Environmental Impacts of Introducing Grain Legumes into European Crop Rotations and Pig Feed Formulas

Concerted Action GL-Pro
WP4: Environmental Analysis
Final report
Deliverable 4.3

Thomas Nemecek and Daniel Baumgartner
Agroscope Reckenholz-Tänikon Research Station ART
(formerly Agroscope FAL Reckenholz)

September 2006

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department
of Economic Affairs DEA
Agroscope Reckenholz-Tänikon
Research Station ART

Authors:
Thomas Nemecek, Daniel Baumgartner
Agroscope Reckenholz-Tänikon Research Station ART
(formerly Agroscope FAL Reckenholz)
Reckenholzstrasse 191
CH-8046 Zurich
Switzerland
http://www.art.admin.ch

Collaboration:

Julia-Sophie von Richthofen	proPlant GmbH, Münster (D)
Hubert Pahl	Technical University, Munich (D)
Gaëtan Dubois	UNIP, Paris (F)
Pierre Casta	ITA, Valladolid (E)
Simon Odermatt, Patrick Weibel	Agroscope Reckenholz-Tänikon (ART), Zurich (CH)
Raphaël Charles	Agroscope Changins-Wädenswil (ACW), Nyon (CH)

GL-Pro: Concerted action, 5th framework programme of the EU
“European extension network for the development of grain legume production in the EU”
Grant no. QLK5-CT-2002-02418
March 2003-May 2006
http://www.grainlegumes.com/gl-pro/default.asp

Coordinator: Benoît Carrouée UNIP, Paris (F)

Management Committee:

Benoît Carrouée, Frédéric Muel	UNIP, Paris (F)
Thomas Nemecek	Agroscope Reckenholz-Tänikon (ART), Zurich (CH)
Hubert Pahl	Technical University, Munich (D)
Anne Schneider	AEP, Paris (F)
Aurora Sombrero	ITA, Valladolid (E)
Thomas Volk	proPlant GmbH, Münster (D)

Summary

Within the framework of the concerted action GL-Pro (grant no. QLK5-CT-2002-02418) in the 5th framework programme of the EU, we studied the following questions:
What are the consequences for the environment

1. of introducing grain legumes into European crop rotations and
2. of replacing soya bean meal from Brazil by grain legumes and other feed ingredients produced in Europe?

This study used the SALCA (Swiss Agricultural Life Cycle Assessment) life cycle assessment method and the ecoinvent life cycle inventory database.

1. Crop Rotation Study

Four regions with potential for increasing their grain legume area were chosen for this study: Saxony-Anhalt (D), Barrois (F), Canton Vaud (CH) and Castilla y León (E). In each of these regions, two crop rotations were defined: a typical cereal-based rotation without grain legumes and an alternative rotation including grain legumes. The production data were collected by the local project partners from statistics, surveys, literature, documents from extension services and using expert knowledge. The impacts of these two crop rotations were compared relative to three functional units representing different functions of agriculture: hectare per year as a measure of the land management function, € gross margin 1 for the financial function and GJ gross energy of the harvested biomass for the productive function. The following environmental impacts were analysed: demand for non-renewable energy resources, global warming potential, ozone formation, eutrophication, acidification, terrestrial and aquatic ecotoxicity and human toxicity. For Canton Vaud, the impacts on biodiversity and soil quality were assessed in addition, using newly developed SALCA methods.

The introduction of grain legumes into intensive crop rotations with a high proportion of cereals and intensive N-fertilisation leads to a reduced energy use, global warming potential, ozone formation and acidification as well as eco- and human toxicity per unit of cultivated area. The main reasons for this are a reduced application of N-fertilisers (no N to the grain legume and less N to the following crop), improved possibilities for using reduced tillage techniques and greater diversification of the crop rotation, which helps to reduce problems caused by weeds and pathogens (and therefore pesticide applications). The nitrate leaching potential tends to be higher in general, but can be reduced by including catch crops or sowing winter grain legumes, where possible. No differences were found for the impacts of crop management on soil quality and biodiversity (studied in Canton Vaud only). In the low-input crop rotation in Spain, the introduction of peas had no favourable environmental effect, mainly because little or no N-fertiliser can be saved. The analysis per € gross margin 1 (financial function) leads to slightly more favourable results for the grain legume crop rotations compared to the analysis per ha and year.

Due to the lower yields of grain legumes compared with cereals, the advantages of grain legumes are smaller when considered per GJ gross energy of the harvested products (productive function). However, the energy efficiency is higher in crop rotations with grain legumes.

2. Pig Feed Study

The LCA case study of feed formulas was calculated for a feed mill in Münster (D). Feed formulas for fattening pigs (three-phase feeding: pre-fattening (28 – 40 kg), initial fattening feed (40 – 60/70 kg) and final fattening feed (60/70 – 117 kg)), were defined based on statistics and expert information. For each feed type two kinds of formulas were defined: a standard formula based on soya bean meal and cereals and an alternative based on field peas, rape seed meal, soya bean meal and cereals, with equivalent growth potential for pig fattening.

The analysis showed environmental benefits from replacing soya beans produced in South America by grain legumes (and rape seed) produced in Europe. The greatest benefits were obtained for the impacts in the area of resource management (energy demand, global

warming potential and ozone formation) followed by the impacts on nutrient management (eutrophication and acidification). The least environmental benefit was found for pollutant management (eco- and human toxicity). Generally it can be said that the larger the share of crop production in the total impact, the smaller the environmental benefits from pea formulas compared to soya formulas.

Crop production of the feed ingredients was the dominant process within the production of pig feed, with a minimum of 50% of the total impact of an impact category, followed by transport and production of mineral feed. Processing of the feed ingredients in the feed and oil mills was of minor relevance for all the main environmental impacts.

Four factors have to be considered when assessing the environmental impacts of pig feed formulas: the share of soya bean meal in the formulas, the proportion of cereals in the formulas, the transport of the feed ingredients, notably the protein concentrates in the feed, and the yield levels of the different crops.

Acknowledgements

This research was supported by the European Commission (grant no. QLK5-CT-2002-02418) and by the Swiss State Secretariat for Education and Research.

We would like to express our thanks to W. Sommer, North Rhine-Westphalia Chamber of Agriculture (Landwirtschaftskammer Nordrhein-Westfalen), Department of Animal Production (Referat Tierproduktion), Münster, Germany, who defined the different pig feed formulas.

We must thank all the partners in the GL-Pro project for contributing to the study by providing data, advice and other information as well as contributing to interesting and fruitful discussions at several meetings.

Special thanks go to Julia-Sophie von Richthofen (proPlant GmbH, Münster), who compiled the production data for the crop rotations and provided data for the feed study, Hubert Pahl (Technical University, Munich), who helped in the conception of the economic-environmental studies, Gaëtan Dubois (UNIP, Paris) and Pierre Casta (ITA, Valladolid), who provided crop production data and helped with the interpretation of the results, and Raphaël Charles, who discussed the case study for Canton Vaud with us.

Contents

Summary 3
Acknowledgements 4
Contents 5
Abbreviations 6
1 Introduction 7
  1.1 Context 7
  1.2 Previous Studies 7
  1.3 Mandate 8
  1.4 Target Groups for this Report 9
2 Definition of Goal and Scope 10
  2.1 Comparison of Crop Rotations 10
    2.1.1 Goal of the Study 10
    2.1.2 Study Regions and Crop Rotations 10
    2.1.3 System Definition and Boundary 11
    2.1.4 Functions and Functional Units 12
    2.1.5 Allocation Procedures 13
  2.2 Comparison of Feed Formulas 13
    2.2.1 Goal of the Study 13
    2.2.2 Study Region and Feed Formulas 13
    2.2.3 System Definition and Boundary 14
    2.2.4 Function and Functional Unit 15
    2.2.5 Allocation Procedures 16
  2.3 Consideration of the Crop Residues 16
  2.4 Data Quality Requirements 17
  2.5 Critical Review 17
3 Life Cycle Inventory Analysis 18
  3.1 Data Collection for LCA of Crop Rotations 18
    3.1.1 Production Inventories 18
    3.1.2 Life Cycle Inventories 18
    3.1.3 Estimation of Direct Field Emissions 18
  3.2 Data Collection for LCA of Feed Formulas 19
    3.2.1 Production Inventories 19
    3.2.2 Life Cycle Inventories 19
    3.2.3 Estimation of Direct Field Emissions 19
  3.3 Calculation Procedures / Tool 19
4 Life Cycle Impact Assessment 20
5 Life Cycle Interpretation 22
6 Results 23
  6.1 Comparison of Crop Rotations 23
    6.1.1 Saxony-Anhalt (D) 23
    6.1.2 Sensitivity analysis for Saxony-Anhalt (D) 27
    6.1.3 Barrois (F) 30
    6.1.4 Vaud (CH) 33
    6.1.5 Castilla y León (E) 38
    6.1.6 Overview of the Results for all Case Studies 42
  6.2 Comparison of Feed Formulas 44
    6.2.1 Detailed Results from Selected Impact Categories 44
    6.2.2 Summary of the Results 49
    6.2.3 Sensitivity Analysis of Allocation Factors for the Oil Extracting Process 50
7 Discussion 52
  7.1 Grain Legumes in Crop Rotations 52
    7.1.1 Effect of the Crop Rotation 52
    7.1.2 Considered Impacts 52

7.1.3 Considered Function of the Cropping System 53
7.2 Grain Legumes in Feed Formulas 53
8 Conclusions and Outlook 56
9 References 58
10 Appendices 61
10.1 Appendix 1: Origin of Feed Ingredients and Transport Distances for the Pig Feed Study 61
10.2 Appendix 2: Production Data used for Calculation of Soya Production in Brazil .. 62
10.3 Appendix 3: Results of the Sensitivity Analysis for Altered Allocation Factors in the Oil Extraction Process 63

Abbreviations

a	year (annum)
CAP	Common Agricultural Policy of the EU
CH	Switzerland
CR1	crop rotation without grain legumes
CR2	crop rotation with grain legumes
D	Germany
DM	dry matter
E	Spain
F	France
GL	grain legume
LCA	life cycle assessment
NRW	North Rhine-Westphalia
PEA	feed formulas with pea and rape seed meal (Germany) as well as soya bean meal (Brazil) as protein supply
SNF	symbiotic nitrogen fixation
SOY	feed formulas with soya bean meal (Brazil) as protein supply

1 Introduction

1.1 Context

Europe’s deficit of materials rich in proteins – today amounting to about 75% – may have potentially adverse effects on the environment, due to several factors. Covering this deficit requires massive imports of soya bean meal, which entails transport over long distances, resulting in adverse environmental impacts. Moreover, the increase in soya bean cultivation in South America is leading to the conversion of natural and semi-natural habitats into arable land, with impacts on biodiversity and soil quality. In addition to these environmental concerns, the increasing cultivation of genetically modified soya beans raises problems of consumer acceptance.

