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Farm level environmental indicators; are they useful? An overview of green accounting systems for European farms

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Abstract

Green accounts or input–output accounting systems (IOA) have been developed in countries with intensive agricultural production to facilitate voluntary improvements in farm environmental performance. There is a need for an overview of indicators used and a review of results and experiences reported. Ten IOA systems covering the topics of the farm's use of nutrients, pesticides and energy were selected from a survey of 55 systems and compared in this paper. The approaches and indicators used vary from systems based on good agricultural practices (GAP) to accounts based systems that use physical input–output units. Many IOA systems use farm gate nutrient balances, pesticide use per hectare and energy use per kilogram product. These indicators are easy to calculate but the resulting value needs separate interpretation for the farmer. Other systems include modeled emissions and rate the yearly farm results using closed scales, which allows for easy interpretation but builds on implicit normative assumptions of best practices. Participating farmers were most often reported to be motivated for the use of IOA but empirical evidence of improved environmental farm performance was scarce. IOA systems should be linked with production planning tools used by the advisory services. Farmers and advisors needs better reference values to evaluate the indicator levels (environmental performance) on the individual farm possibly based on analysis of a larger number of farms. The statistical properties of IOA indicators need to be researched regarding: (1) the relation between changed management practice and changes in indicator values on a given farm over a period of time; (2) the relative importance of systematic versus coincidental differences in environmental performance of a set of farms. It is concluded that IOA systems could become effective tools for agri-environmental improvement of European farms given further development and standardization.
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1. Introduction

Green accounts or input–output accounting systems (IOA) to be used for the assessment of farm input use and efficiency are on the agenda in many countries with intensive agricultural production as a response to the increased interest in the environmental performance of different farming systems. IOA systems including Green accounts typically use a set of indicators to express the degree of environmental impact from a farm based on the use of external inputs in relation to the production and/or the use

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of specific management practices (Goodlass et al., 2001). A number of European countries are interested in including IOA as part of EU agri-environmental support schemes and Danish farmers performing a Green account are subsidized up to € 1000 co-funded by EU. One reason for this interest seems to be a hypothesis that such voluntary systems for environmental improvement of farms may supplement mandatory regulation and that farmers by benchmarking against each other using the indicators in IAO will increase their awareness of possible environmental improvements. It may also be better to stimulate farmers to be managers of their own environment–production interaction than to force them to obey general rules and regulations. From an agroecosystem (Conway, 1987) viewpoint the farmer is the key to improved management of the farm–environment interaction (Matson et al., 1997) and given the right advise he may be able to find locally adapted improvements. Moreover, IOA may lead to marketing advantages and in the long run be included as part of good agricultural practices (GAP).

However, such hypotheses raise several questions such as: are farmers motivated to use IOA on a voluntary basis? What indicators should be used in IOA to express agri-environment relations on a farm in a way that facilitates improved management? What are the possibilities to induce and document environmental improvement using appropriate indicators? What indicators have been developed already and how useful are they for farmers and advisors?

A general overview of 55 different IOAs and similar tools with a preliminary assessment of selected aspects was given in Goodlass et al. (2001, 2003). This paper gives an in-depth assessment and comparison of 10 selected systems with a focus on the differences and usefulness of indicators, especially on energy, nutrient and pesticide use. Van der Werf and Petit (2002) compared 12 very different methods for farm level environmental impact assessment, which used a wide range of indicator types and covered a multitude of issues. They found that the indicators used were seldom validated and recommended that priority should be given to indicators that aim at quantifying the *effect* of a given farming practice vis-à-vis a certain objective (as opposed to indicators describing the farming practice or *means* of production). This corresponds well with intentions in most IOA systems. There is still a lack of validation of such indicators especially from the perspectives of the farm as a managed agroecosystem. To our knowledge a comparison of results from on-farm tests of IOA including the perspective of the farmers is missing in the literature. Therefore, the objective of this paper is to review in detail the suitability for farmers and advisors of the environmental indicators used in well-documented IOA developed for the voluntary use in farm management. Recommendations are given for future indicator development based on the assessments of existing tools and recent literature.

2. Method

Based on a large survey of 55 systems developed for environmental management on European farms (Goodlass et al., 2003) the 10 most promising systems were selected. Selection criteria included the systems (self-reported) success in terms of uptake and improvement in environmental and/or economic performance of participating farms and the (reported) existence of documentation of the indicators and the results. Moreover, care was taken to select systems of different types. The environmental topics covered by the survey were limited to the farm's use of nutrients, pesticides and energy. Only systems for voluntary use were selected. The 10 systems were considered to be state-of-the-art in the development and use of input–output accounting systems, green accounts and environmental indicators for farm management within a European context.

A semi-structured questionnaire was used for telephone interviews (April–October 2000) with relevant persons involved in the development or use of each selected system. Documentation of the systems, published description of the indicators and results in terms of data from farms and interviews with farmers were collected from these resource persons when available. Information regarding the systems published after 2000 have been included if it supplies new information.

