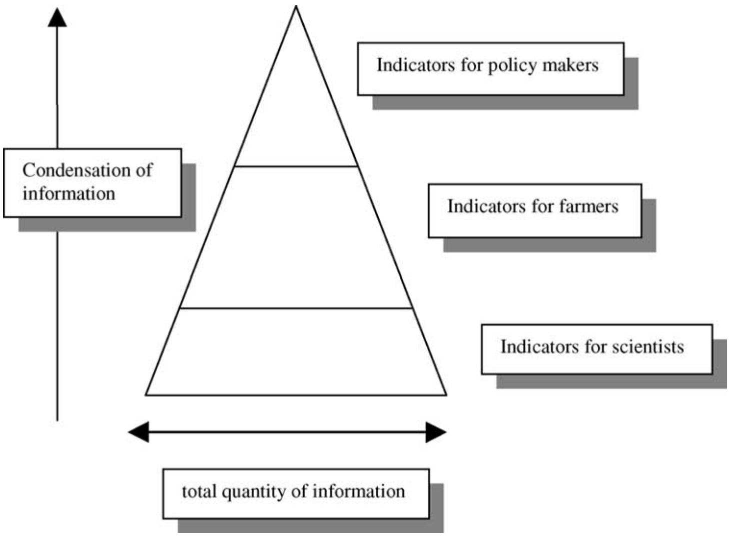

Fig. 1. Relationships between indicators (Braat, 1991).

Usually, this literature promotes the idea of monitoring a range of sustainability indicators recognising that sustainability cannot be condensed into a single definition (Panell and Glenn, 2000). Most of these indicators are strongly ecological in focus and very detailed, or they are policy oriented and developed at aggregate, sector or country level. So, indicators are developed that differ greatly in information content and condensation of this information (Fig. 1). Scientists are most interested in uncondensed data that can be analysed statistically. Policymakers and the public in general can be assumed to prefer condensed data related to policy objectives and free of redundancy.

In either case these indicators lack a close link to farm management decision making. For example, farm management requires rather detailed data related to evaluation criteria and threshold values as set by policy objectives. Indicators at the level of the agricultural production processes enable the right balance to be found between production economics and environmental goals—right there where the production decisions are made (Halberg, 1999). This balance has to take into account both production and pedo-climatic factors at farm level and on more detailed spatial scales.

Hannon (1991) stressed the importance in ecosystem accounting of measuring the material, energy and service trade-offs between all the ecological processes of a given ecosystem. Disregarding such aspects of accounting can also give cause for conflicts between different government programmes or regulations as far as the environmental aims are concerned (Hammond and Goodwin, 1997; Callens and Tyteca, 1999). For example, a regulation that stresses some peculiar components of the pollutant charge while ignoring others might result in a substitution between pollutants and therefore in an overall increase of the global pollutant charge (Meriläinen, 1995). Hardaker (1997) emphasised the need for a systems approach to any strategy that addresses sustainable agriculture and rural development. Such a strategy requires a comprehensive perspective that accounts for the interrelationships between the technical, environmental, social, economic, and political aspects of sustainability.

However, little work has been done on measuring methods of sustainability at farm and lower levels that take into account the technical-economic and the environmental–ecological trade-offs of ecological and production processes.

Against this background, this paper was aimed at evaluating the financial and environmental aspects of sustainability of organic, integrated and conventional farming systems (CFSs) at farm level and on more detailed spatial scales. This was achieved by applying an integrated economic-environmental accounting framework to three farms in Tuscany. The accounting framework was extensively elaborated in a previous paper (Pacini et al., 2002). Here, only its general structure is given together with the description of the most representative indicators of the present study. The impact of FSs and pedo-climatic factors on the indicators were studied at farm, site and field level. Results are presented of the selected indicators.

2. Material and methods

2.1. Defining organic, integrated and CFSs

There are a variety of definitions of organic farming systems (OFSs) (Rigby and Cáceres, 2001). Mannion (1995) refers to organic farming as "a holistic view of agriculture that aims to reflect the profound interrelationship that exists between farm biota, its production and the overall environment". From an application viewpoint, the OFSs analysed in this study comply with the stipulations of the EU Regulation 2092/91 on organic production of agricultural products and the Tuscany L.R. (Regional Law) 54/95 (recently updated by the EU Regulation 1804/99) on organic livestock production.

There is some semantic confusion surrounding the use of terms such as integrated farming systems (IFS), integrated crop management (ICM) and integrated pest management (IPM). However, there appears to be agreement on the broad objectives of IFSs (Morris and Winter, 1999), which have been defined as "a holistic pattern of land use which integrates natural regulation processes with farming activities to achieve maximum replacement of off-farm inputs and to sustain farm income" (El Titi, 1992). The IFSs analysed in this study meet the requirements of the integrated farming code of the EU Regulation 2078/92 Tuscany region agri-environmental enforcement programme (recently updated by the 2000–2006 Tuscany Region Rural Development Plan (TRRDP), which enforces the EU Regulation 1257/99).

The term CFS is often used in the literature to group a variety of FSs that can be either more or less intensive. A reference definition for CFS used in this study comes from the code of good agricultural practice (CGAP) set by the Italian Ministry of Agricultural and Forest Policies to enforce the EU Directive 91/676 (i.e., the so-called "nitrate directive"). All the CFSs under study comply with the CGAP.

2.2. Selection of the farms and sites

Measurement of sustainability was carried out for the 1998–2000 period on the case study farms covering different FSs (conventional, integrated and organic) on different spatial scales. Three farms were chosen, giving preference to the depth of the analysis rather than to the sample size. To achieve insight into the relationship between farm and environmental activities, farms were selected based on the following criteria:

1. Connection with different natural areas in Tuscany.
2. FSs comprising the main important arable crops, livestock and environmental activities in their reference area.
3. Farmlands comprising the main important types of soils, landforms and hydrological conditions of their reference area.
4. Possibility of performing comparisons between different FSs at farm and lower level.
5. Market-oriented farms but with a sound background of participation in experimental projects.