Increasing grain legume production in Europe could be an excellent alternative to the import of soya bean meal. Thanks to their ability to symbiotically fix nitrogen from the air, grain legumes do not need any nitrogen fertilisation. This unique feature offers a great potential for reducing environmental burdens, e.g. through reduced fossil energy use and nitrogen losses. Despite these positive aspects, grain legume cultivation has been neglected within the EU for many years. On the other hand, symbiotic nitrogen fixation causes changes of nitrogen dynamics in cropping systems that may lead to an increase in nitrogen losses, such as nitrate leaching. Changes in feed formulas for animals may positively or negatively influence the environment. What environmental impacts are to be expected from increasing the production and use of grain legumes in Europe?

This study contributes to answering this question.

1.2 Previous Studies

Jensen (1997) discussed the role of grain legumes in the nitrogen cycle in cropping systems. He found that the pea uses inorganic nitrogen efficiently in the upper soil layers, but less efficiently than cereals in deep soil. High amounts of mineral N in the soil reduce symbiotic N fixation (SNF). He found an average N benefit of about 20 kg N/ha from peas in a crop rotation. After a pea harvest, greater quantities of mineral N are found in the soil than after a cereal harvest. Part of this nitrogen can be used by the succeeding crop, but part may also be lost through emissions into the water or into the air. Higher rates of nitrate leaching were found after peas than after cereals.

The preceding crop effect of grain legumes providing nitrogen has been demonstrated many times (e.g. Köpke 1996, Charles & Vullioud 2001). This effect allows higher yields from succeeding crops at the same fertiliser rates or a reduced fertiliser rate for the same yield or a combination of both. It has been demonstrated that the fertilising effect on succeeding crops is highest in systems receiving little or no N fertilisation.

Crews & Peoples (2004) compared the environmental effect of legume N-fixation with industrial fertiliser manufacturing and came to the conclusion that the overall environmental effect of legume N-fixation are moderately positive.

Besides the nitrogen effects, the introduction of grain legumes has also other positive effects, such as the reduction of pesticide use thanks to a diversification of the crop rotation (Munier-Jolain 2002). It should be borne in mind that these effects are not specific to grain legumes.

Carrouée *et al.* (2002) compiled different available sources and discussed the benefits and impacts of introducing grain legumes into crop rotations. They come to a generally positive assessment, with the exception of nitrate leaching, which might be increased, at least in the short term.

Charles & Gosse (2002) showed a significant reduction of nitrogenous emissions with peas compared to wheat, thanks to the fact that peas do not require nitrogen fertiliser.

Life cycle assessment studies carried out at crop level (e.g. Charles & Nemecek 2002) have shown mostly more favourable impacts of peas compared to wheat at crop level. However, per kg of product the impacts of grain legumes may also be higher than those of cereals, mainly due to lower yields (Nemecek *et al.* 2005).

Recently, the current knowledge and the state of the art of the methodology have been compiled in an international scientific workshop (AEP 2006). Several contributions demonstrated that although many elements of the system are well known, there exist sizeable knowledge gaps that have to be filled in order to make a comprehensive assessment of all the positive and negative environmental impacts.

What is currently lacking for the assessment of the impact of grain legume crops on the environment is a comprehensive and systematic assessment and quantification of favourable and adverse environmental impacts of introducing grain legumes into European crop rotations. Such an assessment is performed by means of life cycle assessment in selected European regions in this study.

The second part of the study focuses on the use of grain legumes as animal feed. Van der Werf *et al.* (2005) conducted a study of the environmental impacts of the production of concentrate pig feed in Brittany. The authors defined six diets for pigs, adapted to their development stage. The feed components were either from local, national or overseas sources. The results referring to the production of one ton of pig feed showed a substantial contribution by transport processes to the impact categories energy use, climate change and acidification. A feed consisting mainly of non-processed crop-based ingredients had lower environmental impacts for energy use and higher impacts for terrestrial ecotoxicity compared to a feed containing mainly co-products. Furthermore, comparing wheat-, maize- or co-product-based feeds per ton of compound feed, the wheat-based formulation was the most favourable for the impact categories land use, energy use and climate change. The co-product-based feed had the lowest impacts for acidification and terrestrial ecotoxicity, but otherwise had the highest impacts of the three feed types. The maize-based feed was less favourable than the wheat-based one, the exception being the category of eutrophication, but mostly had fewer impacts than the co-product-based feed (van der Werf *et al.* 2005).

In a similar study Eriksson *et al.* (2005) examined the impact of the feed choice for pig production under Swedish conditions. Three feed formulas were examined: (a) a formula based on cereals and soya bean meal extrapolating the present trend of increasing soya bean use, (b) a formula consisting of barley, peas, rape seed cake from organic production and (c) a formula composed of grains, small amounts of pea and rape seed cake and synthetic amino acids. Results showed that of all feed ingredients, soya bean meal had the highest impacts for all the assessed environmental impacts (Eriksson *et al.* 2005). This study also includes pig rearing. For one kg of pig growth the formula with soya bean meal had higher environmental impacts in terms of energy demand and global warming potential than the formula with the organic feed ingredients including peas. In contrast, the impacts for acidification and eutrophication of the soya formula were lower than for the organic pea formula. The reason for this is the overfeeding with proteins and its consequences, i.e. higher N contents in the pig slurry, with more risks of nitrate leaching and more ammonia losses in the organic pea scenario. The third formula with synthetic amino acids had the lowest impacts in all the above-mentioned environmental impacts compared with the soya and the organic pea formula, except for energy demand (Eriksson *et al.*, 2005).

There are several LCA studies of pig production where the production of feed is included. But the focus of these studies is on the production of pig meat at farm gate (Basset-Mens & van der Werf 2005; Cederberg & Flysjö 2004) or at consumer level, as in Blonk & Effting (2001).

The missing link between the assessment of single feed ingredients and pig meat production is the evaluation of feed formulas. A pilot study covering this field has been undertaken here to fill this gap.

1.3 Mandate

Agroscope FAL Reckenholz (today Agroscope Reckenholz-Tänikon Research Station ART) was mandated by the European Commission to carry out this study within the framework of the concerted action GL-Pro (grant no. QLK5-CT-2002-02418) in the 5th framework programme for research.

The concerted action GL-Pro was managed by UNIP (Union Nationale Interprofessionnelle des Plantes Riches en Protéines), Paris. The project was coordinated by Benoît Carrouée.

Fourteen partners from six European countries participated in the concerted action. More information on GL-Pro can be found at http://www.grainlegumes.com/gl-pro/.

1.4 Target Groups for this Report

This report addresses the following target groups:

- the scientific community
- the extension services
- the authorities and policy makers.

Farmers are not the target group for this scientific report, but should be reached through extension services and by other means of communication.

2 Definition of Goal and Scope

2.1 Comparison of Crop Rotations

2.1.1 Goal of the Study

The goal of the life cycle assessment (LCA) study of crop rotations is to show the environmental impacts of introducing grain legumes into crop rotations in selected European regions.

2.1.2 Study Regions and Crop Rotations

We used the same crop rotations as in the economic analysis (von Richthofen *et al.* 2006). This allows a direct comparison of the results and a comprehensive economic and environmental assessment.

The regions were chosen according to the following criteria:

- Arable regions with potential for increasing their grain legume area
- Data availability
- Possibility of collecting and validating data through GL-Pro partners' contacts.

Because LCA is data- and time-intensive, only four of the eight study regions covered in the economic analysis were included in the environmental study. In each of these four regions two crop rotations were defined:

- Crop rotation 1 (CR1): a typical rotation for the selected region, usually oriented mainly towards cereal production and without grain legumes.
- Crop rotation 2 (CR2): an alternative rotation including grain legumes.

The studied crop rotations are given in Tab. 1 and Fig. 1.

Tab. 1: Overview of the crop rotations compared in the four study regions. GL = grain legumes, OSR = oilseed rape, W = winter wheat, wB = winter barley, sB = spring barley, P = spring peas, wP = winter peas, M = grain maize, SB = soya bean, SF = sunflower, (cc) = catch crop (*Phacelia*). The replaced crops are shown in bold.

