International
Fertilizer Industry
Association

IFA Technical Conference

Marrakech, Morocco
28 September-1 October 1998

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Date of receipt: 4 May 1998

SELECTING THE RIGHT FERTILIZER FROM AN ENVIRONMENTAL LIFE CYCLE PERSPECTIVE[1]

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SUMMARY

The fertilizer industry is frequently blamed for supporting an agriculture which is not environmentally sustainable, and there is a growing opinion that organic farming is the best. A different picture appears when an environmental life cycle analysis is carried out. The paper describes the results of such an analysis, examining an "intensive" (optimal use of fertilizers) versus an "extensive" (reduced use of fertilizers) agricultural system, and also the impacts of using different types of fertilizers (solids, liquids and manure).

The analysis takes account of the environmental impacts from:

1. the excavation of raw materials,
2. the production processes,
3. the transportation of raw materials and finished products, and
4. the application of fertilizers on the field.

The work is based on an internationally recognized model developed and used by the Dutch authorities. It has been tailored to the analysis of fertilizers and takes account of all principal environmental impacts, such as global warming effects, eutrophication, acidification, smog formation, area use, depletion of non-renewable resources, etc. The relative importance of these impacts are weighted, taking account of the criticality of the impact and the required "repair" time.

The paper concludes with what is the right fertilizer from an environmental life cycle perspective.

RESUME

On blâme fréquemment l'industrie des engrais qui favorise une agriculture non durable du point de vue environnement, et l'opinion est de plus en plus en faveur de la fumure organique. Une image différente apparaît quand on effectue une analyse de cycle de vie du point de vue environnement. L'exposé décrit les résultats d'une telle analyse comparant un système agricole "intensif" (emploi optimum d'engrais) à un système "extensif" (emploi réduit) ainsi que les effets de l'emploi de différents types d'engrais (solides, liquides et fumier).

L'analyse tient compte des effets sur l'environnement de :

1. *l'extraction des matières premières,*
2. *les processus de production,*
3. *le transport des matières premières et des produits finis, et*
4. *l'application des engrais sur le terrain.*

Le travail repose sur un modèle reconnu internationalement, mis au point et utilisé par les autorités hollandaises. Il a été adapté aux formules d'engrais et tient compte des principaux effets sur l'environnement, comme l'échauffement général, l'eutrophisation, la formation de brouillard, l'emploi des terres, l'épuisement des ressources non renouvelables, etc. L'importance relative de ces effets est évaluée en tenant compte du caractère critique des effets et de la durée de "réparation" nécessaire.

L'exposé conclut sur l'engrais convenable dans la perspective du cycle de vie lié à l'environnement.

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[1] *Choix du bon engrais dans une perspective de cycle de vie lié à l'environnement*

1. Introduction

The use of mineral fertilizers is a reason for continuous debate on the environmental aspects of agriculture. However, the environmental impact of fertilizer use has to be seen in a Life Cycle perspective to get a right ranking of the environmental impacts.

Life Cycle Analysis (LCA) should be done according to accepted CML and SETAC guidelines. In this paper, the Eco-indicator 95 methodology was used for an integral environmental impact assessment of different farming practices. However, the depletion of energy resources as an important aspect that is relevant in agriculture or the fertilizer industry is not included in the Eco-indicator.

Therefore the Eco-indicator 95 was extended so that it is more suitable for the purpose of assessing agricultural processes. Following the principles of the Eco-indicator 95, a framework for including the depletion of energy resources was developed.

The Eco-indicator methodolgy is being used to compare and evaluate the environmental effects of different fertilization strategies in winter wheat production.