Table 1 gives a short overview of the names and origin of the systems and the topics they cover. All systems originated in northern Europe, no well-documented systems used in southern Europe were found. The farm's use of nutrients in feed and fertilizer was the topic of most systems, except the

Table 1
Input–output accounting systems (IOA) included in the survey[a]

ID	Name and reference	Countries used in	Subject
GA	Green accounts (Anonymous, 2000a)	Denmark	Nutrients (NPK), pesticides energy
EALF	Ethical account for livestock farms (Halberg, 1999a)	Denmark	Nutrients (NP), pesticides, energy
EMA	Environmental management for agriculture (Lewis and Bardon, 1998)	UK (worldwide)	Nutrients (NPK), pesticides, energy
AEI	Agro-ecological indicators (Bockstaller et al., 1997)	France + Germany	Nutrients (NP), pesticides, energy
AEL	Agricultural environment label (De Vries and Boer, 1995; De Vries et al., 1998)	Netherlands	Nutrients (NP), pesticides, energy
REPRO	Repro (Dubsky et al., 2000)	Germany	Nutrients (NPK), pesticides, energy
FHL	Herdbooks system (FHL) (Anonymous, 1999a,b,c)	Luxembourg + Belgium	Nutrients (NPK), energy
STANK	Farm level nutrient balance (STANK) (Anonymous, 2000b)	Sweden	Nutrients (NPK)
EYP	Environmental yardstick for pesticides (Reus and Pak, 1993; Reus and Leendertse, 2000)	Netherlands + Belgium	Pesticides
EY	Energy yardstick (Hageman et al., 1996; Hanegraaf and van Bergen, 1996)	Netherlands	Energy

[a] References are to published description of the tools. More references, detailed descriptions based on questionnaires and telephone interviews may be found in Goodlass et al. (2001).

two specialized energy and pesticide yardstick tools developed in The Netherlands. Six systems covered all three main topics.

Table 2 shows that all systems were developed in the 1990s. Advisors or farmers already used six of the systems in a post-pilot phase: the British, the Swedish and one Dutch system each reported use by more than 1500 farmers. Two systems were linked to a market oriented labeling scheme. Most systems used a variety of data sources for the calculation of the yearly indicator values, primarily actual input–output data from field and farm level. A detailed description of each of the selected systems is given in Goodlass et al. (2001).

3. Results and discussion

The systems developers overall goal of developing the IOAs was most often to facilitate environmental improvement on farms through self-regulation. The hypothesis was that at least some farmers are willing to consider environmental impact from their farm in their management. For this idea to have a significant impact some conditions must be met, such as (1) proper selection of indicators relevant from societal point of view, (2) high uptake by (pilot) farmers (including both motivation and understanding), (3) technical possibilities for environmental improvement of different farm types at limited costs and (4) a strong relation between the actual farm management and variation in indicator values between farms and years.

3.1. What are the indicators that have been used in the IOA systems?

Tables 3–5 show the variation in indicators used for the three main topics in the 10 selected IOA systems. Most systems based the indicators on input data (e.g. fertilizer or pesticide use on the given farm) but there was a difference in how this was related to the resulting production. For Nitrogen (N, Table 3) most systems calculated an actual balance between inputs and outputs in products and used the “N-surplus per ha” at the farm level as the indicator. This approach seems to be generally applicable and Sveinsson et al. (1998) have discussed methodological differences in the calculation of N–balances. The systems agro-ecological indicators (AEI, Bockstaller et al., 1997) and environmental management of agriculture (EMA, Lewis and Bardon, 1998) focused on the crop or field level and compare fertilizer use with standard recommended use (crop needs) and modeled risks of N-losses. This may be relevant for cash crop productions, but on mixed

Table 2
Development stage, usage and data needs of 10 selected IOA systems

	GA	EALF	EMA	AEI	AEL	REPRO	FHL	STANK	EYP	EY
Operational stage										
Research/pilot, used by developers only	x	x		x		x				
In use by extensionists/farmers	(x)		x		X		x	x	x	x
Start date	1999[a]	1994[b]	1997	1994	1995	1996	1992	1996[c]	1991[d]	1996[e]
No. of farmers using system	95	20	*5000*[f]	*50*	153[g]	*50*	240	1500	*4000*	50
Auditing										
By external regulatory body	n	n	n	n	y (label)	y	n (label)	n	y	y
Input data										
Available from farm accounts	x	x	x		Some	nd	x	x	?[h]	x
Actual input–output data	x	x	x	x	X	nd	x	x	x	x
Budgeted data						nd		x		
Field level	x	x	x	x	X	nd			x	
Farm level	x	x			X	nd	x	x	x	x
Defaults used for some variables	x	x	x	x	X	nd		x	x	

nd = not documented; italic = estimate.

[a] Previous version (no. 6 in initial survey) began in 1994/1995, number of farmers >300 in 2002.
[b] Pilot phase completed in 1997, some aspects incorporated into system 5.
[c] An earlier (manual) version existed.
[d] Developed in 1991/1992, tested in 1993/1994 and used in practice since 1994.
[e] There was a development phase from 1994 to 1996.
[f] Assumes that each copy sold to an adviser is used for 10 farmer clients.
[g] Based on arable farmer numbers in 1997 (for the other sectors information is in ha).
[h] Farmers who deliver products under certified labels keep this information, the government may make it mandatory for all to keep them in the future.

farms, the indicator must include the livestock production, because managers take decisions for the whole farm system including feeding strategy and handling of manure (Halberg et al., 1995).

Most of the pesticide indicators (Table 4) used active ingredients (AI) but differed with respect to the assumptions and calculations leading to the indicator. The system agriculture environment label (AEL) simply shows "kg AI used" and the EALF/GA compares the pesticide dosages used with standard recommended dosages to give an accumulated treatment frequency index. These are simple indicators to explain and farmers may easily compare results between years but they do not discriminate between pesticides with different environmental impact or toxicity. Other systems (EMA, AEI and EYP) give scores according to modeled losses or risks associated with the particular pesticide use on a farm or field. The AEI uses expert opinions and fuzzy logic to score for the risk of water and air contamination on a 0–10 scale partly based on the pesticide application toxicity and crop soil cover (Van der Werf and Zimmer, 1998). The EMA estimates an eco-rating based on hazard warnings and scores based on risk parameters such as each pesticide's solubility and soil half-life. The Dutch EYP assigns separate environmental impact points (EIP) based on a comparison of predicted environmental concentrations (PEC) for groundwater, water organisms and for soil organisms with national standards (e.g. 0.01 × LC50 for water organisms).