Region	Crop rotation 1 (without GL)	Crop rotation 2 (with GL)
Saxony-Anhalt (D)	OSR-W-**W**-W-wB	OSR-W-**P**-W-wB
Barrois (F)	OSR-W-W-wB	OSR-W-**wP**-W-wB
Canton Vaud (CH)	OSR-W-(cc)**M**-W-OSR-W-(cc)**M**-W	OSR-W-(cc)**P**-W-OSR-W-(cc)**SB**-W
Castilla y León (E)	**SF**-W-wB-sB	**P**-W-wB-sB

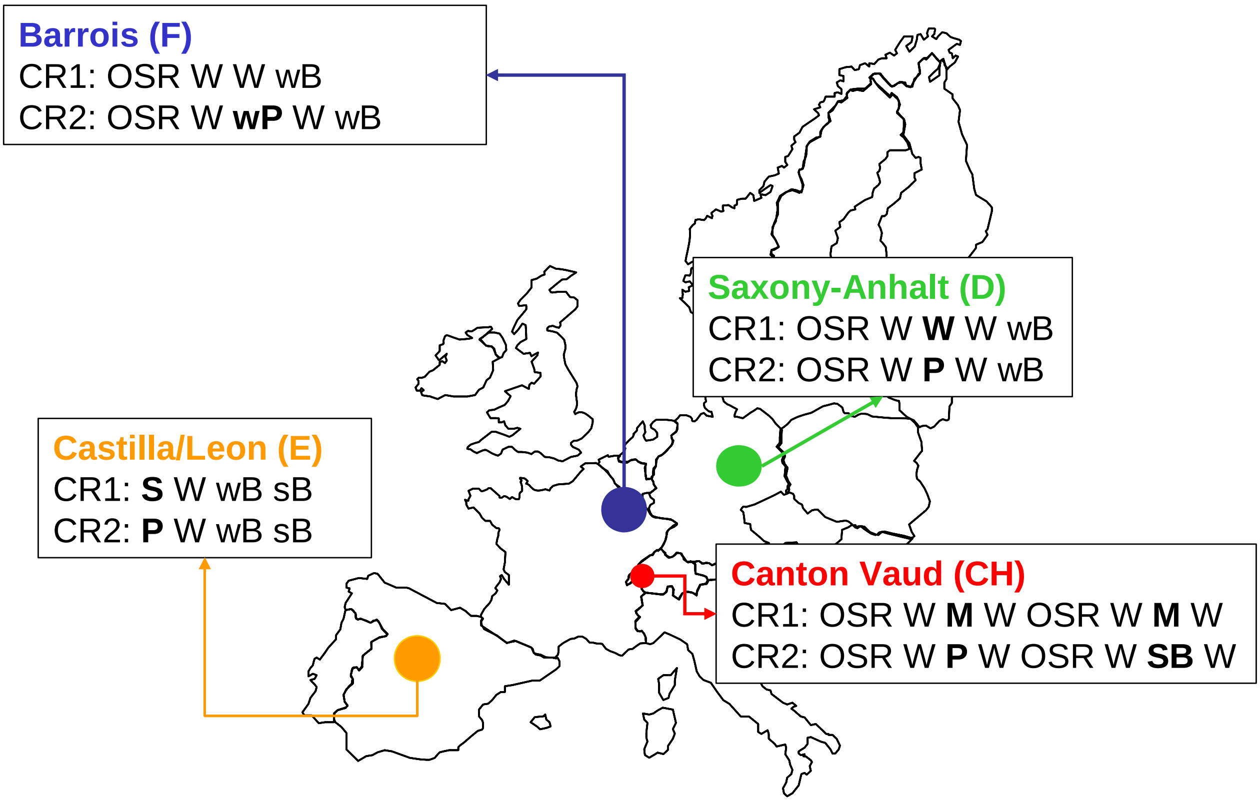

Fig. 1: Overview of the crop rotations compared in the four study regions. OSR: Winter rape seed, W: Winter wheat, wB: Winter barley, sB: Spring barley, P: Spring peas, wP: Winter peas, M: Grain maize, S: Sunflower. The replaced crops are shown in bold.

2.1.3 System Definition and Boundary

The system boundary is set at the farm gate. This is in analogy with the life cycle assessment (LCA) study by Nemecek *et al.* (2005). The considered system includes all inputs and processes required to deliver a storable product at the farm gate. Grain drying is included, whenever necessary, in order to obtain a storable product.
The following items in particular were included (see also Fig. 2):

- *Infrastructure*: manufacturing and maintenance of machinery and buildings (shed to house the machines).
- Operation of the *machines* (including fuel delivery and combustion)
- Fertilisers (in the case studies only mineral fertilisers were included, assuming that the farm has no livestock)
- *Pesticide production*
- All *field operations*: soil tillage, seedbed preparation, sowing, fertilisation, plant protection, harvest, stubble cultivation, transport to the farm and grain drying
- *Direct field emissions*: nitrate, ammonia, nitrous oxide, phosphorus, heavy metals and pesticides.

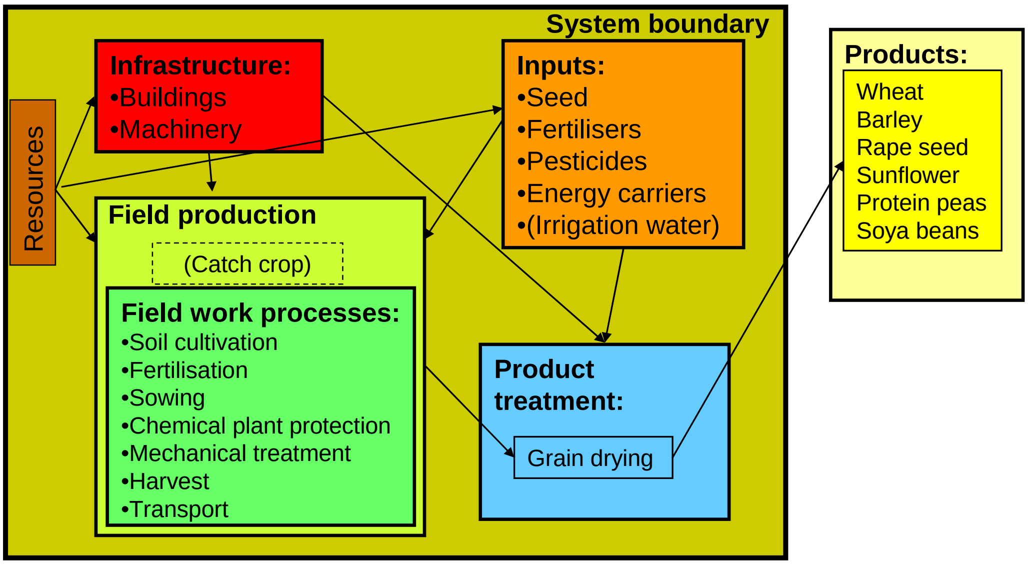

Fig. 2: Description and delimitation of the system investigated.

Temporal system boundary: the LCA starts with the first and ends with the last crop in the crop rotation[1]. The calculation begins after the harvest of the crop preceding the first crop and ends with the harvest of the last crop in the rotation. Stubble cultivation is counted to the harvested crop. Any period between the harvesting of a crop and soil tillage or sowing of the next crop is attributed to the next crop.

2.1.4 Functions and Functional Units

As agriculture is multifunctional, we need to consider several functions. Three functions are used according to Nemecek *et al.* (2005):

1. *Land management function*: this describes the cultivation of land so as to minimise the environmental impacts per area and time unit. This is usually achieved by minimising the land use intensity. This function mainly reflects the perspective of society, to preserve land for agricultural production.
2. *Productive function*: this activity aims at producing food, feed or biomass for other uses (bioenergy, renewable materials). The goal is to minimise the environmental impacts per product unit. This function mainly reflects the perspective of the consumers.
3. *Financial function*: from the perspective of the farmer, income is the main motivation for agricultural production. The goal is to minimise the environmental impacts per €.

The three functions are measured by three different functional units:

1. The land management function is measured by *hectares per year*.
2. The productive function is quantified by physical units. Nemecek *et al.* (2005) used kg dry matter (DM), MJ netto energy lactation and MJ gross energy of the products. We chose *MJ gross energy* of the products as the functional unit. This unit is informative for animal nutrition as well as for human consumption. Kg DM is not suited here, since the crop rotations considered include the oil crops rape seed and sunflowers, which have low yields and high energy concentrations. MJ netto energy lactation is not relevant for the systems considered, since the use of the products for dairy cows is of minor importance.
3. For the financial function, the *gross margin 1* (expressed in €) is used (total receipts minus the direct production costs). The prices and subsidies correspond to the "Agenda 2000" of the Common Agricultural Policy (see von Richthofen *et al*. 2006).

---

[1] Note that the definition of the first crop in the crop rotation is quite arbitrary. It is assumed that the crop rotation forms a closed cycle, i.e. the first crop follows the last crop.

This decision was taken for the LCA study in order to be comparable with the economic study.

2.1.5 Allocation Procedures

Since no co-products result from the systems investigated, no allocation for co-products is required. Straw is not harvested, in line with the assumption that the farm has no livestock. The restitution of nutrients from incorporated crop residues is considered according to Tab. 4.

Allocation for shared infrastructure was performed following the procedures described in Nemecek *et al.* (2004 & 2005).

2.2 Comparison of Feed Formulas

2.2.1 Goal of the Study

The goal of the LCA study of feed formulas is to assess the environmental impacts of pig feed where the protein sources are either soya beans of South American origin or grain legumes (e.g. field peas) of European provenance.

2.2.2 Study Region and Feed Formulas

For the LCA case study of feed formulas the feed mill is located in Münster, a city in North Rhine-Westphalia (NRW), Germany. Two feed formulas for fattening pigs (three-phase feeding), i.e. a pre-fattening feed (28 – 40 kg), an initial fattening feed (40 – 60/70 kg) and a final fattening feed (60/70 – 117 kg), were defined by a feeding expert at the Chamber of Agriculture of North Rhine-Westphalia (LWK NRW), Dr. W. Sommer. For each feed type there is a formula based on soya bean meal and cereals (SOY) and an alternative based on field peas, rape seed meal, soya bean meal and cereals (PEA). The two alternatives have equivalent growth potential for pig fattening (Tab. 2). Due to the piglets' nutritional requirements the pea formulas for the pre-fattening and initial fattening phases contain a small amount of soya bean meal.

The region was chosen because NRW is one of the most important pig production areas in Germany with more than 20% of the German national pig production (Crépon *et al.*, 2005). Due to this fact, several feed mills are located in the area.