Table 1 gives the general description of the three selected farms. Le Rene is an organic farm that until the end of 1999 also used to have an area which was cultivated conventionally. It was the reason why the OFS and the CFS were applied simultaneously on two different areas in this farm in 1998 and 1999, allowing for comparisons under common management and climatic conditions. The farm is located in the Migliarino-San Rossore-Massaciuccoli Regional Park (Pisa and Lucca Provinces), on Tuscany's northern coast (latitude 44°N). The climate is moist Mediterranean due to the vicinity to mountain areas (Alpi Apuane and Monte Pisano) with a mean annual rainfall of 950 mm. The Alberese farm used to be an integrated mixed farm. At the beginning of 1999 a 3-year period of conversion to organic agriculture was started, thus during 1999 and 2000 only organic production techniques were used on the farm. It is located in the Maremma Regional Park (Grosseto Province), on the southern coast of Tuscany (latitude 43 °N). The climate is dry Mediterranean with a mean annual rainfall of 625 mm. The Sereni farm is an organic farm whose

Table 1
General description of the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

	Le Rene	Alberese	Sereni
Region	S. Rossore Regional Park	Maremma Regional Park	Mugello basin
Landform	Flat	Flat and hilly[a]	Flat and hilly
Farm type	Arable	Mixed cattle–arable–horticultural–arboricultural[a]	Mixed dairy–arboricultural[a]
FS	Organic and conventional (1998 and 1999, part of the farm)	Integrated (1998) and organic (1999 and 2000)	Organic (before 1993) and conventional (since 1993)
Total area	476 ha	3441 ha	352 ha
Agricultural area used[b]	452 ha	593 ha	156 ha
Livestock—CFS[c]	–	–	313 dairy cows
Livestock—IFS[d]	–	110 horses, 460 beef cows	–
Livestock—OFS[e]	–	102 horses, 389 beef cows	241 dairy cows

[a] Arboricultural crops, which are disregarded in this paper, cover all the cropland on hilly landforms of the Alberese farm. Consequently, this portion of the Alberese cropland is disregarded as well.
[b] Permanent pastures excluded.
[c] Livestock under the CFS on the Sereni farm (before 1993).
[d] Livestock under the IFS on the Alberese (before 1999).
[e] Livestock under the OFS on the Alberese farm (since 1999) and on the Sereni farm (since 1993).

conversion period took from 1992 to 1995 and has operated as a fully fledged organic farm since then. It is located in the Mugello basin, some 30 km north of Florence, northern Tuscany (latitude 44 °N). The Mugello district has a pre-mountain climate with a mean annual rainfall of 1000 mm.

To perform a detailed spatial scale analysis each farm was divided into several different sites (Table 2) according to landform, soil and irrigation conditions. Site-representative rotations were identified based on temporal succession and spatial distribution of the crops. Some minor changes were observed in the rotational schemes. For instance, on some fields of the Le Rene site 1 hard wheat (*Triticum* spp.) was replaced by spelt (*Triticum dicoccon Schrank*) and rye (*Secale cereale* L.), which together comprised the 15% of the winter cereal area; sweet vetch for seed by berseem clover (*Trifolium alexandrinum* L.) alfalfa (*Medicago sativa* L.) for seed and broadbean (*Vicia faba* L.). On the Alberese site 3 hard wheat was replaced by barley (*Hordeum* spp.; 15% of the winter cereal area); berseem clover–oats (*Avena* spp.) ley by vetch-oats ley (*Vicia sativa* L.) and Italian ryegrass (*Lolium multiflorum* var.). In addition to the crops of the site-representative rotations, small portions of farmland were cropped with broadbean, tomato (*Lycopersicon esculentum* Mill.), chickpea (*Cicer arietinum* L.) and French bean (*Phaseolus vulgaris* L.) on the Alberese farm. On this farm, grasslands, which were cropped very extensively, were assimilated to permanent pasture from an environmental viewpoint. On the Le Rene site 3 in 1998 sugar beet (*Beta vulgaris* L.) had been cropped as well. In addition to the farm and the site levels, fields were identified as the lowest hierarchical levels on the basis of the ecological infrastructure network.

2.3. Data collection and processing

Data collection and processing of the environmental indicators for the measurement of sustainability were performed through application of an environmental accounting information system (EAIS). The information system was holistically designed to simultaneously and integrally take into account all the ecological and production processes that potentially affect the state of the agro-ecosystem. The EAIS was organised into several systems and modules (i.e., sub-systems). Environmental critical points observed inphysiographic areas in Tuscany formed the basis for selection of the modules, within which a number of environmental processes take place that affect the given critical

Table 2
Description of the cropland sites on the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany[a]

Sites	Land form	FAO (1998) soil classification	Geological soil classification	Soil texture	Irrigation	OFS[b] rotation	IFS[c] rotation	CFS[d] rotation
Le Rene								
Site 1	Flat	Haplic Cambisol	Alluvial plain	Clay	Not irrigated	S–W–SV–W	–	–
Site 2	Flat	Haplic Cambisol	Alluvial plain	Silt loam	Not irrigated	–	–	W
Site 3	Flat	Haplic Cambisol	Alluvial plain	Clay loam	Not irrigated	–	–	W
Site 4	Flat	Endogleyc Cambisol	Peat soil	Peat	Not irrigated	Set-aside	–	Set-aside
Alberese[e]								
Site 1	Flat	Eutric Cambisol	Terra rossa	Silt loam	Not irrigated	Permanent pasture	Permanent pasture	–
Site 2	Flat	Eutric Cambisol	Alluvial flat	Silty clay loam	Not irrigated	S–W	W	–
Site 3	Flat	Calcaric Fluvisol	Floodplain	Silty clay loam	Irrigated	S–3A–MG–W	S–L–W	–
Site 4	Flat	Calcaric Fluvisol	Salt field	Silty clay loam	Not irrigated	Permanent pasture	Permanent pasture	–
Sereni								
Site 1	Hilly	Eutric Cambisol	Alluvial slope	Clay	Not irrigated	B–BB	–	3A–4G
Site 2	Hilly	Eutric Regosol	Alluvial slope	Sandy clay	Not irrigated	MS–B–BB–B–4G	–	3A–4G
Site 3	Flat	Eutric Cambisol	Alluvial terrace	Clay loam	Not irrigated	MS–B–BB–B–3A	–	MS–B–R–3A
Site 4	Flat	Eutric Cambisol	Alluvial terrace	Clay loam	Irrigated	MG–B–MG–3A	–	MS–B–R–3A
Site 5	Flat	Eutric Fluvisol	Alluvial valley floor	Loam	Irrigated	MG–B–MG–3A	–	MG
Site 6	Flat	Eutric Fluvisol	Alluvial valley floor	Loam	Not irrigated	MS–B–BB–B–3A	–	MS–B–R–3A