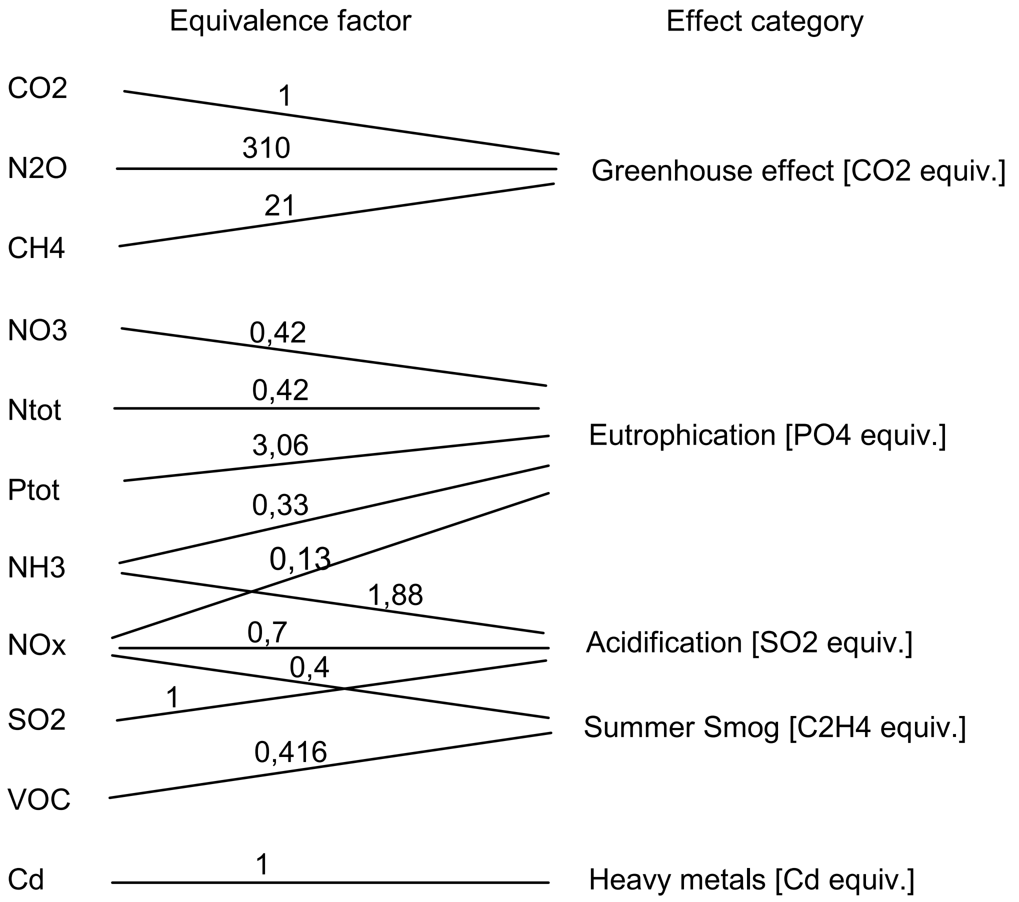
2. Background

The Eco-indicator 95 method (NOH, 1995) is a procedure in four steps.

The first step, the *inventory* is a listing of all emissions and resources used in a production system.

The second step, the *characterization* is to group the emissions according to their environmental effects using equivalence factors, which characterize their contribution to the respective effect (Figure 1). The higher the equivalence factor, the higher is the contribution of an emission to the respective effect.

Figure 1 - Inventory and characterization of emissions



In the third step, the *normalization,* the contribution of each effect score to the value of the respective effect score in Europe is examined. This is done by dividing each effect score by the effect score produced by one average European person during one year (Table 1). The result is a normalized dimension less score for each effect.

Table 1 - Normalization values for Europe* (per year)

	Unit	Normalization value per capita	Uncertainty
Greenhouse effect	kg CO_2 equ.	**11891**	Small
Acidification	kg SO_2 equ.	**111**	Small
Eutrophication	kg PO4 equ.	**38**	Moderate
Heavy metals	kg Cd equ.	**0.05**	Large
Summer Smog	kg C_2H_4 equ.	**17**	Moderate
Energy depletion	GJ	**248**	Small

* without former USSR

However, the normalized effect scores say little about the potential of the different effect categories to harm the environment. Therefore, in the fourth step called *evaluation,* the normalized effect scores are multiplied by a weighing or evaluation factor (Table 2) to obtain so-called Eco-indicator values for each effect.