Tab. 2: Composition of the pig feed formulas considered. Ingredients are expressed in % of the feed composition. SOY: Feed formula based on soya bean meal and cereals; PEA: Feed formula based on field peas, rape seed meal, soya bean meal and cereals.

Feed type **Feed ingredients (in % of 1 kg feed)**		**Pre-fattening** 28 - 40 kg		**Initial fattening** 40 - 60/70 kg		**Final fattening** 60/70 - 117 kg	
		SOY	**PEA**	**SOY**	**PEA**	**SOY**	**PEA**
peas	%	-	10	-	15	-	20
soya bean meal	%	21	13.5	18	8	11	-
rape seed meal	%	-	5	-	6	-	4
barley	%	40	25	40	25	47	30
wheat	%	36	43.5	39	43	39	43
sum of cereals	%	76	68.5	79	68	86	73
mineral feed	%	3 (III)	3 (I)	3 (III)	3 (I)	3 (IV)	3 (II)
each kg feed contains							
crude protein	%	18.0	18.0	17.1	17.0	14.8	14.5
energy	MJ ME	13.0	13.0	13.0	13.0	13.0	13.0
phosphorus	%	0.48	0.50	0.47	0.50	0.45	0.46
lysine	%	1.05	1.05	0.99	1.00	0.83	0.83
methionine	%	0.63	0.65	0.61	0.62	0.52	0.52
threonine	%	0.62	0.64	0.59	0.60	0.50	0.50
tryptophane	%	0.22	0.21	0.21	0.19	0.18	0.16
lysine/energy	g/ MJ ME	0.81	0.81	0.76	0.77	0.64	0.64

2.2.3 System Definition and Boundary

A cradle-to-gate approach has been chosen. The system encompasses inputs into agricultural production (i.e. seeds, fertilisers, pesticides, fuel, etc.), infrastructure (buildings, machinery and equipment), the agricultural production of feed ingredients, all transport, processing and storage and ends with different feed formulas for pig fattening (Fig. 3).

The basic information for the design of this case study are taken from a report on a meeting between J.S. von Richthofen, proPlant GmbH, and H. Jebsen, head of the Feed Department (purchase of commodities) at AGRAVIS Raiffeisen AG (von Richthofen J.S., proPlant GmbH, Münster (D) personal communication, 2005). Details of the origin of the feed components and the transport distances are shown in Appendix 1.

The system boundary is set at the feed mill gate.

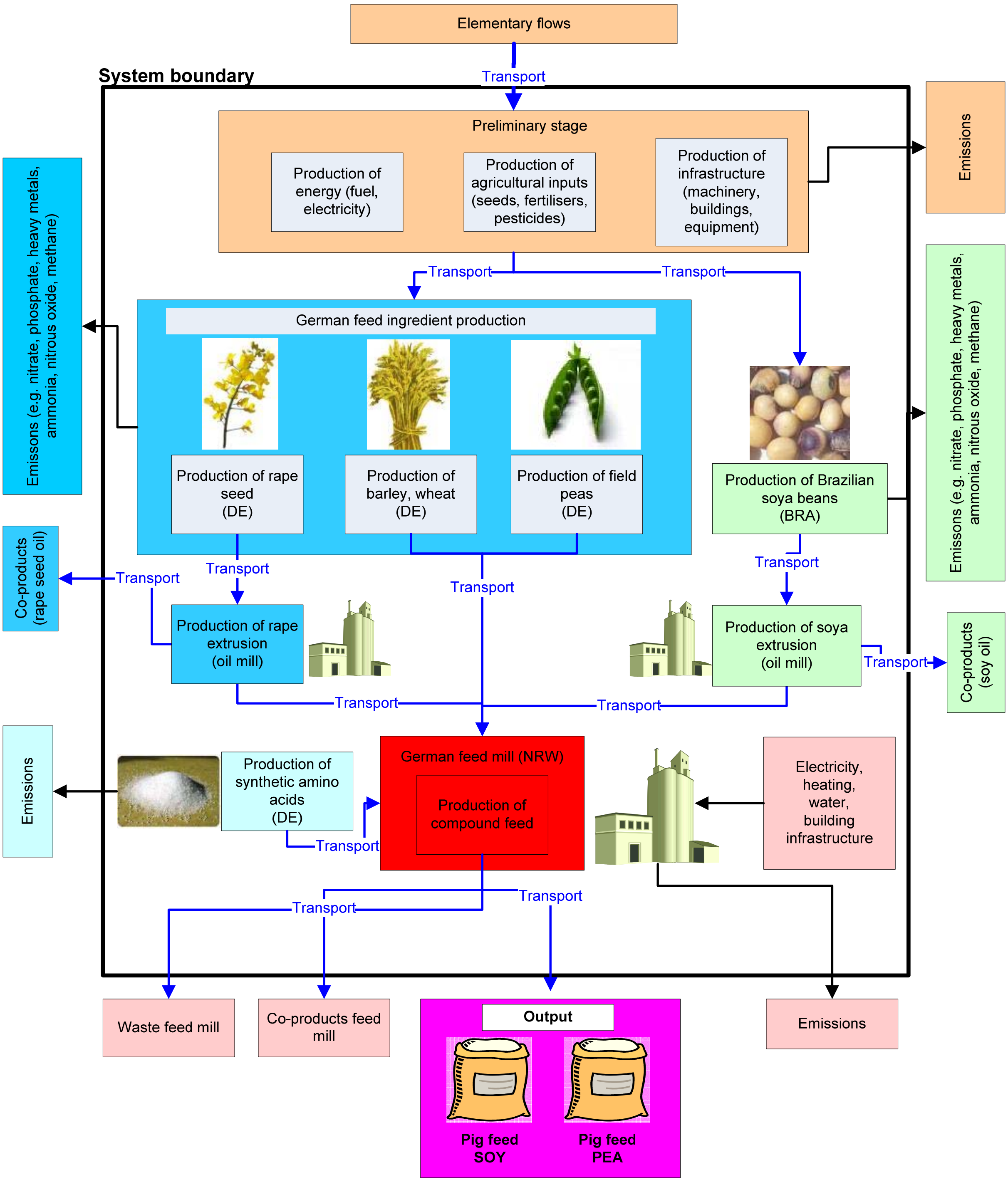

Fig. 3: Description and delimitation of the pig feed study

2.2.4 Function and Functional Unit

Agriculture has different functions for society and the environment as described in 2.1.4. The LCA study of feed formulas focuses on the productive function of agriculture, i.e. the production of feedstuff in this case.

The functional unit is 1 kg of pig feed at the feed mill gate.

For this study the choice of 1 kg of crude protein as the functional unit would not be appropriate as the compared feeds are equal in energy content, similar in crude protein content and cover the animals' requirements as regards protein quality (see Tab. 2). In addition, the focus of the study is on the replacement of South American soya beans by European grain legumes considering their entire feeding value and not just their use as a source of proteins.

2.2.5 Allocation Procedures

Some feed ingredients are co-products (e.g. soya bean meal, rape seed meal) of processes producing more than one product (oil and meal). The allocation for their resource use and emissions is based on the mass of the products for raw material production as well as transport and the economic value of the products for processing. We argue that transport (and therefore the associated emissions) is closely related to the mass of the transported goods, whereas in the process of pressing seeds the inputs used and the resulting outputs are linked to the economic interest of extracting oils (and obtaining their co-products). Therefore the economic allocation is applied. An exception is hexane, a solvent which is uniquely used to maximise the oil yield. Therefore it is fully part of the oil extracting process.

Since transport is allocated according to the mass principle, the exact location of the oil or feed mill is not relevant and does not influence the results.

The allocation factors used are given in Tab. 3.

A sensitivity analysis for the allocation factors is performed in Chapter 6.2.3.

Tab. 3: Allocation factors in pig feed study

Product / process	Unit	**Soya**		**Oil seed rape**		**Allocation**
		oil	meal	oil	meal	
soya	[kg]	18%	82%			mass
oil seed rape	[kg]			42%	58%	mass
hexane	[kg]	100%	0%	100%	0%	no allocation [2]
electricity	[MJ]	33%	67%	69%	31%	economic
fuel oil	[MJ]	33%	67%	69%	31%	economic
natural gas	[MJ]	33%	67%	69%	31%	economic
water	[m3]	33%	67%	69%	31%	economic
hexane emission in air	[kg]	100%	0%	100%	0%	mass
waste	[kg]	33%	67%	69%	31%	economic
sewage	[m3]	33%	67%	69%	31%	economic
transport lorry	[km]	18%	82%	42%	58%	mass
transport rail	[km]	18%	82%	42%	58%	mass
transport barge	[km]	18%	82%	42%	58%	mass
transport vessel	[km]	18%	82%	42%	58%	mass [2]

2.3 Consideration of the Crop Residues

The crop residues need special attention when calculating the LCA. Part of the nutrients in the fertilisers is exported by the products and another part remains in the crop residues and is restored to the soil. These nutrients are fully or partly available to the following crop and therefore the fertiliser rate applied to the following crop can be reduced. In the same way the crop receives nutrients from the preceding crop, which reduces its fertiliser requirements. This also includes the preceding effect of grain legumes.

Two different procedures were applied to the two parts of the study:

- The study of crop rotations reflects the practice of farmers in the region. Therefore the effective fertiliser rates are used in the calculations as shown in Tab. 4. Furthermore, this method of calculation is congruent with the procedure applied in the economic analysis and ensures comparability of the economic and environmental studies. As we are considering the whole crop rotations, these effects do not matter and do not influence the total result of the crop rotation.
- In the feed formula study, this calculation procedure would not be appropriate, since we are dealing with individual crops or raw materials and not the whole crop rotation. There would be a bias, since the crop residues are a direct consequence of growing a crop and should therefore be attributed to the crop producing them. For this reason, the fertiliser effect of crop residues was attributed to the crop causing it. The procedure (Tab. 4) is analogous to the one applied in Nemecek *et al.* (2005).