[a] Crop legend: S, Sunflower (*Heliantuus annus* L.); W, Hard wheat (*Triticum durum* Desf.); SV, Sweet vetch for seed (*Hedysarum coronarium* L.); A, Alfalfa (*Medicago sativa* L.); MG, Maize grain (*Zea mays* L.); L, Berseem clover–oats ley (*Trifolium alexandrinum* L. and *Avena sativa* L., respectively); B, Barley (*Hordeum vulgare* L.); BB, Broad bean (*Vicia faba paucijuga* var. *minor* Beck); G, Orchardgrass–Tall fescue–Birdsfoot trefoil grassland (*Dactylis glomerata* L., *Festuca arundinacea* Schreb. and *Lotus corniculatus* L., respectively); MS, Maize silage; R, Italian ryegrass (*Lolium multiflorum* var. *italicum* A.Br.).

[b] Organic farming system.

[c] Integrated farming system.

[d] Conventional farming system.

[e] The Alberese farm has also a fifth site which is destined for woodland.

points. The performance of the management of each environmental process was quantified by a set of environmental indicators. The structure of the EAIS enabled implementation at different levels of analysis ranging from (1) a high detailed level (a-level) to (2) a low detailed level (b-level). The a-level would apply to representative farms for research purposes aimed at the planning and monitoring phases of policy design. The b-level would apply to ordinary farms for the auditing and monitoring phases of policy implementation. In this paper results focus on the a-level. For more details on the EAIS structure, reference is made to Pacini et al. (2002).

Besides the environmental indicators, a set of financial indicators was calculated, namely the gross margins including revenues from production, compensation and agri-environment payments, costs of fertilisers and pesticides, maintenance costs of ecological infrastructures (surface drainage system and hedges) and other variable costs.

The EAIS indicators, together with the financial indicators, formed the integrated economic-environmental accounting framework that was used to evaluate the environmental and financial aspects of sustainability at farm level and more detailed spatial scales.

In Fig. 2 indicators are placed in relation to their corresponding calculation reference spatial scale. Depending on the specific purposes, each indicator can also be aggregated and used at higher levels. For example, the herbaceous plant biodiversity indicator (HPBI)

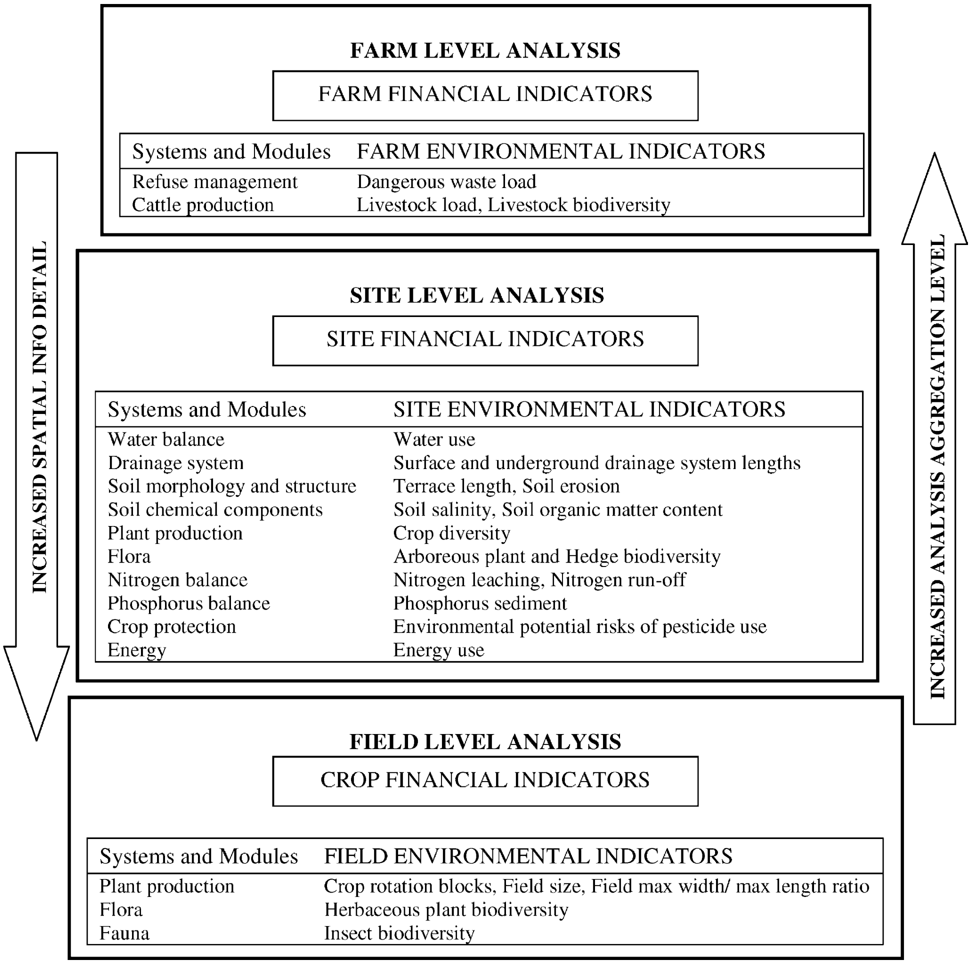

Fig. 2. General overview of environmental and financial indicators and their spatial scales.

can be used at field level to analyse the relation between biodiversity and crop production, at site level to analyse the impact of site-specific features (e.g., soil conditions and site intrinsic natural value) on biodiversity, and at farm level to asses the impact of different FSs as well as different regional pedo-climates. Four agronomic-physiographic spatial scales were used in this study, namely field (a portion of a site limited by ecological infrastructures), site (4–200 ha), landscape (200–4000 ha) and region[1] (thousands of square kilometres). In this study the landscape scales coincide with the farm management units, chosen as representative of their corresponding regions. Differences between the impacts of regional pedo-climates were studied by comparison of the three farms, i.e. landscapes. For the definitions of site, landscape and region and for further details on spatial and temporal scales in agro-ecosystem analysis and management, reference is made to Bailey (1988), Schleusner (1994), De Ridder (1997) and Prato (2000).