In the *evaluation* the distance-to-target method is used to establish weighing factors for the normalized effect scores. Distance to target means the distance between the current level and a target level of an effect. The target level of an effect category represents an acceptable minimum level of impairment to ecosystems and human health according to scientific knowledge. Table 2 gives the individual evaluation or weighing factors for each effect.

Table 2 - Weighing factors for environmental effects

Environmental impact	Weighing factor	Target
Greenhouse effect	2.5	0.1°C rise every 10 years, 5% ecosystem degradation
Acidification	10	5% ecosystem degradation, exceedance of critical acid loads
Eutrophication	5	Rivers and lakes, degradation of an unknown number of aquatic ecosystems (5% degradation)
Summer smog	2.5	Occurrence of smog periods, health complaints, prevention of agricultural damage
Heavy metals	5	Lead content in children’s blood, Cadmium content in rivers
Energy depletion	2.5	Energy consumption covered solely by use of renewable resources

The result of this evaluation procedure is an Eco-indicator score for each effect category. As these scores are dimension less they can be summed up and then present the total Eco-indicator score for a system.

3. Environmental effects of different fertilizing systems

3.1. System definition and system boundary

The environmental effect of different fertilizer regimes to produce winter wheat has been examined. As N fertilizer AN, Urea, UAN, NPK/AN and AN/cattle slurry were chosen. Important figures about the systems are given in Tables 3 and 4.

Table 3 - Definition of the systems used for the LCA calculations

	AN or Urea or UAN	**AN and cattle slurry**	**NPK 16:16:16 and AN**
Fertilization	170 kg N/ha 40 kg P_2O_5/ha (TSP) 40 kg K_2O/ha (KCl) 4 applications	130 kg N/ha (AN) 40 kg N/ha (slurry) 40 kg P_2O_5/ha (slurry) 110 kg K_2O/ha (slurry) 3 applications	40 kg N/ha (NPK) 130 kg N/ha (AN) 40 kg P_2O_5/ha (NPK) 40 kg K_2O/ha (NPK) 3 applications
Plant protection	8 kg substance/ha 4 applications		
Yield	8.5 tons/ha		

Table 4 - Energy use and important emissions

	AN	***Urea***	***UAN***	***NPK 16:16:16***	***Cattle slurry***[1]
N fertilizer production	***per ton N produced***				
GJ	36	41	32	65	-
kg CO2	1487	1689	1343	3350	-
kg N2O	16.9	0.03	7.50	5.63	-
kg NH3	0.00	0.98	0.00	1.00	-
Agriculture [2]	***per ton N applied***				
Leaching kg NO3-N	93	83	89	94	90
Volatilization kg NH3	77	167	116	77	240
Denitrification kg N2O	17	15	16	17	16