---

[2] Hexane is solely used for the oil extracting process. Therefore it is fully attributed to the oil.

Tab. 4: Procedure for calculating the nutrients in the crop residues in the two studies. NR = nutrient requirement, CR = nutrients in crop residues, FR = fertiliser rate.

	Crop1	Crop2	Crop3	Crop4
Nutrient requirement	**NR1**	**NR2**	**NR3**	**NR4**
Nutrients in crop residues	**CR1**	**CR2**	**CR3**	**CR4**
Fertiliser rate crop rotation study	**FR1=NR1-CR4**	**FR2=NR2-CR1**	**FR3=NR3-CR2**	**FR4=NR4-CR3**
Fertiliser rate feed formula study	**FR1=NR1-CR1**	**FR2=NR2-CR2**	**FR3=NR3-CR3**	**FR4=NR4-CR4**

2.4 Data Quality Requirements

For the assessment of data quality requirements we distinguish between production inventories and life cycle inventories.

Production inventories are technical, agricultural descriptions of the production systems. They include specifications on the type and quantity of the inputs used, type and date of the measures taken and the outputs of the different systems.

Data quality requirements are defined for time-related coverage, geographical coverage and technology coverage:

- Time-related coverage: Data should not be older than five years and production data should cover an entire year of production. Fluctuating data are derived from statistics for the last three to five years, whenever possible.
- Geographical coverage: Data were collected at the level of their action, i.e. in this study on a regional level.
- Technology coverage: Generally the aim was to have data as close as possible to the system studied. Examples are production aspects of the crops or of the feed mill. If the actual type of data was not available, then data from the closest corresponding type were used.

Life cycle inventories: The life cycle inventories are taken from the ecoinvent database version 1.2 (corrected version of ecoinvent data v1.1; ecoinvent Centre, 2004).

Details of the properties of the life cycle inventories are given by Frischknecht *et al.* (2004a).

2.5 Critical Review

The SALCA methodology used for the calculation of the crop rotation study was critically reviewed by Prof. U. Köpke, University of Bonn, within the framework of the project “Life cycle assessment of Swiss farming systems for arable crops and forage production” in December 2005 (see Nemecek *et al.* 2005). This critical review also covered the application of the method to crop rotations.

Furthermore, the life cycle inventories from the ecoinvent database have undergone an internal review by another institute participating in the project. The datasets on agriculture have been reviewed by EMPA in St. Gallen.

As these two important parts of the study have already been reviewed, no further critical review has been performed for this study.

3 Life Cycle Inventory Analysis

3.1 Data Collection for LCA of Crop Rotations

3.1.1 Production Inventories

The production inventories, i.e. agronomical-technical description of the cropping systems, were taken from the common data collection of the economic and environmental analyses in the GL-Pro project. This means that the two studies are based on an identical dataset and therefore are directly comparable.
The datasets are described in von Richthofen *et al.* (2006).

3.1.2 Life Cycle Inventories

Life cycle inventories of infrastructure, inputs and processes were taken from the ecoinvent database version 1.2 (Frischknecht *et al.* 2004a, Nemecek *et al.* 2004).

3.1.3 Estimation of Direct Field Emissions

Various direct field emissions were estimated by means of models according to the SALCA method (see Gaillard *et al.* 2006 and Nemecek *et al.* 2005). Only a brief overview is given below, mentioning the main aspects relevant to this report. Please refer to the cited sources for further information.

- *Ammonia* (NH_3): The losses are estimated from the quantity of nitrogen fertilisers and fixed emission factors according to Menzi *et al.* (1997). The emission factors are dependent on the type of fertiliser, ranging from 2% to 15%.
- *Nitrous oxide* (N_2O): direct and induced emissions are considered (according to the IPCC method (Schmid *et al.* 2000). Direct emissions stem from the application of nitrogen fertiliser (factor 1.25% of N released as N_2O), incorporation of crop residues (1.25% of the N released as N_2O) and symbiotic nitrogen fixation. For the latter, 60% of the N in the shoot of grain legumes were considered to come from symbiotic nitrogen fixation (according to Schmid *et al*. 2000). This quantity was multiplied by an emission factor of 1.25% to obtain an estimate of the nitrous oxide emissions. In addition to the direct emissions, induced emissions from ammonia and nitrate losses were considered. The respective factors are 1% for ammonia-N and 2.5% for nitrate-N.
- *Phosphorus*: three paths of P emissions to water were included, namely run-off (as phosphate) and erosion (as phosphorus) to rivers as well as leaching to ground water (as phosphate). The land-use category, the type of fertiliser, the quantity of P spread and characteristics and duration of soil cover (for erosion) were considered. The model used is described in Prasuhn (2006).
- *Nitrate* (NO_3^-): nitrate leaching was estimated on a monthly basis by accounting for N mineralisation in the soil and N-uptake by the vegetation (specific to each crop). If mineralisation exceeds uptake, nitrate leaching can potentially occur. In addition, a risk of nitrate leaching from fertiliser application during unfavourable periods was calculated, taking into account the crop, month of application and the potential rooting depth. The model assumes a 15% increase of N mineralisation in six months after incorporation of the crop residues. It calculates the potential leaching rate in a first step. In a second step, the effective leaching rate is estimated by taking the precipitation during winter into account (October to March). The highest risk of nitrate leaching occurs during the winter period and depends on the amount of seepage, which in turn depends on the precipitations during winter. The transformation factor according to Richner *et al.* (2006) was therefore corrected according to the precipitation during the winter months October to March. The method is described in Richner *et al.* (2006).

- *Heavy metal emissions* were assessed by an input-output balance. The following inputs are considered: seed, fertilisers and pesticides. The outputs included are the harvested products, erosion and leaching. The quantities lost to water bodies by erosion or leaching are only partly considered, since the farmer only partly controls these processes. The allocation factor is derived from the share of the agricultural inputs in the total inputs (including deposition). The model is described by Freiermuth (2006).
- *Pesticide emissions* were calculated as emissions into agricultural soil.

3.2 Data Collection for LCA of Feed Formulas

3.2.1 Production Inventories

As for the LCA study of crop rotations, the production inventories, i.e. agronomical-technical description of the cropping systems for wheat, barley, oilseed rape and field peas, were taken of the data collection of the economic and environmental analyses in the GL-Pro project for the Saxony-Anhalt region.

The origin of the feed ingredients and the transport distances are given in Appendix 1.

The production inventory for soya beans from Brazil was compiled for this purpose by Agroscope Reckenholz-Tänikon Research Station ART. It is based on data from literature (Cederberg & Flysjö 2004; Ostermayer *et al.* 2002; www.ncfap.org; USDA, 2006; www.worldweather.org). The main figures used are given in the Appendix 2.

3.2.2 Life Cycle Inventories

Life cycle inventories of infrastructure, inputs and processes were taken from the ecoinvent database version 1.2 (Frischknecht *et al.* 2004a, Nemecek *et al.* 2004). This concerns especially transport, oil and feed mill.

3.2.3 Estimation of Direct Field Emissions

The various direct field emissions for the LCA of feed formulas are calculated using the same models as for the LCA of crop rotations (see 3.1.3).

3.3 Calculation Procedures / Tool

The LCA of crop rotations is performed with the SALCA-crop tool version 2.02 (as in Nemecek *et al.* 2005). The tool consists of modules programmed in Microsoft EXCEL® and a system implemented in the TEAM™ software (Version 4.0) from PriceWaterHouse Coopers/Ecobilan, Paris, France.

The LCA of feed formulas was calculated by a tool in TEAM built for this purpose.

4 Life Cycle Impact Assessment

Within the framework of the SALCA method (Gaillard *et al*. 2006), a selection of relevant impact categories and impact assessment methods has been made for the study of agricultural systems. The selection is based on mid-point categories, mainly from the methods EDIP97 (Hauschild & Wenzel 1998) and CML01 (Guinée *et al.* 2001).
The following environmental impacts are considered:

- Demand for non-renewable *energy resources* (oil, coal and lignite, natural gas and uranium), using the upper heating or gross calorific value for fossil fuels according to Frischknecht *et al.* (2004b).
- *Global warming potential* over 100 years (according to IPCC 2001).
- *Ozone formation* potential (so-called “summer smog” according to the EDIP97 method, Hauschild & Wenzel 1998)
- *Eutrophication* potential (impact of the losses of N and P to aquatic and terrestrial ecosystems, according to the EDIP97 method, Hauschild & Wenzel 1998)
- *Acidification* potential (impact of acidifying substances released into ecosystems, according to the EDIP97 method, Hauschild & Wenzel 1998)
- *Terrestrial ecotoxicity* potential (impact of toxic pollutants on terrestrial ecosystems, according to the EDIP97 method, Hauschild & Wenzel 1998)
- *Aquatic ecotoxicity* potential (impact of toxic pollutants on aquatic ecosystems, according to the EDIP97 method, Hauschild & Wenzel 1998)
- *Human toxicity* potential (impact of toxic pollutants on human health, according to the CML01 method, Guinée *et al.* 2001)

In addition to these classical impact categories, two new categories with high relevance for agricultural systems were considered:

- *Biodiversity*: the SALCA-biodiversity method (Jeanneret *et al.* 2006) assesses the impacts of cultivation practices on eleven groups of indicator organisms, by considering two characteristics (total species richness and species with high ecological requirements).
- *Soil quality*: the SALCA-soil quality method assesses the impacts of cultivation practices on nine soil quality indicators, representing physical, chemical and biological properties of the soil (Oberholzer *et al.* 2006).

The impact on biodiversity and soil quality could only be calculated for the case study in Canton Vaud (CH), since the parameterisation and plausibility test were carried out only under Swiss conditions.