In this paper results are presented of selected environmental indicators, namely the nutrient, erosion, pesticide and biodiversity indicators. Nutrient and erosion indicators were calculated for site-representative fields on a rotational temporal scale using the groundwater loading effects of agricultural management systems (GLEAMS) model (Knisel, 1993). Results were reported as annual averages of the reference period. The pesticide indicator for site-representative fields on an annual scale was calculated with the EPRIP (environmental potential risk indicator for pesticides) yardstick (Trevisan et al., 1999). For comparison purposes, both GLEAMS and EPRIP programs were run using 1998 climatic data at landscape level for all the FSs. Common site-specific soil databases were employed for the comparison of different FSs on the same site. The Sereni 1994 CFS techniques were updated to meet standard techniques used in the Mugello area. On the Alberese farm the techniques of the system “in conversion” and of the steady-state system were assumed to be unaltered.

The HPBI was measured using a simplified version of the Braun-Blanquet method (Cappelletti, 1976; Arrigoni et al., 1985). The Braun-Blanquet method is a commonly used census method that assesses the biodiversity of vascular plants by estimating the cover percentages of species and their distribution in the field observed. In this research only species cover was taken into account. This method was applied on the farms under study to each different crop and green space of each site. The site and farm biodiversity indicator values were calculated as the weighted mean of values relative to the area of each crop and green space.

The arboreous plant biodiversity indicator (APBI) represented the rate between the sum of the farm’s wooded areas, each multiplied by a coefficient that evaluates its type (Mediterranean macchia, broadleaved wood, conifer wood or reforestation area) and spatial distribution, and the total farm or site area. The hedge biodiversity indicator (HBI) represented the rate between the hedge length, multiplied by coefficients that assess age and endemic origins of the plants, and the total farm or site agricultural area used (less permanent pasture areas).

The crop diversity indicator (CDI) was used in this research to perform a conjoined evaluation of crop diversity within sites and non-adjacency among single fields. The method used for the calculation of the CDI was derived from the Shannon index. The Shannon index is a proportional abundance index that reflects both the evenness and species richness of a given vegetal or animal assembly, computed from the species shares in a given assembly (Önal, 1997). The Shannon index was applied to cultivated instead of spontaneous species and the shares were calculated from surfaces instead of numbers of individuals. Each site was divided into different crop diversity minimum areas (CDMAs) calculated as a sum of the average field surfaces of each different crop type present in the site. Finally, the Shannon index method was applied to each CDMA and the results were summed up (and multiplied by 1000) to give the CDI value at site level.

Data on the biodiversity indicators were collected at field (HPBI) and site level (APBI, HBI and CDI) during the 1998–2000 period. Results were reported as annual FS averages, or to study annual effects, on an annual scale.

Aggregation of the indicator values from field to site level and from site to farm level was done by means of a weighted mean of the field and site values of the corresponding areas. For more details on

[1] Note that the agro-ecosystem analysis level “region” does not correspond in the present study with the administrative level “Tuscany Region”.

environmental indicator processing methods refer to Pacini et al. (2002).

As to the financial indicators, outcomes refer to 1998 except for Alberese OFS (1999) and Sereni CFS (1994). For comparison purposes, 1998 prices were also applied to Alberese OFS and Sereni CFS. For the Le Rene and the Alberese farms, prices, yields, area compensation payments (EU Regulation 1765/92), integrated and organic measure payments (EU Regulation 2078/92, further on mentioned also as agri-environment payments) were reported from the RICA-FADN. Net crop productive factor inputs were obtained by excluding the variable costs of ecological infrastructures from the RICA-FADN crop-attributed total value. For the Sereni farm, which does not participate in the Tuscany RICA-FADN, data were collected using crop record cards.

3. Results

3.1. Indicator accounting framework

The accounting framework was used here to compare the impact of CFSs, IFSs and OFSs on financial returns and the agro-ecosystems within farms. Comparisons between impacts of pedo-climatic factors at different spatial scales were considered as well (between farms belonging to different landscapes/regions and between sites of the same farm).

Because of space limitations, this paper only presents results of selected indicators, namely nutrient losses, soil erosion, environmental potential risks of pesticide use and biodiversity. These indicators and their results are representative of the entire list in Fig. 2 as they cover the main environmental threats in the Tuscany region (Regione Toscana, Giunta Regionale, ARPAT, 1999). The selected indicators allow conclusions to be drawn on the impact of pedo-climatic factors under different FSs, which is not possible for the larger set of indicators (e.g., water use and surface drainage system length). Not reported here are the indicators of dangerous waste load, livestock load, soil salinity and soil organic matter content that primarily pertain to the auditing purpose of the EAIS (see Section 2.3). The indicators of livestock biodiversity, underground drainage system length and terrace length were not applicable for the case study farms and the energy use indicator presented redundant information already covered by the nutrient and pesticide indicators. Results on crop rotation blocks, field size, and width/length ratio are very well summarised by the CDI. Finally, results from the insect biodiversity indicator that was applied only during 2000 proved to be insignificant for FS comparisons and inconclusive as to the impact of the pedo-climatic factors.

Table 3 summarises the financial and environmental results of the selected indicators at the system level for the three case study farms. In the following sections, the results are analysed in more detail. Financial indicators are treated at farm level. As to the environmental indicators, results are presented at farm level for both system and pedo-climatic impacts. Site level analysis focuses on the soil component of the pedo-climatic impact (i.e., same climate but different soils) while the field level analysis treats system comparisons on a more detailed spatial scale.