Reus et al. (2002) compared the methods and models used in EMA, AEI and EYP with other European pesticide indicators and recommended, "to develop a harmonized scientific framework for an EU pesticide indicator" that is embedded in a farmer decision support system. The generic method of comparing PEC-type values with public standards in environmental compartments seems the most promising and is also in principle compatible with life cycle assessment (LCA, Hauschild, 2000). As discussed by Van der Werf and Petit (2002) indicators which may be used both on an area basis (IOA approach) and in a product approach (environmental load per kg produce, LCA) should be preferred.

The energy indicators (Table 5) differ with respect to the farm system boundaries: the EMA and GA only

Table 3
Comparison of different indicators of nitrogen use and loss applied in 10 reviewed IOA systems

	N-balances	N-efficiency	Emission risk	Eco-rating
Indicators	Farm level N-surplus, kg ha^{-1}	N use efficiency, %	Points on scale, 0–10	Calculation of eco-rating on the indicator scale, ±100
Calculation	(Input − output), ha^{-1}. Sum of all imported N less all N in sold products and corrected for change in stocks[a]	((Input − output)/output) × 100%. The farm level surplus divided by sum of N in products[b]	−(Sum of modeled losses in kg N/30) + (sum of mitigation efforts in kg N/30)	Based on the relative difference between a defined standard fertilization rate and the actual fertilizer used[c]
Data needed	All actual input in fields and stables. Production and sales. N content inventory	All actual input in fields and stables. Production and sales. N content inventory	Fertilizer use, kg N ha^{-1}. Crop type, soil type	Fertilizer use, kg N ha^{-1}, timing, rainfall, soil type. Standard crop N requirements.
Examples, system name	GA, EALF, STANK, AEL, FHL, REPRO	EALF	AEI	EMA
Evaluation, reference used	Range of farms (politically defined levels)	Range of farms with similar production	Scale 0–10, 7 represents integrated farming	Good agricultural practice = standard good practice
Farmers reactions	Generally positive (when not compulsory)	Interested but surprised (EALF)		Positive according to interview but no documentation exist

[a] The exact way of calculating farm gate balances and balances for single enterprises (field or crop level) may differ slightly among IOA systems but the basic idea is the same.

[b] The farm level efficiency is only interpretable for farms with a single dominant enterprise. For mixed farming systems the N use efficiency should be calculated for the major enterprises separately (e.g. for pig fattening and for sugar beets separately on a mixed pig and cash crop farm).

[c] The calculation of the nitrogen indicator in EMA combines the fraction ((standard fertilizer rate − actual fertilizer used)/actual fertilizer used) with information regarding the timing and soil type to give an eco-rating on the general scale from −100 to 100 (after multiplication with a scaling factor).

Table 4
Comparison of different pesticide use indicators applied in 10 reviewed IOA systems

Indicator	Treatment frequency index (TFI)[a]	Pesticide use, active ingredients (AI)	ECO-rating, ±100 scale	IPEST scale value, 0–10	Environmental impact points (EIP)
Calculation method	$\sum$(kg product ha^{-1}/standard treatment kg ha^{-1}), TFI averaged for all crops	($\sum$ kg AI)/ha, calculated for separate crops	Baseline eco-rating based on label hazard warnings for AI's; adjusted for local conditions, scoring. Table used to assign environmental risk values	AI-eco-tox values, adjusted for local conditions. Aggregated and transformed into scaled indicator (0–10). IPEST = 10−K$\sum$ I-pest	Score (EIP) = $\sum$(PEC/public environmental standard)[b], 100×, AI used
Example, IOA system[c]	EALF GA	AEL	EMA	AEI	EYP
Reference material	National average own historic data	Max total use AI per ha	GAP (best practice) with risk bands	Crop specific *K*-value chosen so IPEST = 7 for integrated farming (IAFS)	EIP <100 for approved farms rewarded
Data needs and model tools	Kg product used. Table of standard treatments (approved dosages)	kg AI used	kg AI used, site information (location of water bodies, etc.). Hazard warning labels + model of effect of solubility, etc.	kg AI used, site conditions, application method. Fuzzy expert model.	kg AI used. Table values of environmental standards, models of PEC

[a] TFI: average number of standard pesticide treatments used by area and year. Standard treatment is the approved dosage of a pesticide for a certain crop.

[b] PEC: predicted environmental concentration in the compartments groundwater, soil and water organisms, see text. PEC is defined for 1 kg AI for each pesticide and compartment and divided by the public environmental standard for that compartment. To calculate EIP this is multiplied by kg AI used by farmer.

[c] For full name, see Table 1.