As the assessment of the impacts on ecotoxicity is highly dependent on the choice of the impact assessment method, we also show the results of the alternative method CML01.
According to Nemecek *et al*. (2005) ecotoxicity points were used instead of the original units, to facilitate communication of the results. Note that the definition of the ecotoxicity points differs between the two methods, therefore the results are not comparable in absolute terms. The following definitions apply to this study:

- EDIP97: 1 aquatic ecotoxicity point = 1000 m^3 water
- EDIP97: 1 terrestrial ecotoxicity point = 1000 m^3 soil
- CML01: 1 aquatic ecotoxicity point = 1 kg 1,4 DCB-eq
- CML01: 1 terrestrial ecotoxicity point = 1 kg 1,4 DCB-eq
- CML01: 1 terrestrial ecotoxicity point = 1 kg 1,4 DCB-eq

For the detailed representation of the results, four impact categories were chosen:

- energy demand,
- global warming potential,
- eutrophication potential,
- terrestrial ecotoxicity potential (according to EDIP97).

The choice is based on the correlation between the different impact categories. Nemecek *et al.* (2005) have shown that – based on the correlations – three groups of impact categories could be distinguished (five including biodiversity and soil quality). The three groups are: resource management, nutrient management and pollutant management. Energy demand and global warming were chosen as representative of the first group, eutrophication for the second and terrestrial ecotoxicity for the third group.

5 Life Cycle Interpretation

There is a need to assess the differences between the scenarios compared. Are they significant and relevant? The LCA calculations are subject to various sources of uncertainty (see Nemecek *et al.* 2005). A full analysis of statistical significance is not feasible, because the uncertainty of many of the parameters is unknown.

The assessment of the differences between the two crop rotations (CR1: without grain legumes and CR2: with grain legumes) has been performed by classes. This helps the reader easily to detect the relevant differences. We used the assessment classes given by Nemecek *et al.* (2005) for single crops and adjusted them for the fact that only one crop out of four or five was changed in the crop rotation (Tab. 5).

The same assessment classes were also used in the comparison of feed formulas (Chapter 6.2).

Tab. 5: Assessment of the differences between the two crop rotations by classes.

Class	**Resource management**	**Nutrient management**	**Pollutant management**	**Biodiversity**
very favourable	< 88.9%	< 80.0%	< 72.7%	> 103.8%
favourable	88.9% - 96.0%	80.0% - 92.3%	72.7% - 88.9%	103.8% - 101.3%
similar	96.0% - 104.2%	92.3% - 108.3%	88.9% - 112.5%	101.3% - 98.8%
unfavourable	104.2% - 112.5%	108.3% - 125.0%	112.5% - 137.5%	98.8% - 96.4%
very unfavourable	> 112.5%	> 125.0%	> 137.5%	< 96.4%

6 Results

6.1 Comparison of Crop Rotations

The analysis is performed per area unit (ha per year) in a first step. In a second step the impacts are also evaluated per GJ gross energy and per € gross margin 1.
By way of example, the analysis is carried out and discussed in more detail for the Saxony-Anhalt region. For the other three regions we focus mainly on those aspects that are different in order to avoid too many repetitions. A sensitivity analysis for three parameters is performed for the Saxony-Anhalt region only.

6.1.1 Saxony-Anhalt (D)

Resource Management

The demand for non-renewable energy resources (Fig. 4) is reduced by 14% per area unit in the alternative crop rotation (CR2). This difference is caused by three factors:

- The pea crop as a legume does not need any nitrogen fertilisation. Therefore the energy demand of the category "Fertilisers and nutrients" is substantially lower for peas, since only P- and K-fertilisers are required. The manufacturing of nitrogen fertilisers is a very energy-consuming process (Nemecek & Erzinger 2005).
- The amount of nitrogen applied to the wheat crop following peas is reduced. In CR1 the third wheat crop receives 180 kg N/ha, in CR2 only 157 kg N/ha. This saving also results in a reduced consumption of energy resources.
- Soil tillage is reduced as well. It is assumed that the soil is cultivated by plough in CR1 and by cultivator in CR2. Ploughing requires high tractor power and results in significant diesel consumption.

Therefore the introduction of peas into the crop rotation (in this case) leads to a significant reduction in fossil fuel consumption. The reduction of 14% is substantial, since we exchanged only one crop out of five (theoretical potential of 20%).

The impact on climate change (global warming over 100 years, Fig. 5) is dominated by carbon dioxide (CO_2) and nitrous oxide (N_2O). Both emissions are reduced in CR2 compared to CR1, which is explained by the lower use of N-fertilisers and machinery. However, the difference between the two crop rotations is only 11%, which is less than the difference in the energy demand. The reason lies in the induced emissions of nitrous oxide (N_2O), a highly effective greenhouse gas, and in N_2O emissions related to symbiotic nitrogen fixation (SNF). According to the IPCC method emissions of ammonia, nitrate and nitrogen oxides cause emissions of nitrous oxide (Schmid *et al.* 2000), which can be quite significant. Since the nitrate losses are slightly higher in CR2 than in CR1 according to the model calculations, the total emissions of nitrous oxide are not reduced to the same extent as the quantity of N-fertiliser. Furthermore, the IPCC method assumes an emission of N_2O related to SNF.
We performed a sensitivity analysis for certain factors, as some of the emission coefficients are highly uncertain (see Chapter 6.1.2).

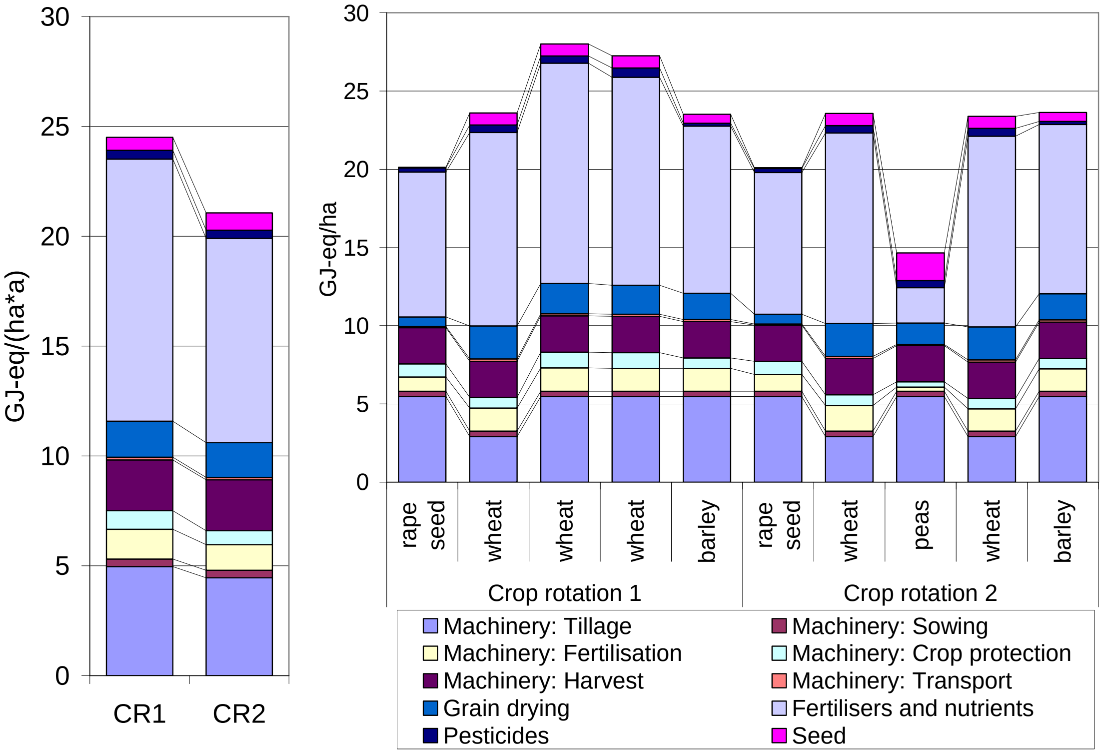

Fig. 4: Demand for non-renewable energy resources of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Saxony-Anhalt (D).

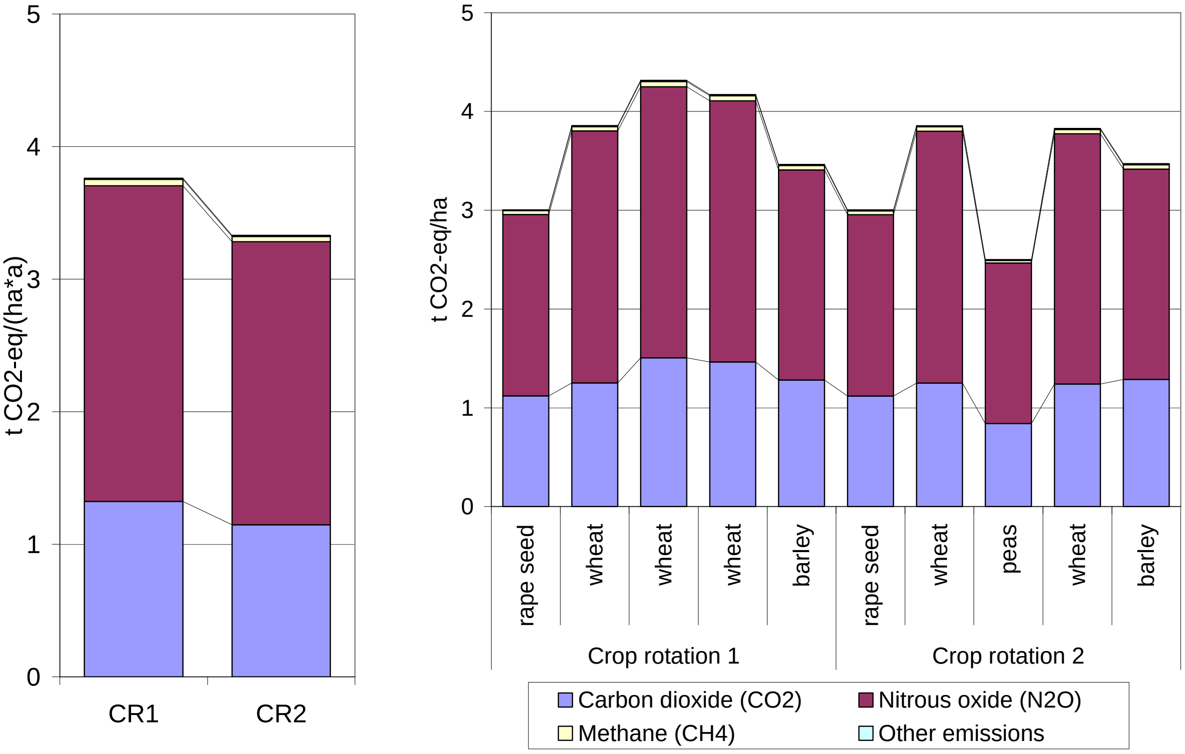

Fig. 5: Global warming potential over 100 years of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Saxony-Anhalt (D).