3.2. Financial results

Table 4 summarises the financial results of the different FSs on the Le Rene, Alberese and Sereni farms. The OFS gross margins in the Le Rene and the Sereni farm were found to be 5.6% (953 versus 902 €/ha) and 8.6% higher (2191 versus 2017 € /ha), respectively, than the corresponding CFS gross margins. In both cases the positive results of the OFS were mainly determined by a combination of higher prices for organic products, the organic agriculture payments and lower variable costs for fertilisers (only for Sereni OFS) and pesticides. Revenue increase due to all these factors were higher than the decrease caused by lower OFS yields. These results mirror those in previously published comparisons of OFSs and CFSs (e.g. Lampkin and Padel, 1994).

On the Alberese farm the gross margin decreased by 4.7% (429 versus 450 € /ha) in the first year of conversion, primarily due to the fact that while yields decreased, the farm products could not get higher prices as they could not be certified as organic before the end of the 3-year conversion period. Higher agri-environment payments and lower costs for fertilisers and pesticides for the OFS only partially covered this difference. Systems undergoing conversion like the Alberese farm may experience se-

Table 3
Summary of financial and environmental results of the OFSs, IFSs and CFSs at the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

	Le Rene		Alberese		Sereni	
	OFS[a]	CFS[b]	OFS	IFS[c]	OFS	CFS
Gross margin (€ /ha a.a.u.[d] less p.p.[e])	953	902	429	450	2191	2017
Nutrient, erosion and pesticide indicators						
Nitrogen leaching (kg/ha a.a.u. less p.p.)	10.8	25.8	10.6	32.0	17.1	28.3
Nitrogen run-off (kg/ha a.a.u. less p.p.)	10.0	10.9	1.5	1.3	3.9	10.5
Nitrogen losses (kg/ha a.a.u. less p.p.)	20.8	36.7	12.1	33.3	21.0	38.8
Phosphorus sediment (kg/ha a.a.u. less p.p.)	0.1	0.2	0.1	0.0	2.6	0.6
Soil erosion (t/ha a.a.u. less p.p.)	0.0	0.1	0.0	0.0	3.9	1.4
EPRIP[f] (score/ha a.a.u. less p.p.)	0.0	7.8	0.0	1.0	0.0	41.0
Biodiversity indicators						
HPBI[g] (score/ha total area less woodland)	69	52	124	117	82	n.a.[h]
APBI[i] (% total area)	3.4	9.6	44.0	44.0	41.0	41.0
HBI[j] (m/ha a.a.u. less p.p.)	9.3	0.0	23.8	23.8	67.3	0.0
CDI[k] (score/ha)	4.8	1.8	4.0	3.4	17.3	n.a.

[a] Organic farming system.
[b] Conventional farming system.
[c] Integrated farming system.
[d] Agricultural area used.
[e] Permanent pastures.
[f] Environmental potential risk indicator for pesticides.
[g] Herbaceous plant biodiversity indicator.
[h] Not applicable.
[i] Arboreous plant biodiversity indicator.
[j] Hedge biodiversity indicator.
[k] Crop diversity indicator.

Table 4
Comparison of financial results (€ /ha) of the OFSs, IFSs and CFSs at the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

	Le Rene		Alberese		Sereni	
	OFS[a]	CFS[b]	OFS	IFS[c]	OFS	CFS
Revenues						
Products	730	722	609	779	2135	2350
Compensation payments	333	480	263	324	207	126
Agri-environment payments	187	0	156	130	146	0
Total	1250	1202	1028	1233	2488	2476
Variable costs						
Fertilisers	90	71	40	61	0	46
Pesticides	0	28	0	33	0	61
Ecological infrastructure maintenance	9	10	21	20	5	5
Other costs	198	191	538	669	292	347
Total	297	300	599	783	297	459
Gross margin	953	902	429	450	2191	2017

[a] Organic farming system.
[b] Conventional farming system.
[c] Integrated farming system.

rious financial difficulties also because in Tuscany the agri-environment measures tailored to conversion are limited. Implementation of organic farming methods depends rather on favourable market prices (or price expectations) for organic products.

Ecological infrastructure maintenance costs on the case study farms were very low and therefore irrelevant. These results can be explained by the fact that these maintenance activities do not entail sensitive and visible effects on the farm productions in the short term. Moreover, farms on hilly sites may be not interested in investing in structures that would mostly benefit other farms located on the flat ground.

The Sereni farm agri-environment payments (146 € /ha) were lower than the gross margin difference between the OFS and the CFS (174 € /ha—2191 versus 2017 € /ha). The OFS compensation payments on this farm were also higher. The agri-environment payments (187 € /ha) on the Le Rene farm were decisive for the achievement of the OFS higher gross margin (51 € /ha—953 versus 902 € /ha). However, a large share of the agri-environment extra-income was used to compensate for the decrease of compensation payments as a result of extensification of the rotations under the OFS (147 € /ha—333 versus 480 € /ha). On the Alberese farm the compensation payment decrease (61 € /ha—263 versus 324 € /ha) greatly exceeded the revenue increase of agri-environment measure payments (26 € /ha—156 versus 130 € /ha). There seems to be some discord between the agri-environment measures and the CAP producers' support system (at least for the Le Rene and the Alberese farms).

3.3. Environmental results

3.3.1. Nutrient losses and soil erosion

3.3.1.1. Farm level analysis. In Table 3 results on nitrogen leaching, run-off, losses, phosphorus sediment and soil erosion are displayed. Results of these indicators are treated together because all of them were calculated with GLEAMS. As expected, the OFS performed better than the IFS and the CFS for nitrogen leaching on all the three farms. The lowest difference in nitrogen losses occurred on the Le Rene farm (20.8 versus 36.7 kg/ha). As to nitrogen run-off, phosphorus sediment and soil erosion, the OFS is almost equal to the CFS and the IFS on the Le Rene and the Alberese farm, respectively. On the Sereni farm that is partially hilly, the OFS was worse than the CFS as far as phosphorus sediment and soil erosion were concerned. This depends on the implementation of long rotations under the OFS, which implies the cropping on hilly ground of more tillage-requiring crops like maize, barley, broad bean, compared to grassland and alfalfa under the CFS. Coiner et al. (2001) arrive at the same conclusions for landscapes.