Table 5
Indicators of energy use in 10 reviewed IOA systems

	Energy use	Energy efficiency	CO_2 Emission	Energy saving management
Indicators	MJ ha^{-1}	MJ kg^{-1} product	kg CO_2 kg^{-1} product	Eco-rating, ±100 scale
Calculation	Sum MJ input/ha	(MJ input/kg product)	MJ input × CO_2 equivalents[a]	MJ energy consumed, emissions
Data needed	Direct energy use, actual (GA) or modelled (AEI), indirect energy (AEI)	Actual direct and indirect energy use, MJ; energy equivalents, actual output, kg	Actual direct and indirect energy use, MJ; energy and CO_2 equivalents; actual output, kg	Actual direct energy use
Examples, system name[b]	GA, AEI	EALF, AEL, EY, REPRO	EY	EMA
Evaluation, reference used	Range of farms, Integrated farming	Range of farms, maximum level defined within system (AEL)	Range of farms	Best practice
Farmers reactions		Not interested in indirect energy use	Low interest	

[a] Use of energy converted from MJ to kg CO^2 released using standards for each energy carrier, e.g. diesel and electricity.
[b] For full name see Table 1.

includes direct energy actually used on the farm (diesel and electricity) while AEI, EALF, EY and Repro also include indirect energy use, e.g. energy used for the production of concentrates and fertiliser. Most systems relate the energy use to the amount of products produced, e.g. MJ per kg milk, but EY also calculates the emissions of green house gasses and EMA use the eco rating system also applied for N and pesticides. It may be misleading to limit the calculation to the farms direct energy use because energy costs for home produced and purchased feeds are partly complementary and because it favors the use of contractors compared with farmers using own machinery (Refsgaard et al., 1998).

There is a difference between on the one hand the indicators based on actual input use and product output and on the other hand indicators based on modelled losses of N, pesticides or green house gasses. The “true” input–output indicators are often relatively simple to calculate, precise (if they are based on farm account data) and the link between farm management and the indicator may be easier explained (e.g. decreased protein feed use for pigs produced should result in lower N-surplus from the farm). The advantage of including (risk of) emissions in the other type of indicators (systems like EMA and AEI) could be that this links the farmer’s practices more directly with the environmental issues behind the indicator choices (e.g. the effect of pesticide leaching is more interesting than a record of the amount used).

However, the modeling of emissions and other losses introduces an extra degree of uncertainty into the indicator (since actual measurements on each farm is not possible within an IOA approach) and may include factors that are outside farmers’ control, e.g. climate and soil type. As discussed by Girardin et al. (1999) there are unavoidable normative choices to be made when choosing and creating indicators, especially when defining the objectives (i.e. why is it relevant to address the nutrient and energy use on a farm) and when determining the references, norms and thresholds. In some systems many of these normative assumptions have been built into the indicators in the farm of e.g. scorings and closed scales while in others reference values and norms are applied at a later stage to interpret the indicator values on a farm, see below.

Some indicators include information regarding the farmer’s management practices (e.g. in EMA: “Was the harvest interval complied with” for pesticides; Lewis and Bardon, 1998), and combine the accounts data and action data into a point system (EMA, AEI, see Tables 3–5). In such cases, care should be taken to avoid double counting, e.g. giving a farmer one point for taking specific measures for reducing leaching and again give points when this is reflected in a reduced N-input. In a simple IOA system any management improvement would only be counted once, namely in the aggregated N-surplus figure. Halberg (1998) discussed the distinction between indicators based on farmers' management practices (control indicators) versus indicators based on recordings of consequences for the farming system (state indicators). The latter type describes an accumulated result over a specific period of time (e.g. the farm gate N surplus is the combined effect of all management operations which influence the farm's N-turnover), and thus indirectly includes the information given by control indicators. The result recorded in state indicators is—of course—subject to uncontrollable factors also (e.g. diseases, climate) but their interpretation will often build on discussions with the farmer concerning what he did and why, see below. Van der Werf and Petit (2002) use a similar distinction (means-based versus effect-based farm level environmental indicators) and concludes that means-based indicators are not suitable for recognizing errors or guiding change, especially when the evaluation concerns farming practices that has been defined a priori as sustainable (e.g. organic or integrated farming).

Many of the indicators presented in Tables 3–5 are useful on the farm level but they may also fit into a more overall methodology of agri-environmental indicator development such as the driving force-state-response (DSR), approach (OECD, 1997) or the driving force pressure state impact response (DPSIR) concept (Smeets et al., 1999). These approaches are meant as structures for guiding selection of environmental indicators by making choices explicit in terms of whether an indicator describes an agro-economic driving force (D) for environmental pressure, the state (S) of the environment itself or a response (R) to degraded environment from (groups in) society. The OECD proposed to use farm gate nutrient balances and indicators of pesticide use as D indicators (see also Hansen et al. (2001)).

The indicator systems that are based on true IO accounts data and possibly combined with valid models of emissions and losses (of, e.g. nitrate, carbon dioxide or methane) will be easier to link with life cycle assessments (LCA, Cederberg, 2002). The reason is that the LCA methodology uses environmental impact categories such as emissions to the atmosphere, eutrophication of and toxic effects in surface and ground water (Lewis and Bardon, 1998; Halberg et al., 2003).

3.2. Are farmers motivated to use IOA on a voluntary basis?

The experience reported from most of the systems was that the farmers were interested in learning how to include environmental aspects in their management, especially if they understand the issues and may improve their performance at no extra costs. Table 6 shows the results from eight systems where a systematic review was quoted. Farmers participating in EALF, AI, AEL and EYP considered the quantification of the pesticide use and the information on the differences in toxicity towards non-target organisms interesting. Farmers also mentioned the nutrient balances as new and surprising information that it was possible to react upon (EALP, AEL, STANK). In general most of the farmers answered that they have changed their management due to the systems in relation to nutrients, pesticides and energy. But, both in EALF and EY, it is the experience that farmers found it difficult to understand the idea of "indirect energy use". This topic seems to be too abstract and may be addressed by the efficient use of feed and fertilizer, some farmers say. Most systems report only small economical effects of using the systems for a limited number of years.