Nutrient Management

The eutrophication potential (Fig. 6) of the two crop rotations is a result of two contrary effects:

- On the one hand, nitrate leaching is slightly increased by 4% after the introduction of peas according to the model calculation. This results from three factors with diverging consequences:
  1. The reduction in the number of nitrogen applications and the total quantity of nitrogen fertiliser over the crop rotation does not substantially reduce the risk of nitrate leaching, because the N-applications occur in phases of rapid plant growth and therefore do not normally engender nitrate losses (Richner *et al*. 2006).
  2. In CR2 spring peas are introduced instead of winter wheat. This leads to a significantly longer period of bare soil (August to March) than when winter wheat is sown. This increases the risk of nitrate leaching.
  3. The amount of mineral nitrogen in the soil is higher after peas than after wheat, partly due to the pea's relatively shallow root system. Furthermore, pea straw contains more nitrogen than wheat straw and its decomposition leads to higher N mineralisation. Therefore nitrate leaching under the wheat following peas is higher than under wheat following wheat (Jensen 1997).
- On the other hand, all other nitrogenous emissions are lower for CR2. This applies to the losses of ammonia (-26%), nitrous oxide (-10%) and nitrogen oxides (-11%). The reasons are the lower quantity of N-fertilisers and – in the case of NO_x – also the lower use of machinery.

Phosphorus emissions play a minor role for the combined eutrophication potential. Since the quantities of P hardly differ between the two crop rotations, there is no difference in the total P-losses.

In total, the eutrophication potential is similar (-2%) for the two crop rotations. Chapter 6.1.2 gives results for the sensitivity analysis regarding the eutrophication potential.

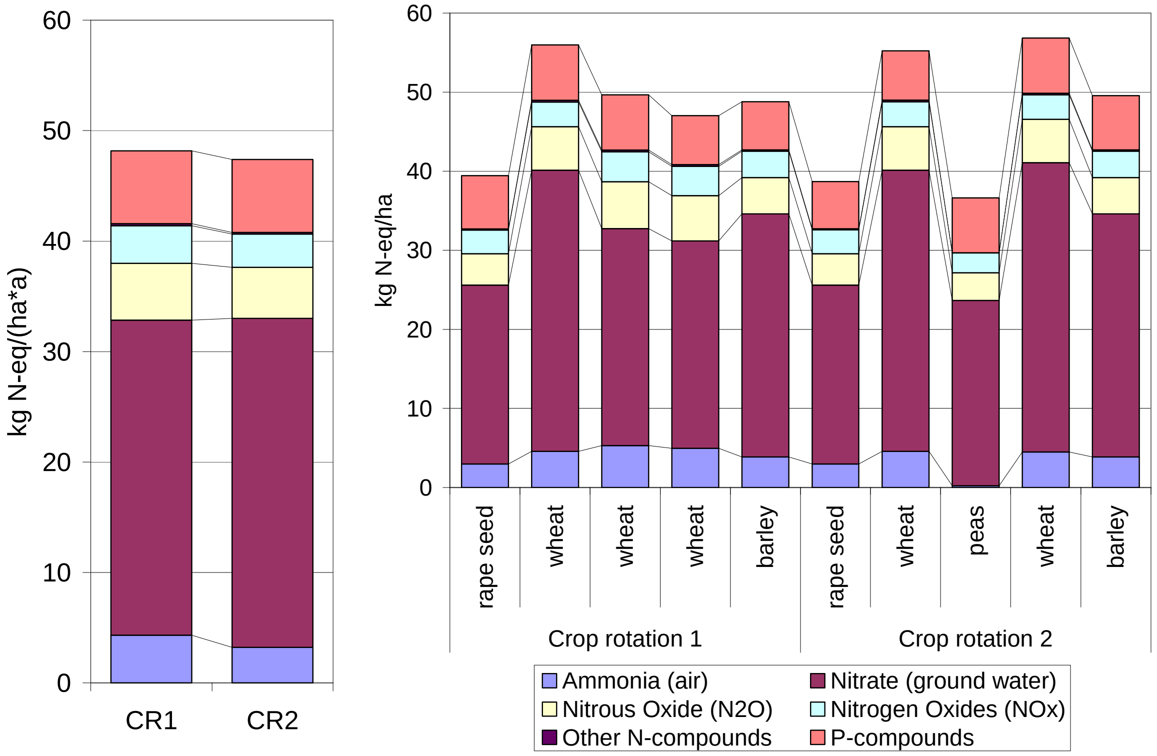

Fig. 6: Eutrophication potential (combined potential of N and P) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Saxony-Anhalt (D).

Pollutant Management

The terrestrial ecotoxicity potential (according to EDIP97, Fig. 7) is dominated by fungicides and insecticides; the other categories do not play a significant role. The most important active ingredient is the cereal fungicide propiconazole. The following insecticides contribute to terrestrial ecotoxicity as well: lambda-cyhalothrin (all crops), cypermethrin in rape seed and pirimicarb in peas. The terrestrial ecotoxicity potential is significantly lower for CR2 compared to CR1. On the one hand, the amount of pesticides used in the wheat following peas (CR2) was reduced compared to the third wheat in CR1. Furthermore, the products applied in peas seem to be less problematic than those in wheat.

This result is also confirmed by the alternative method CML01 (Tab. 6), although the differences between the two crop rotations are smaller with this method.

For the assessment of toxicity in general we should keep in mind that this is a difficult matter, associated with a high uncertainty. Therefore the results for toxicity have to be interpreted with great care. Furthermore, the ecotoxicity potential is in general dominated by a few active ingredients. Therefore the choice of product is crucial for the results and exchanging one product for another can give a completely different impact.

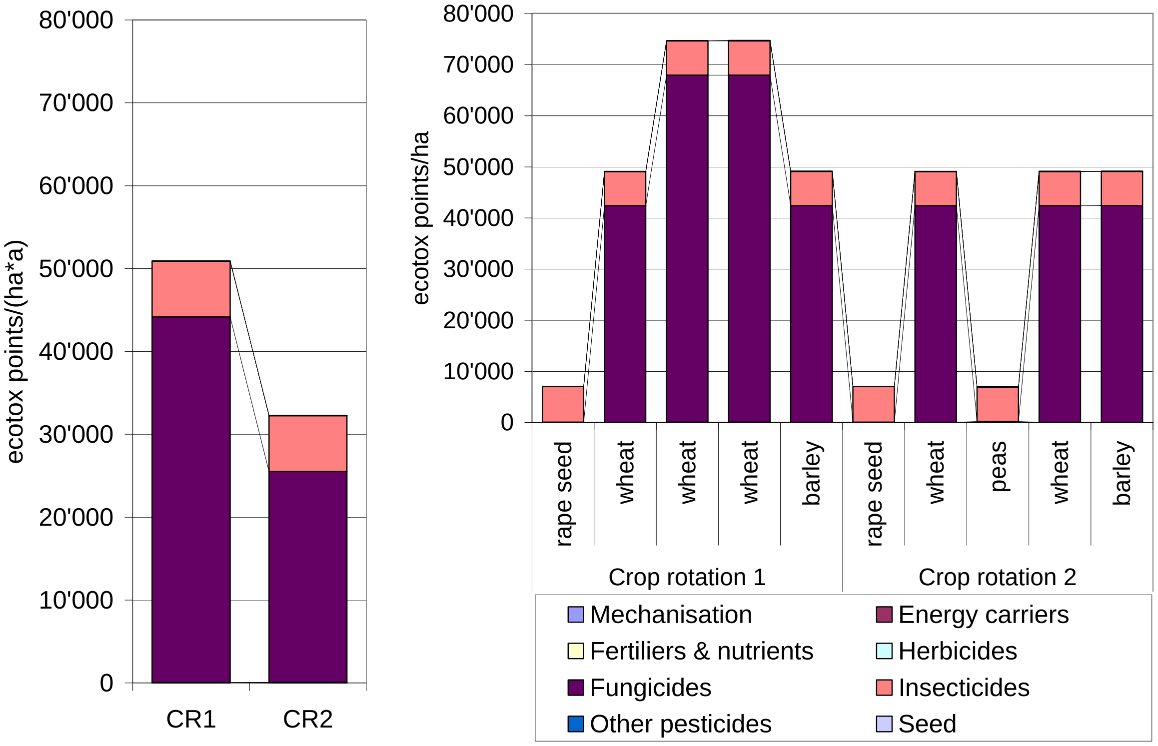

Fig. 7: Terrestrial ecotoxicity potential (EDIP) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Saxony-Anhalt (D).

Summary of the Results

Tab. 6 gives a general overview of the results for the three functional units. CR2 shows a generally positive result per ha for energy demand, global warming, ozone formation (which is mainly related to the use of machinery), acidification (dominated by ammonia and therefore closely related to the use of N-fertilisers), terrestrial ecotoxicity and human toxicity.