Nutrient losses were highly affected by regional pedo-climatic conditions. The OFS nitrogen losses on the Alberese farm (12.1 kg/ha) were lower than on the Le Rene (20.8 kg/ha) and the Sereni farm (21.0 kg/ha). The differences between the farm types and related rotations could affect these results in addition to the pedo-climatic factors. However, the last mentioned seemed to be a particularly dominant factor. For example, on the Sereni farm, whose FS is more intensive and environmentally risky (dairy, with application of animal excreta), nitrogen losses were about equal to those of the Le Rene farm (arable, organic fertilisers). Specially considering the pedo-climatic factor, and taking into account that the cattle graze on the permanent pastures (no excreta application on rotation crops), the performance of the IFS on the Alberese farm was no better for nitrogen losses than the CFS on the other two farms (33.3 versus 36.7 and 38.8 kg/ha), and was even worse for nitrogen leaching (32.0 versus 25.8 and 28.3 kg/ha). This seems to be due to a slight difference between the IFS and the CFS with regard to the amount of fertiliser used and is consistent with reports in the literature. For example, Bailey et al. (1999) report that there is no significant difference between the two systems with respect to beetles and spiders, earthworms and nitrate residues.

3.3.1.2. Site level analysis. In Table 5 nitrogen losses of the three farms are shown for cropped sites. High differences in losses under the same FS are mainly attributable to rotations. But again the soil factor is very decisive. Simulation results for the same rotations on different sites of the same farm and under the same FS showed that the differences between nitrogen losses oscillated between a minimum of 15% on the Sereni OFS (28.8 on site 5 versus 33.1 kg/ha on site 4) and a maximum of 40% on the Le Rene

Table 5
Comparison of nitrogen (N) losses of the OFSs, IFSs and CFSs on cropped sites of the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

	Le Rene			Alberese				Sereni											
	OFS[a]	CFS[b]		OFS		IFS[c]		OFS						CFS					
	1	2	3	2	3	2	3	1	2	3	4	5	6	1	2	3	4	5	6
N losses (kg/ha)	20.8	47.9	34.2	11.5	12.2	20.2	34.6	18.1	7.3	33.4	33.1	28.8	16.8	12.9	15.9	49.9	43.0	73.7	37.7

[a] Organic farming system.
[b] Conventional farming system.
[c] Integrated farming system.

CFS (34.2 on site 3 versus 47.9 kg/ha on site 2). The rotation maize silage/barley/Italian rye-grass/alfalfa on site Sereni CFS 3, which was not irrigated, produced higher N losses (49.9 kg/ha) than the same rotation on site Sereni CFS 4, which on the contrary was irrigated (43.0 kg/ha).

Table 6 presents a comparison of the impact of rotations and soil physical characteristics on erosion. Results are shown for site 1 and 2 of the Sereni farm, which are the only sloping cropped sites. Sites Sereni 1 and 2 have equal slopes but the alfalfa/grassland rotation on site CFS 1 produced a level of erosion almost 100% lower than the same rotation on site CFS 2 (1.9 versus 3.5 t/ha). This is due to the different soil conditions of the two sites (clay in site 1 and sandy clay in site 2). Results are reversed under the OFS, where the erosion produced by the barley/broad bean rotation on site 1 was three times that of the maize silage/barley/broad bean/maize silage/grassland rotation on site 2 (16.7 versus 5.5 t/ha). In this case the management factor (rotation choice) overwhelmed the environmental factor (soil characteristics).

Table 6
Soil erosion of the OFSs and the CFSs at site level on the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

	Sereni			
	OFS[a]		CFS[b]	
	1	2	1	2
Soil erosion (t/ha)	16.7	5.5	1.9	3.5

[a] Organic farming system.
[b] Conventional farming system.

3.3.2. *Pesticide risk*

3.3.2.1. Farm level analysis. Table 3 displays results on environmental risk due to pesticides. OFS on the three farms posed no environmental risk. The performance of the Sereni CFS was very poor, possibly because of the more intensive crop plan and techniques used. In general EPRIP showed low impacts in relation to the EPRIP yardstick range of possible results (1–625). In fact, according to the EPRIP yardstick classification, the risk ranges from “none” on the Alberese farm (EPRIP $\leq$ 1), to “negligible” on the Le Rene farm (2 $\leq$ EPRIP $\leq$ 16), to “small” on the Sereni farm (17 $\leq$ EPRIP $\leq$ 81).

In Table 7 the impacts of the different crop techniques (treatments, pesticide types) for winter cereals on representative sites of the three farms under survey are compared. Winter cereals, which are the only pesticide-treated crops on all the three farms are barley on the Sereni farm, and durum wheat on the Le Rene and the Alberese farm. CFSr (CFS crop technique of the Le Rene farm) had the best EPRIP regardless of the pedo-climatic conditions or the farm type. On the Alberese farm the environmental impacts of the IFS crop technique, which is the actual technique applied on this farm, were the worst. This confirms what already stressed for the nitrogen indicators and reported in the literature (Bailey et al., 1999).

The performance of all three crop techniques was best on the Alberese farm and worst on the Sereni farm, which again emphasises the decisive role of the regional pedo-climate. The *site level analysis* revealed no relevant difference between site-specific results from the same farm.

Table 7
EPRIP score for winter cereals with different integrated and conventional crop protection techniques on representative sites of the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

	Le Rene			Alberese			Sereni		
Crop technique	*CFSr*[a]	IFS[b]	CFSs[c]	CFSr	*IFS*	CFSs	CFSr	IFS	*CFSs*
EPRIP (score/ha)[d]	*1*[e]	4	8	1	*4*[e]	3	1	6	*61*[e]

[a] CFS crop technique of the Le Rene farm.
[b] IFS crop technique of the Alberese farm.
[c] CFS crop technique of the Sereni farm.
[d] Environmental potential risk indicator for pesticides.
[e] Results in italics refer to the actual crop techniques of each farm.