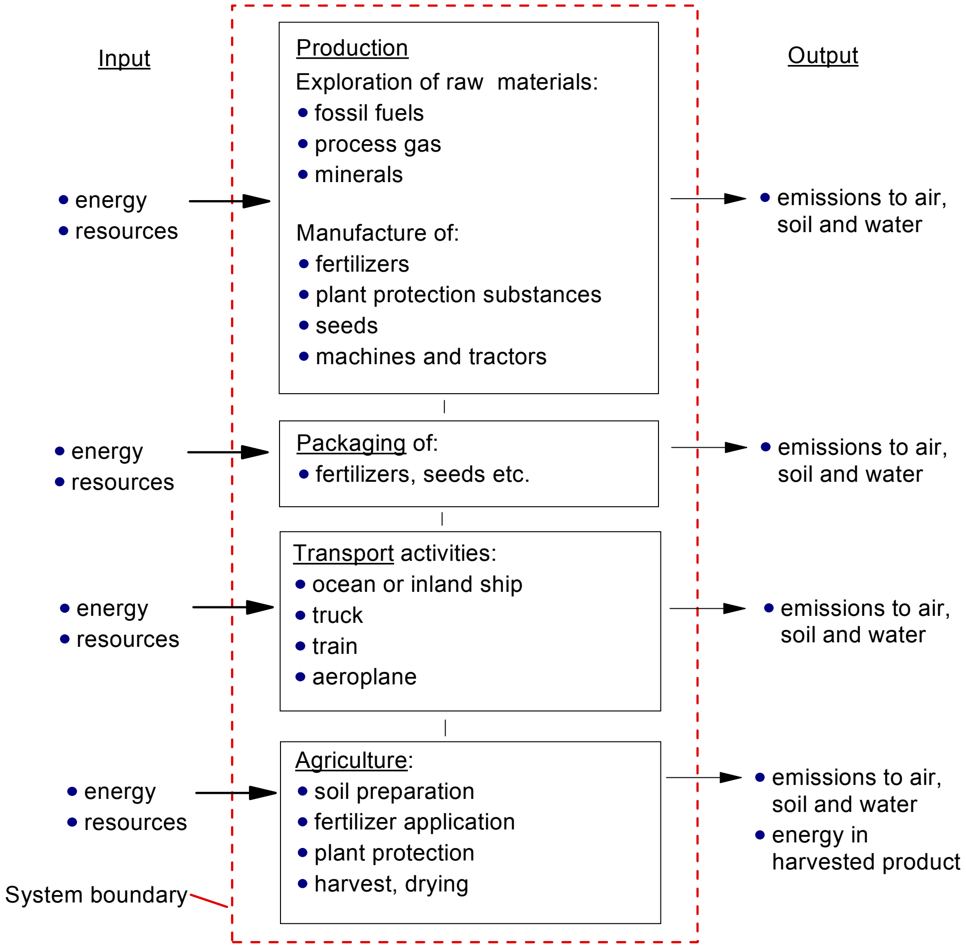
[1] Cattle slurry: production of cattle slurry not considered

[2] NH3 volatilization: source ECETOC Study (1994) and Schulz, D. (1998)
N2O denitrification: source: IPPC (1995), Bouwman, A.F. (1995)

The life cycle of a fertilizer is taken into account (exploration of raw materials and fossil fuels; transport of raw materials; production, transport and application of fertilizers), except for cattle slurry. Here only emissions and energy use during and after application of cattle slurry is considered.

Figure 2 provides on overview about the system boundary. All inputs and outputs are related to one ton of winter wheat grain (product related functional unit).

Figure 2 - Sub-systems and boundary of the winter wheat system



Energy use and emissions for different on-farm activities involved in crop production (application, soil preparation, seeding, harvesting) were calculated using the following data from literature:

- Energy use for the use of farm machinery (tractor and implements) was calculated as 10 MJ per hour and per ton of machinery use, assuming energy use in production of machinery is 40 MJ per kg (Grosse, 1984), and a working life of machinery of 4000 hours in 10 years.
- Energy use for the repair of farm machinery was assumed to be 188 MJ per ha and year (Haas and Köpke, 1994).
- Energy use for the production of seed was calculated using data of Oheimb et al. (1987), i.e. 3,5 MJ per kg.
- Energy used in the production of plant protection substances was 114 MJ per kg (Oheimb et al., 1987), which was a mean value for herbicides, fungicides, insecticides, and plant growth regulators.
- Fuel consumption in field operatioons (e.g. soil preparation, fertilization, seeding etc.) was calculated according to data of KTBL (1994) and Hydro Agri (1993).
- Energy use involved in the drying of cereal grain was calculated according to data from Hydro Agri (1993). 50% of the harvested grain was assumed to require drying from 16% to 14% moisture content.