The farmers involved in the pilot projects may have been extra positive due to a feeling of co-responsibility for the particular IOA. Also, they are probably not representative for the total European farming community. There are differences between farmers in the way they use quantitative information in their management (Leeuwis, 1993; Ohlmer, 1998; Noe and Halberg, 2002). While some farmers readily use complicated quantified information on their technical–economical efficiency others rely primarily on practical skills and verbal exchange of information between colleagues. Graphical information in the form of "spider-webs" as in, e.g. AEI (Bockstaller et al., 1997) is probably easier to digest. It is not clear from the reports how large a percentage of farmers would possibly be interested in using IOA. In the broad review 30 systems estimated farmer uptake. Twelve of these systems expected more than 50% uptake (5 of these compensated farmers for the costs involved), while 11 systems expected 0–25% uptake among farmers

Table 6
Information on the farmers uptake and evaluation of IOA systems[a]

Farmers view regarding	EALF	AEI	STANK	AEL	EY	FHL	EYP	GA
No. farmers using system	20	50	1500	153	120	240	4000	300
No. farmers in evaluation	20	17	2–400	<153	<120	<240	185	63
Relevance and usefulness of indicators	OK: explanations accepted for all, though energy indicator difficult to understand	All understand message but not calculations	50% found nutrient balances interesting and relevant	OK: pesticide, P-balance, waste relevant Not OK: N-bal, field-margins	Direct energy use interesting but indirect too abstract and irrelevant	Farmers positive	Good, useful, increased knowledge on toxicity	Interesting and relevant for nutrients, pesticides energy
Costs/work required	High, mostly by experts	4–16 h, no comments	Rely on advisor, cheap for farmer	48% find costs too high, not compensated	2–3 h, acceptable	2–3 h to fill in data, free if part of label else 12.000 LUF year	?	Advisor 8–15 h, farmers 2–3 h
Economic effects	Small	Small	?	Generally acceptable 46%: too high costs to reach N loss goals	?	Marketing benefits, saved costs: average 100.000 LUF	Half of 106 farmers had lower costs, half had higher or equal costs	?
Possibility to improve environmental performance at low costs	OK for energy, pesticides, P, Cu (N use already strongly regulated)	?	85% say they changed nutrient management	OK: pesticides P surplus, field margins, not OK: N surplus	OK: direct energy use dairy, not OK: pig production, indirect energy	OK: energy use via reduction in feed use	Use less toxic pesticides, include in management	Pesticides use (TFI) to some extent, improved feeding for reduced N
Other problems	Lack reference values, negative opinion if mandatory	Negative opinion if mandatory to use IOA	Lack reference values, negative if mandatory				Fear change from voluntary to mandatory regulation	Lack reference values for energy

[a] EMA was used by more than 1000 farmers. There were however no systematic assessments of farmers' evaluations of this system. See Table 1 for description of systems.

(Goodlass et al., 2001). Three of the systems are already used by a large number of farmers (Table 2).

3.3. What are the possibilities for environmental improvement on a voluntary basis?

When initially asked about the effects of the systems 35 of the 55 systems reported that participating farmers had improved their environmental performance (Goodlass et al., 2001). However, only few documented results in terms of improvements on specific farms were found in this detailed review and only for five systems: EALF, EAL, EY, FHL, EYP. The two Dutch systems (AEL and EYP) report high reductions in pesticide use (75% measured in AI and 90% in EIP) and toxic load (70–90%) respectively. The Danish ethical account (EALF) and the GA resulted in a changed attitudes to the use of pesticides according to the farmers and advisors involved, but this was difficult to document in the treatment frequency index (TFI).

Regarding nutrients, AEL reported a 44% reduction in nitrogen surplus per hectare, but it is unclear over which time span this was found. In the 3-year pilot phase of the EALF it was not possible to observe a significant trend across the 20 farms (Halberg, 1999a) partly because the farms had already made adjustments due to the mandatory fertilizer accounts introduced in Denmark. Farmers and advisors using the GA found a number of possibilities for reducing N surplus in both stable and fields. But it was considered too early to evaluate the effects on the nutrient balances on the pilot farms. The energy yardstick resulted in 6–7% decrease in direct and indirect energy use per kilogram of milk and in 17% reduction in indirect energy use per kilogram of pig gain. The FHL system reports some reductions in energy use in meat production mostly due to reduced use of concentrates. In general only a few effects could be documented though it was the interviewees' opinions that there had been significant effects. This probably reflects the difficulties in relating changes on a farm directly to the use of IOA especially in pilot projects with a limited number of farms and years. But it also points to the fact that it may be difficult for farmers to improve their environmental performance if the IOA tool is not linked with planning and management tools (see later).

In the future work with IOA systems a more careful impact assessment should be carried out, e.g. following principles from development work using end-of-project surveys (Mikkelsen, 1995). A closer monitoring and documentation of say 100 farms using the EMA tool in the UK and the STANK in Sweden would be useful. New results based on an extended test group (60 farmers) seem to confirm that farmers are indeed interested in the Danish GA. The GA is now used in Denmark as an "accompanying measure" under the GAP and in the year 2001 350 farmers (mostly larger livestock farms) used this option for support to establish a Green account.

The evidence of large variation in environmental performance (indicator values) between comparable farms suggests that on many farms environmental improvement is possible although not always without costs (Vereijken, 1998; Halberg, 1999a; Reinhard and Thijssen, 2000; Oenema et al., 2001; Ondersteijn et al., 2002). Moreover, analyses of farm data show a relation between farm management and environmental performance (Rougoor et al., 1997; Refsgaard et al., 1998; Halberg, 1999a; Ondersteijn et al., 2003). The point is that the variation in environmental performance could be used for benchmarking in much the same way that farmers use the large differences in economic performance and technical efficiency as goals for improvement. IOA indicators have been used to illustrate to farmers in the pilot projects that there is room for environmental improvement on many farms without reducing total production by adjustment of, e.g. the use of input or the crop–livestock interactions. The next step should be to test whether only farmers who already have higher than average environmental awareness are willing to use IOA (in which case the effects of using the IOA may be low).