3.3.3. Biodiversity

3.3.3.1. Farm level analysis. Table 3 presents the biodiversity indicator results as averages of the annual values of each FS. The HPBI of the OFS was better than the CFS and the IFS on the Le Rene and the Alberese farm, respectively. But, as can be noted in Table 8, where the complete sequence of the HPBI annual values is displayed, this was achieved on the Alberese farm only in the second year of conversion (2000). Table 3 also shows minor differences in APBI between the FSs. As far as hedges are concerned, both on the Le Rene and the Sereni farm, the crop technique conversion was accompanied by an improvement of these green infrastructures. The CDI of the OFS was always higher. On the Alberese farm it increased during the conversion from 3.4 in 1998 to 4.6 in 2000. The management of biodiversity on the Sereni OFS as to ecological infrastructures (APBI and HBI) and crop plan (CDI) was the most accurate. This can explain the good HPBI result achieved despite the more intensive land use on this farm (see gross margins). As to the regional impact, the Alberese farm's HPBI was far better than the OFS HPBI of the other two farms both under the OFS (Table 8, 1999 year) and under the IFS (1998 year). Farm type related factors contributed to these results but, again, the regional factor, in this case expressed by the seed bank capacity of the given areas, played an important role. Farm averages of the 1998, 1999 and 2000 years show that the absolute values of the HPBI of the green spaces of the Alberese farm were higher than those of the Le Rene farm (both OFS and CFS) and the Sereni farm. Note, due to dry climatic conditions, the scores of the 2000 HPBI green spaces on the Le Rene farm were considerably lower than that of the previous 2 years.

Table 8
Year effect of the HPBI (total farm value and green spaces absolute value) at the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

	Le Rene				Alberese		Sereni	
	OFS[a]		CFS/OFS[b]		IFS/OFS[c]		OFS[a]	
	Farm total value (score/ha)	Green spaces absolute value (score)	Farm total value (score/ha)	Green spaces absolute value (score)	Farm total value (score/ha)	Green spaces absolute value (score)	Farm total value (score/ha)	Green spaces absolute value (score)
1998 HPBI[d]	71	125	54	109	117	132	75	122
1999 HPBI	73	120	44	113	117	137	89	135
2000 HPBI	63	84	57	79	131	169	n.c.[e]	n.c.

[a] Results of the OFS on the Le Rene site 1 and on the Sereni farm.
[b] Results of the CFS (1998–1999) and of the OFS (2000) on the Le Rene sites 2 and 3.
[c] Results of the IFS (1998) and of the OFS (1999–2000) on the Alberese farm.
[d] Herbaceous plant biodiversity indicator.
[e] Data not collected.

Table 9
Field level results of the HPBI for two sites and different FSs at the Alberese farm (Alberese, Grosseto), Tuscany

	IFS[a] (1998)		OFS[b] (1999)		OFS (2000)	
	2	3	2	3	2	3
Wheat HPBI[c] absolute value (score)	1	33	73	71	38	49
Other crops HPBI absolute value (score)	n.a.[d]	110	116	67	91	66
Green spaces HPBI absolute value (score)	86	149	136	141	145	151
Site HPBI Total value (score/ha total area[e])	71	96	123	87	131	82

[a] Integrated farming system.
[b] Organic farming system.
[c] Herbaceous plant biodiversity indicator.
[d] Not applicable—no other crop on the site in 1998.
[e] Less woodland.

3.3.3.2. Site level analysis. The HPBI trends during the conversion of the two cropped Alberese farm sites (sites 2 and 3) are shown in Table 9. Differences between site HPBI total values of the same farm appear to be more dependent on the crop plan and/or the green spaces share than on the site intrinsic natural value. The HPBI annual absolute values of wheat, other crops and green spaces were similar. Exceptions are particularly attributable to successful/unsuccessful weed control operations (e.g., site 2 wheat value in 1998), coincidental circumstances (e.g., site 2 1998 green spaces value, which was probably partly underestimated because of overgrazing in the sample), changing crop plans (e.g., values of the other crops) or to the seed bank capacity of the monitored fields. The other farms under survey also produced similar findings.

3.3.3.3. Field level analysis. Table 9 presents the HPBI absolute values of wheat, which was the only pesticide-treated crop under the IFS, other crops and green spaces. Wheat values increased in the first year of conversion and decreased again in 2000. This could have been due to the improved management crop technique ability under the OFS and to an improved reaction of the agro-ecosystem to the new techniques. Average absolute values of the other crops are decreasing year by year. This decrease under the OFS can be explained by the introduction in the crop plan of more intensively cultivated cash crops. Green spaces absolute values increased slightly during the 3-year period.

The 2000 OFS wheat average (43.5) of site 2 (38) and 3 (49) was 32% higher than the 1998 site 3 IFS value (33). Wheat cover decreased by less than 1% (from 100¯ to 99%) on the Alberese site 2 from 1998 to 2000 and even increased on site 3 (from 95 to 98%) during the same period. Steady-state FS changes differed. The Le Rene farm wheat HPBI was 34 for the CFS and 69 for the OFS (+103%). Cover percentages decreased from 93% in CFS to 88% in the OFS (−5%). These results can probably be attributed to the use of selective pesticides for the IFS and the CFS, and support the above-mentioned findings on the positive financial performances of OFS.

4. Discussion

4.1. Evaluation of sustainability based on environmental thresholds

Besides a relative evaluation of sustainability among the FSs, an absolute evaluation can be done on the basis of environmental sustainability thresholds implemented by regulations and laws or found in the literature. In Table 10 the indicator results are compared to environmental thresholds in terms of compliance (Y) or non-compliance (N). The phosphorus sediment compliance was linked to the threshold for soil erosion based on the processing method used for the calculation of this indicator. When necessary, the thresholds were adapted to EAIS equivalents (the fourth column) based on regional pedo-climatic features (water leaching and run-off) and EAIS indicator processing methods (i.e., HPBI and CDI).