Fuel consumption for transport, energy content of diesel and emissions involved in the combustion of diesel fuel were taken from Chalmers (Gothenburg) and Eidgenössische Technische Hochschule (Zürich).

3.2. Life cycle analysis of fertilizing systems

As a first step the emissions were aggregated to effect categories according to their potential to contribute to the respective effect Figure 1). The aggregated effects were then related to one ton of winter wheat grain.

In a second step the aggregated effects were normalized according to the procedure described in chapter 2. The effects/ton of grain values were divided by per capita normalization values (Table 1), which has the advantage of creating a dimension less score for each effect. Table 5 shows the normalized effect scores (as percentage values) for the different fertilizing systems.

Table 5 - Contribution of the fertilizing systems (effects per ton of grain) to the environmental effects in Europe (effects caused by one average European person)

	Greenhouse effect	Acidification	Eutrophication	Summer Smog	Heavy metals	Energy depletion
AN, TSP, KCl	2.73 %	3.46 %	3.81 %	2.55 %	1.40 %	0.66 %
Urea, TSP, KCl	2.16 %	6.37 %	5.45 %	2.39 %	1.40 %	0.76 %
UAN, TSP, KCl	2.35 %	4.90 %	4.56 %	2.46 %	1.40 %	0.68 %
NPK, AN	2.52 %	3.47 %	3.77 %	2.50 %	1.40 %	0.70 %
AN, cattle slurry	2.60 %	6.54 %	5.89 %	2.42 %	0 %	0.57 %

The values clearly show that the contribution of agricultural production to acidification and eutrophication in Europe is much higher than its contribution to the greenhouse effect, the depletion of energy resources, the formation of summer smog and the accumulation of heavy metals.

However, the normalized effect scores say little about the potential of the different effect categories to harm the environment.

Therefore, the normalized effect scores were multiplied by a weighing factor (Table 2) to obtain the so-called Eco-indicator per tonne of grain. The higher the Eco-indicator value, the greater the potential harm to the environment. Weighing factors were highest for acidification and eutrophication categories (see Table 2).

Figure 3 shows the highest Eco-indicator for Urea and AN/cattle slurry systems, which was mainly due to their higher eutrophication and acidification. There was little difference in the other Eco-indicator values for the different categories between the systems.

Figure 4 gives the share of production, packaging, transport and agriculture to the total eco-indicator values. This shows that agriculture is carrying the highest environmental burden (87-95% of the eco-indicator values). Production is responsible for the remaining 5-10% of the eco-indicators, and this analysis shows that packaging and transport have very little negative effect on the environment.

Figure 3 - Eco Indicator values of the winter wheat production systems per ton of grain