3.4. How do facilitators help farmers interpret and use the information from IOA?

The variation in indicator values between comparable farms may be the primary driving force for the improvement of environmental performance, but the information given by the indicators alone is not sufficient for introducing changes on a farm. The farmer will need interpretations of his results, and advice on how to implement the necessary changes. Accordingly, it was found that the most successful systems were linked with advisory services already used by farmers such as fertiliser planning etc. (with the possible exceptions of the systems linked to market advantages).

Thus, the most important advantages of introducing IOAs may be that it legitimizes that the local extension officer/advisor introduces environmental aspects into the farm planning process.

There may, however, be potential improvements that are not easy to find using traditional enterprise level advisory tools because of crop–livestock interactions (Halberg and Jensen, 1996). New, more integrated advisory tools that take a whole farm approach should therefore be developed. Some improvements in environmental performance are only achievable on a longer term, e.g. after a change of crop rotation, feeding systems or housing of animals. Therefore, indicators in IOA may be used in strategic planning tools (Harsh et al., 1996; Hémidy, 1996; Halberg, 1999b).

Advisors and farmers need reference values in order to interpret the results of individual farms but this has only been addressed on an ad hoc basis for many of the reviewed systems. There is a need to develop useful and valid (objective) reference and target values for the indicators selected for IOA. There are different possible ways for this:

- Politically set target values (for example, for TFI, as it will be the case in a new pesticide account for Danish farmers promoted by the government).
- Modelled (expected) results if a farmer follows standards for good agricultural practice (GAP). The systems EMA, FHL, GA and the EY used GAP or other "best practices" according to some assumptions as reference values for the farms, for example regarding N surplus.
- The farm's results in previous years. Such historic data was used more or less by most systems and assumes that differences between years can be explained to a large degree by changes in the farmers' management. This is discussed later.
- Best or average practice from a set of comparable farms usually within the same project (this was used by most systems, see Tables 3–5).
- Best practices among a larger, statistically analyzed data set representing farm variation at sector level in a country or region. Here the variation between existing farms is used based on the idea that these may represent the possibilities within a spectrum of economically attractive production methods (Reinhard and Thijssen, 2000).
- Transformation of indicators to closed scales representing the range between good and poor agri-environmental performance The AEI used a graphical illustration combining the scores (0–10) for each indicator in a web (Bockstaller et al., 1997), which allows an easy overview of changes from last year's scores and shows which indicators have the most critical value according to the assumptions behind the scale, see also EYP, Table 4.

In a discussion of sustainability concepts Von Wirén-Lehr (2001) distinguish between *absolute* evaluation procedures which use a priori defined margins or threshold values and *relative* evaluation, which builds on comparisons between different systems. The first two alternatives mentioned above would belong to the absolute category together with certain types of closed scale transformations (the last bullet). The advantage from an IOA point of view would be that there is a clear reference value to compare against such as the critical pesticide loads used in the pesticide indicator in EYP, see above. However, such politically/publicly set standards to compare indicator values with do not presently exist for more than a few cases. It is possible to compare part of farm management with GAP or to model the result of, say N-surplus, given that a specific farmer follows GAP (this is used by GA). However, this is a relatively conservative standard, which actually do not convey very much new information to those farmers, who may already be following the recommendations in a GAP guideline. The principle of benchmarking, i.e. comparing one farm's result with the average of other farms (or selection of the best) is a relative evaluation procedure and in the available documentation of the IOA systems there was a large variation between farms. Therefore, at least the farms with high environmental impact should be able to find a potential for improvement using benchmarking against the better performing farms of comparable size and production. Apart from the small samples used in the IOA projects few data sets exist showing the environmental performance of a larger number of single farms. This has still to be developed for the agro-environmental indicators, possibly based on existing systems of farm surveys and monitoring of economical performance, e.g.

the farm accountancy data network (FADN), which is the EU system for reporting comparable farm level economical statistics (Poppe and Meeusen, 2000).

The transformation of indicators to a closed scale may facilitate an easy interpretation and give a fast overview of which environmental issues that may be most problematic on a given farm. However, to make such a scale will often involve normative assumptions regarding what are reasonable levels of agri-environmental impact (Girardin et al., 1999). It is unclear how these underlying value statements were actually addressed when introducing the systems to the farmers. As a minimum they should be explained and the origin of the target values for “integrated farming” or “best practice” should be made clear (e.g. who defined the good practices?). Another disadvantage of transformations into scales could be that it becomes more difficult for the farmer to understand how to improve on the agri-environmental issue behind the indicator.

When interpreting the indicator values, the farmer and the facilitator need to understand the relationship between the indicator values and farmers’ management practices. Therefore, this relationship is at the core of the practicability of systems and indicators and should be tested as part of the indicator development for IOA systems. If it is not proven that the indicators chosen are significantly influenced by the farmers’ choices of strategies, there is a risk that the advisors and farmers will be wasting time and energy on recordings without importance. Two methods exist to empirically evaluate the relationships between indicator values and farm management. The first is based on the differences between farms. Halberg (1999a) analyzed nutrient balances, energy use and pesticide use (TFI) on 20 farms over 3 years and found that even after correction for soil type and farming system, there was a significant difference between individual farms in the indicator values. Such differences could to a large extent be explained by differences in—among others—feeding (Nielsen and Kristensen, 2001) and crop rotation and their impact on the protein supply of dairy cows and manure use efficiency (Børsting et al., 2003). The econometric approach described by Reinhard and Thijssen (2000) may be developed into a functional tool for advisors.