OFSs comply with thresholds to a higher extent (17 indicators out of 24) than CFSs (9/14) and IFSs

Table 10
Compliance of FSs with environmental sustainability thresholds at the Le Rene farm (Coltano, Pisa), the Alberese farm (Alberese, Grosseto) and the Sereni farm (Borgo San Lorenzo, Florence), Tuscany

Indicator	Environmental sustainability threshold	Source[a]	EAIS[b] equivalent	Compliance					
				Le Rene		Alberese		Sereni	
				OFS[c]	CFS[d]	OFS	IFS[e]	OFS	CFS
Nitrogen leaching	50 mg/l	(a)	Le Rene = 33 kg N/ha Alberese = 16 kg N/ha Sereni = 27 kg N/ha	Y[f]	Y	Y	N[g]	Y	N
Nitrogen run-off	50 mg/l	(a)	Le Rene = 17 kg N/ha Alberese = 2 kg N/ha Sereni = 11 kg N/ha	Y	Y	Y	Y	Y	Y
Soil erosion	1 t/ha	(b)	1 t/ha	Y	Y	Y	Y	N	N
EPRIP[h]	81 score/ha	(c)	81 score/ha	Y	Y	Y	Y	Y	Y
HPBI[i]	50 species per farm	(d)	48 score/ha	Y	Y	Y	Y	Y	n.a.[j]
APBI[k]	5%	(e)	5%	N	Y	Y	Y	Y	Y
HBI[l]	1000–2000 m/25 ha	(f)	60 m/ha	N	N	N	N	Y	N
CDI[m]	Field area $\leq$ 5 ha Crop adjacency = 0 Rotation blocks $\geq$ 4	(g) (h)	30 score/ha	N	N	N	N	N	n.a.

[a] Source legend: (a) EU Directive 91/676; (b) Pimentel et al. (1995) and Kabourakis (1996); (c) Trevisan et al. (1999), EU Directive 91/414; (d) and (e) Vereijken (1999); (f) Schotman (1988); (g) Smeding (1995); (h) Vereijken (1999).
[b] Environmental accounting information system.
[c] Organic farming system.
[d] Conventional farming system.
[e] Integrated farming system.
[f] Yes (compliance).
[g] No (non-compliance).
[h] Environmental potential risk indicator for pesticides.
[i] Herbaceous plant biodiversity indicator.
[j] Not applicable.
[k] Arboreous plant biodiversity indicator.
[l] Hedge biodiversity indicator.
[m] Crop diversity indicator.

(5/8). A cross-view of the findings of Tables 3 and 10 reveals that the statement “organic agriculture = sustainability” is not always valid from an environmental point of view, even though the performance of the OFS was largely better than the other FSs. Some indicators that performed better in OFSs were nevertheless unsustainable when compared to their corresponding thresholds (see the Le Rene HBI and CDI and the Alberese CDI). On the other hand, many of the indicators that performed worse in the IFSs and the CFSs complied with thresholds (10/15).

A limitation of the use of sustainability thresholds is that they are extremely difficult to determine, especially in relation to the intrinsic carrying capacity and resilience of a given ecosystem. Some of the thresholds reported in Table 10 (i.e., those of soil erosion and of field area) could be too restrictive under certain conditions (i.e., hilly landforms and arable farms) and this might lead to an incorrect evaluation of the environmental performances. For example, Zanchi (1983) proposes a soil erosion threshold of 8–9 t/ha for soils and landforms similar to those of the Sereni hilly sites. Nevertheless, thresholds are indispensable to operationalise sustainability both at farm management and at policy design level, and as this example demonstrates, to evaluate the differences between FS in absolute terms.

Section 3.2 shows that current agri-environment and support measures in certain situations prove to be conflicting. The application of environmental thresholds for the evaluation of FS sustainability in the planning phase of policy design can improve the environmental-economic effectiveness of agri-environment and support measures. This is particularly relevant under the current circumstances, where the EU aims to shift support from production to sustainability of rural systems and to shift farmers' role progressively from that of food suppliers to that of custodians of the countryside.

4.2. Future research

More extensive analysis needs to be carried out of instalment and maintenance cost (planting/building) of ecological infrastructures. The same applies to the underground drainage system and the terraces, which were not applicable to the case-study farms. With special reference to the EPRIP yardstick, the EAIS method should be tested on other farm types (e.g., wine, olive, etc.) and on different IFSs and CFSs, also on the basis of previously published works (Kabourakis, 1996). Regarding the insect biodiversity indicator, the results (not shown) of the case study were insufficient to draw conclusions either on FS or on the pedo-climatic impact. It was speculated that the indicator processing method as such is applicable for different crops/green spaces of different regions, takes into account some site-specific features and that its results match well with those of the HPBI.

The EAIS could also be applied at district level to ordinary farms to check the procedures of data transfer from district representative farms to ordinary farms. On the former farms a more detailed EAIS could be applied for research purposes. On the other hand, a simplified EAIS could be used on ordinary farms for auditing and monitoring purposes; however, it should also rely on scientific evidence obtained from researches conducted on representative farms.

This paper discussed the financial–environmental trade-offs only at farm level because of the close interrelations between production processes belonging to different sites on the farms. However, these trade-offs can also be expected at site and field level. Mathematical programming models are commonly used at farm level for the study of the economic-environmental trade-offs. By formulating the model structure so as to introduce the spatial variability of the environmental and (if necessary) production processes, these trade-offs could be considered right there where the production decisions are made (i.e., at field, site and farm level).

5. Conclusions

A holistic, integrated economic-environmental accounting framework was applied to three case-study farms to evaluate the sustainability of OFSs, IFSs and CFSs. The impact of FSs on a number of indicators was studied together with that of pedo-climatic factors at farm, site and field level.

Results provide evidence on three main aspects: (1) the OFS has the potential to improve the efficiency of many environmental indicators as well as being remunerative; (2) the environmental responses of OFSs, as well as IFSs and CFS can be highly affected by the pedo-climatic factors, both at regional and site scale; (3) the fact that OFS in most cases environmentally perform better than IFS and CFS does not mean ipso facto that they are sustainable when compared to the intrinsic carrying capacity and resilience of a given ecosystem.

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