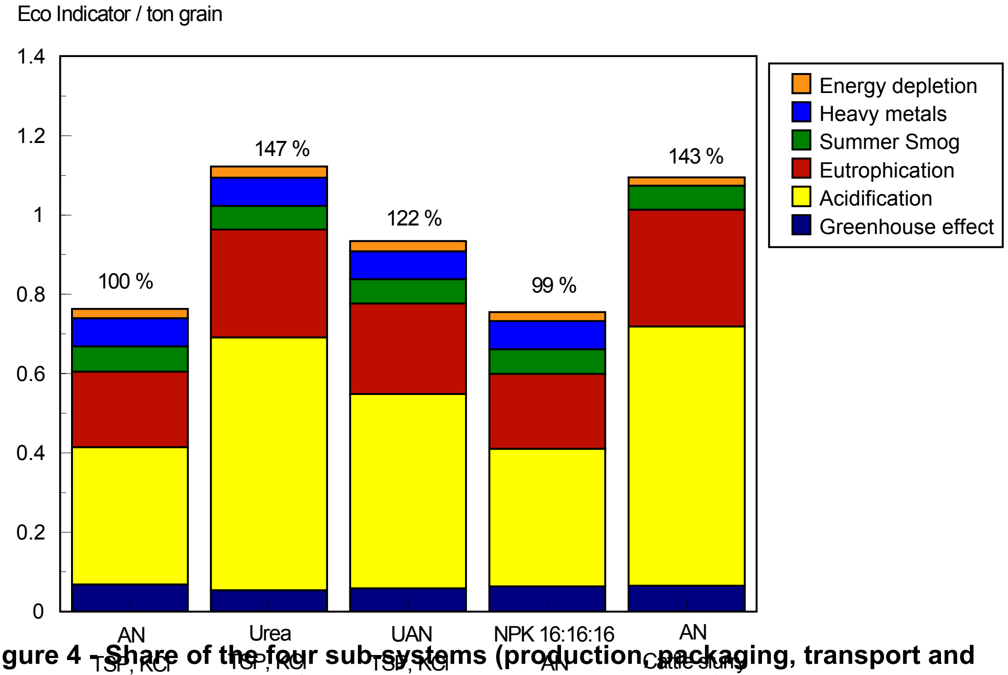
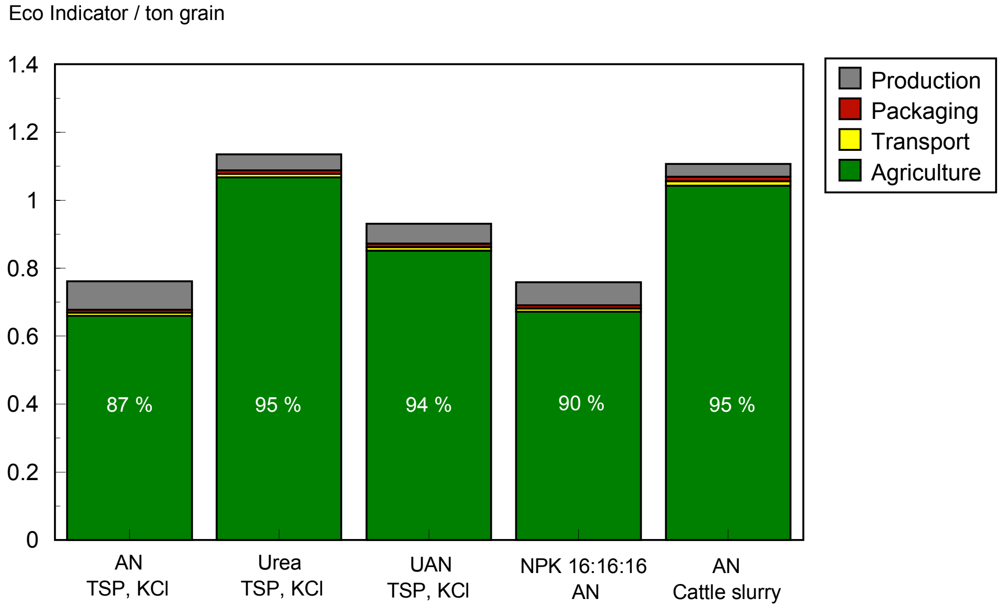


Figure 4 - Share of the four sub-systems (production, packaging, transport and agriculture) on total Eco Indicator per ton of grain



4. Summary

Life cycle analysis was used to compare and evaluate the effects on the environment of five different fertilizing systems in winter wheat production systems. The Eco-indicator 95 approach was chosen to assess the impacts.

The results showed that agriculture contributes to about 90 % to the total environmental impact of the winter wheat production systems.

For the systems the effects of acidification and eutrophication were higher than for greenhouse effect, depletion of energy resources, summer smog formation and accumulation of heavy metals.

The total eco indicator score for the Urea and AN/cattle slurry system was highest, due to highest eco-indicator values for acidification and eutrophication.

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