The second method is based on differences between years on a specific farm. To test if changed management practices could explain the change in e.g. N-surplus on a farm the changes in the different items of the N-balance calculations during the time period in question should be evaluated. Thus, if the sum of changes in the items under the farmers control (e.g. import of fodder or use of fertiliser) to a large extend equals the change in overall N balance, then it may be concluded that the difference between years is due to management. If not, an attempt should be made to 1. Check again for errors in input use, status/stocks or concentrations, and 2. To find explanations in the uncontrollable factors such as low yields in crops or in the variability in amount of nutrients in manure import/export. This approach was followed to some extent in several systems, but documentation of the process and conclusions have not been published.

Related to this is the question of stochastic variation in indicator values. If the indicators in the IOA are meant to give information on differences between farms or differences between years on a given farm it is necessary to have ideas of the size of the statistical variation on the indicator estimates. If for example a farm has a calculated N-surplus of 150 kg/ha in 1 year and 170 the other, is it then reasonable to look for an agronomic explanation (e.g. more feed used per produced pig) or, could the difference be just a coincidence due to stochastic variation (e.g. in the N content of the cash crops or imported manure). Similarly, if the eco-rating increases on a farm from 5 to 6 on a 10-point scale, has the farmer then improved his management or could it be coincidental? In none of the researched systems were the use of confidence intervals or variation coefficients an established part of the procedure. Thus, no evaluation of the precision of the estimated indicator values to reflect systematic changes in management was available.

3.5. What topics should be included in future IOA?

Basically, the selection of agri-environmental indicators builds on values and objectives concerning what are important environmental impact from farming. Thus, indicator selection should be explicitly based on concepts of sustainable agriculture as discussed by Kristensen and Halberg (1997). This review was limited to indicators of nutrients, energy and pesticides use. The environmental impacts of these inputs seem to be considered of general relevance in regions with intensive agriculture and a number of pragmatic indicators exist that may be explained to farmers (OECD, 1997). Other environmental aspects that may be included relatively easily in IOA using the same basic principles are water use and efficiency and the use of medicine (e.g. antibiotics as growth promoters) and heavy metals such as Cu and Zn. Water use was included in EMA and in three other indicator systems reviewed by Van der Werf and Petit (2002). The EALF introduced Cu and Zn balances on farm and field level and reports some interest among pig farmers (who use high amounts as growth promoters and to reduce diarrhea) when the potential soil quality problems were explained.

Soil fertility was included in AEI and EMA, but mostly based on evaluations of the farmer's management practices. The IOA REPRO and other systems reviewed by Goodlass et al. (2001) included indicators for humus balance or soil losses. The objective of sustainable soil management is however multi-dimensional and includes sustaining or enhancing the chemical, the biological and the physical soil properties (Doran and Parkin, 1994) and reduction of soil erosion. Schjønning et al. (2004) argue that indicators of soil quality management should build on explicit objectives related to three areas of concern, namely biological productivity, environmental properties of soils (such as enhancing water quality) and the soils' ability to support human health. The authors find it problematic when soil quality indicators are chosen only as a technical concept without clear reference to the prioritized criteria. There seems to be a lack of consensus regarding the selection of general soil quality indicators for practical use in IOA. On reason may be that geographical differences in soil types, topography, climate, etc. have the implication that the relevant soil quality indicators and their thresholds should be defined at the local level (Schjønning et al., 2004). This may be a good explanation for the different focus found in the IOA systems (e.g. soil fertility, heavy metals, organic matter, soil erosion) but most often clear reasons for choosing only one or two aspects out of the multidimensional soil quality topic were not given by system developers.

The impact of intensification, respectively, extensification (e.g. abandonment of permanent grass) on landscape and biodiversity, was included in different forms in EALF and EMA and in several other systems described in Goodlass et al. (2001) and Van der Werf and Petit (2002). Again, there seems to be no consensus even at generic level in the choice of indicators for an advisory tool partly because different values of landscape and biodiversity were in focus. A reason may be that these topics differ in their local or regional significance, which should be reflected in the choice of indicators (see, e.g. Oñate et al., 2000; Noe et al., 2003).

4. Recommendations for the future use of IOA systems

In order to develop further the usefulness of IOA for European farmers a number of issues should be considered:

- Indicators should be selected based on explicit and precise environmental objectives and with realistic demands for data and calculation efforts. Table 7 gives examples of such indicators concerning nutrient losses, energy use and pesticide use that may be recommended. Priority should been given to quantitative indicators that may show changes on a farm over time and are relatively easy to calculate, audit and understand. The nutrient and energy indicators and the TFI for pesticides only show the use and efficiency of these inputs and do not estimate actual environmental impacts. This is different for, e.g. the EIP that estimates actual environmental consequences of a farm's pesticide use. The latter type is preferable in the long perspective also for nutrient losses if models of losses get more reliable and comparable. For fossil energy consumption the calculation of green house gas emission is well established and could be used to transform the unit MJ into CO_2-equivalents.
- When using indicators shown in Table 7 the expert or advisor has a responsibility to interpret the indicator values in relation to reference values. There is an urgent need to develop well-documented reference material for benchmarking on the individual farm. For the non-scaled quantitative indicators such reference values could be established by analysis of a larger number of farms. For indicators using a built-in scaling or judgement a transparent procedure for the establishment of the scale

Table 7
Indicators to be used in IOA recommended on the basis of the reviewed systems with documentation of effect and/or uptake[a]

Topic	Nutrient use		Energy use		Pesticide use	
Indicator	Surplus N and P, kg ha^{-1}	Efficiency, % output $input^{-1}$	Direct energy, MJ or MJ ha^{-1}	Total energy Use, MJ kg^{-1} product	Treatment frequency index	Environmental impact points[b]
Sectors and farm types	Crops, pigs, dairy, poultry, horticulture, mixed farms	Crops, pigs, dairy, poultry, horticulture	Cash crops, pigs, poultry	Crops, pigs, dairy, horticulture, mixed farms	Crops, mixed farms	Crops, mixed farms
Reference values	Best practice between comparable farms, own historic results	Best practice between comparable farms or enterprises, own historic results	Own historic results, best practice between comparable farms	Own historic results, best practice between comparable farms	Public target values for different crops, own historic results	Environmental standards, own historic data
Time/price[c]	2–4 h	"Surplus" + 15 min	30 min	2–4 h	30 min	2–3 h (?)
Other demands or assumptions	General production and account data readily available	Builds on N, P surplus	General production and account data readily available	Standards for indirect energy use needed (LCA-type)	Field data available	Field data available, special software necessary
Comments (see text for details)	Simple but still difficulties with N-fixation and export of manure	Ibid	Only focusing on direct energy may be problematic	Calculation and explanation of indirect energy use problematic	Compares pesticide use, not risk of environmental impact	Origin of PEC and environmental standards important

[a] Other indicators than the mentioned may prove valuable after further development, especially for pesticide use. For an extended list of indicators used in IOA systems see Tables 3–5.

[b] Based on, e.g. the EIP and PEC in EYP, see Table 4. The main objective for such an indicator should be to distinguish pesticides based on their toxicity.

[c] Only the time used for calculating indicator values on a particular farm given the assumptions mentioned below. The time indicated does not include time to discuss improvements on a particular farm.

and its threshold values needs to be established and explained. The indicators may be presented graphically, for example, in the form of spider webs, but transformation into closed scales based on normative comparisons should be avoided.

- There is a need for more research into the statistical properties of indicators especially regarding: (1) the relation between coincidental changes and the effects of changed management practice on changes in indicator values on a given farm over a period of time; (2) the relative importance of systematic versus coincidental differences in environmental performance of a set of farms used to establish reference values. In both cases the question is linked to the possibilities for farmers to actually impact on their IOA results by changing their management. Developers of IOA should thus demonstrate the actual relation between farm management and levels of indicator values on different farms. Also, more evidence should be presented of the possibilities for voluntary environmental improvements in different farm types as measured by the indicators.
- The precise understanding of an indicator value on a given farm (e.g. the reason for a high N surplus) can only come from a detailed analysis of the resource use efficiency in the farm's subsystems or enterprises (e.g. the protein supply and efficiency in the herd). Therefore, the use of IOA should be linked with technical–economic extension such as fertiliser and feed planning in order to include the environmental aspects in the process of improving farm management.

5. Conclusions

- Input–output accounting systems can facilitate farmers and advisors to improve the environmental performance of both crop and livestock production. There is often a potential for improvement of nutrient and energy efficiency with no extra costs to the farmers in a broad spectrum of farm types and enterprises. Such tools can also encourage farmers to reduce pesticide use and choose less toxic pesticides. Farmers testing IOA have been interested if the indicator values were followed by an interpretation and they usually agreed to the importance of the environmental topic behind the indicator. However, more studies of the actual results in terms of changed management are needed.
- Input–output accounting systems works best when linked to tools for production planning possibly used with the help of advisory services. This link may help to make it legitimate for advisors to address environmental issues in their contact with farmers.
- Evidence of farmers actually reducing their costs significantly due to improved environmental performance and efficiency in input use is scarce. Though cost reduction is possible in some cases it will probably not be a strong driving force for IOA because of the relatively low costs of many farm inputs. Important driving forces in pilot projects have been farmers' interest in their environmental performance as compared with others, advantages of labeling and the possibility of reducing demands for compliance with rule based regulations such as stocking rates or manure storage capacity.
- A number of indicators suitable for the (voluntary) documentation of the amount and efficiency of use of nutrients, pesticides and energy on farm and enterprise level have been developed as part of IOA. Recommendable indicators should quantify the result of farm management over at period of time in way that makes it possible to interpret the value in relation to environmental objectives and to benchmark against other farms or historic data. Examples are given in Table 7.
- Better reference values for evaluation of the individual farm's results and for benchmarking should be developed as part of IOA. Moreover, system developers should verify the relation between farm management and levels of chosen indicators on the different farms.
- Most IOA tools include one or more of the topics Nutrient surplus, Energy use and pesticides use which seems to have general importance in Europe. Other areas that may be included in IOA tools are the use of medicine (e.g. antibiotics as growth promoters) and heavy metals such as Cu and Zn. Other agriculture–environment interactions such as the impact on soil quality, biodiversity and nature or landscape quality could be included in future "Green accounts" for farms but the development of simple indicators to address these topics with wide geographical coverage is problematic.

- The experiences reviewed from all over Europe points to an increased interest among researchers, advisors, farmers and politicians for the possibilities to use green accounting to facilitate environmental improvement at farm level. Input–output accounting tools are already being implemented on a larger scale in some European countries and data regarding their uptake and efficiency should be recorded more systematically in order to facilitate future exchange of experiences.

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