Since gross margin 1 is 5% higher in CR2 compared to CR1, the result is even more favourable related to the financial function.

On the contrary, the differences are smaller for the productive function (unit GJ gross energy), yet still the positive assessment prevails. This is due to the fact that the average yield of wheat is 7.4 t/ha in Saxony-Anhalt and thus almost twice as high as the yield of peas (3.8 t/ha) and therefore the production of gross energy is lower in CR2 than in CR1. The lower yield of peas is partly compensated by the yield increase of the wheat that follows. Nevertheless, the energy efficiency is 8% better in CR2 than in CR1, which means that less fossil energy is used to produce one unit of gross energy in biomass. In CR1 this value is 0.227 GJ-eq/GJ gross energy and in CR2 0.21 GJ-eq/GJ gross energy. We should keep in mind that the form of energy is completely different: the energy demand refers to fossil and nuclear energy resources, the gross energy yield refers to transformed solar energy.

Tab. 6: Overview of the environmental impacts of the crop rotation without (CR1) and with (CR2) grain legumes in Saxony-Anhalt (D) for the three functional units. See Tab. 5 for an explanation of the colour coding.

	per ha and year			**per € gross margin 1**			**per GJ gross energy yield**		
Summary of the impacts:	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**
energy demand [GJ-eq]	2.45E+1	2.11E+1	86%	3.81E-2	3.12E-2	82%	2.27E-1	2.10E-1	92%
global warming potential [t CO2-eq]	3.76E+0	3.33E+0	89%	5.84E-3	4.94E-3	85%	3.48E-2	3.31E-2	95%
ozone formation [kg ethylene-Eq]	7.90E-1	7.09E-1	90%	1.23E-3	1.05E-3	86%	7.31E-3	7.05E-3	96%
eutrophication, combined potential N & P [kg N-eq]	4.82E+1	4.74E+1	98%	7.48E-2	7.03E-2	94%	4.46E-1	4.71E-1	106%
eutrophication, separate N potential [kg N]	4.16E+1	4.08E+1	98%	6.46E-2	6.05E-2	94%	3.85E-1	4.06E-1	105%
eutrophication, separate P potential [kg P]	9.11E-1	9.12E-1	100%	1.42E-3	1.35E-3	96%	8.44E-3	9.07E-3	107%
acidification [kg SO2-eq]	2.14E+1	1.77E+1	83%	3.33E-2	2.63E-2	79%	1.99E-1	1.76E-1	89%
terrestrial ecotoxicity EDIP [points]	5.09E+4	3.23E+4	63%	7.91E+1	4.79E+1	61%	4.72E+2	3.21E+2	68%
aquatic ecotoxicity EDIP [points]	3.85E+3	3.90E+3	102%	5.97E+0	5.79E+0	97%	3.56E+1	3.88E+1	109%
terrestrial ecotoxicity CML [points]	1.94E+2	1.93E+2	99%	3.02E-1	2.86E-1	95%	1.80E+0	1.92E+0	106%
aquatic ecotoxicity CML [points]	5.95E+2	5.71E+2	96%	9.23E-1	8.46E-1	92%	5.51E+0	5.67E+0	103%
human toxicity CML [points]	7.47E+2	6.36E+2	85%	1.16E+0	9.44E-1	81%	6.92E+0	6.33E+0	91%
Functional units				644	674	105%	108	101	93%
				€/(ha*year)			GJ/(ha*year)		

6.1.2 Sensitivity analysis for Saxony-Anhalt (D)

Some of the assumptions (presence or absence of catch crops) and emission factors (for nitrate and nitrous oxide) are uncertain, as has been clearly demonstrated in AEP (2006). Therefore we perform here a sensitivity analysis for three potentially critical aspects:

a) Introduction of a catch crop in CR2: in the standard calculation (Chapter 6.1.1) no catch crop was included. Therefore, the effect of introducing a catch crop (before peas) is tested in the sensitivity analysis.
b) Effect of increased nitrogen mineralisation after a pea harvest: according to the model (Richner *et al*. 2006), N mineralisation increases after the incorporation of pea residues. In the sensitivity analysis no such increase is calculated.
c) Effect of the emissions of nitrous oxide directly or indirectly related to symbiotic nitrogen fixation (SNF): the emissions related to SNF are set at 0 in the sensitivity analysis.

a) Effect of a Catch Crop

The introduction of a catch crop before peas reduces nitrate leaching in the winter period (-7%, Fig. 8). This shows that the problem of nitrate leaching can be effectively managed by catch crops and confirms the findings of Nemecek *et al.* (2005) that the combination of a catch crop and a spring-sown crop leads to less nitrate losses than sowing a winter crop alone.

Furthermore, the results presented indicate that the problem of nitrate leaching in this case study is mainly related to the fact that peas were sown in spring. A similar effect could be expected for other spring-sown crops, too (Carrouée *et al*. 2006).

The global warming potential was increased by sowing a catch crop (Fig. 9). This is due to the application of nitrogen at the sowing of the catch crop (30 kg N/ha).

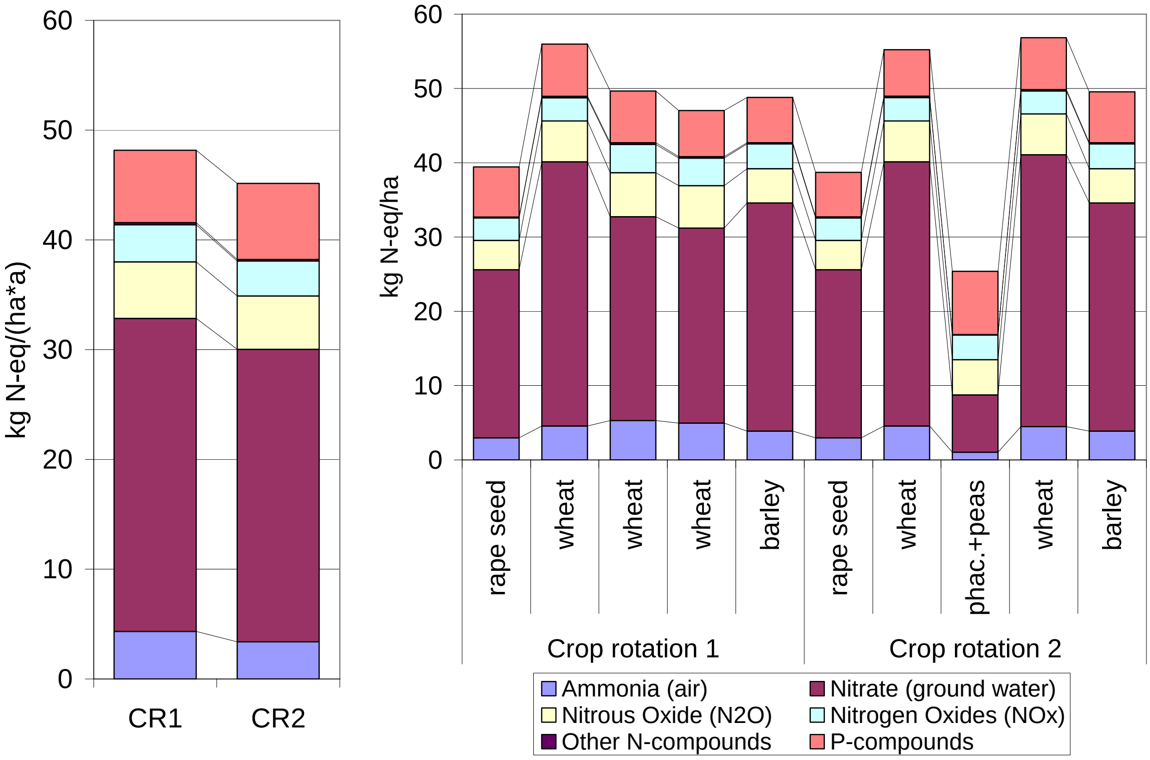

Fig. 8: Eutrophication potential (combined potential of N and P) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Saxony-Anhalt (D) after introduction of a catch crop (*Phacelia*) before peas.

b) Effect of Increased N Mineralisation

After the incorporation of crop residues, increased N mineralisation may occur (Jensen 1997). In the SALCA nitrate model (Richner *et al*. 2006) this process is considered by assuming that N mineralisation is increased by 15% in six months after the incorporation of the residues. However, the effect of the crop residues has been called into question by Carrouée *et al*. (2006).

In the sensitivity analysis a calculation was performed without this increase. As shown in Fig. 10, the amount of nitrate leached changes only very little (less than 1%). The reason for this small difference is that in most months the N uptake of the following wheat exceeds the N mineralisation in the soil and therefore causes hardly any risk of leaching. An increase of N mineralisation by 15% thus has almost no effect in this case. Therefore we can conclude that the factor for the increase in N mineralisation after incorporation of grain legume residues is not critical for the conclusions.

c) Effect of Emissions of Nitrous Oxide related to SNF

The current IPCC emission factor for N_2O of 1.25% of the N from symbiotic N fixation is currently being reviewed (Smith 2006) and there are indications that the real emissions are well below this value. In the sensitivity analysis the IPCC-factor for N_2O emissions from symbiotic nitrogen fixation is set to 0%, in order to show the importance of this process. The total emissions of N_2O in CR2 are decreased by 7%; those of the pea crop by as much as 47% (Fig. 9, only the totals per crop rotation shown).

The eutrophication potential (Fig. 10) is slightly reduced as well.

Hence we can clearly see that this factor has a strong influence on the results. The estimated reduction of the global warming potential due to the introduction of peas might therefore be underestimated in this study. In the light of the high uncertainty associated with the estimation of this parameter, it is urgent for this question to be studied in greater depth in order to achieve clear and sound conclusions.

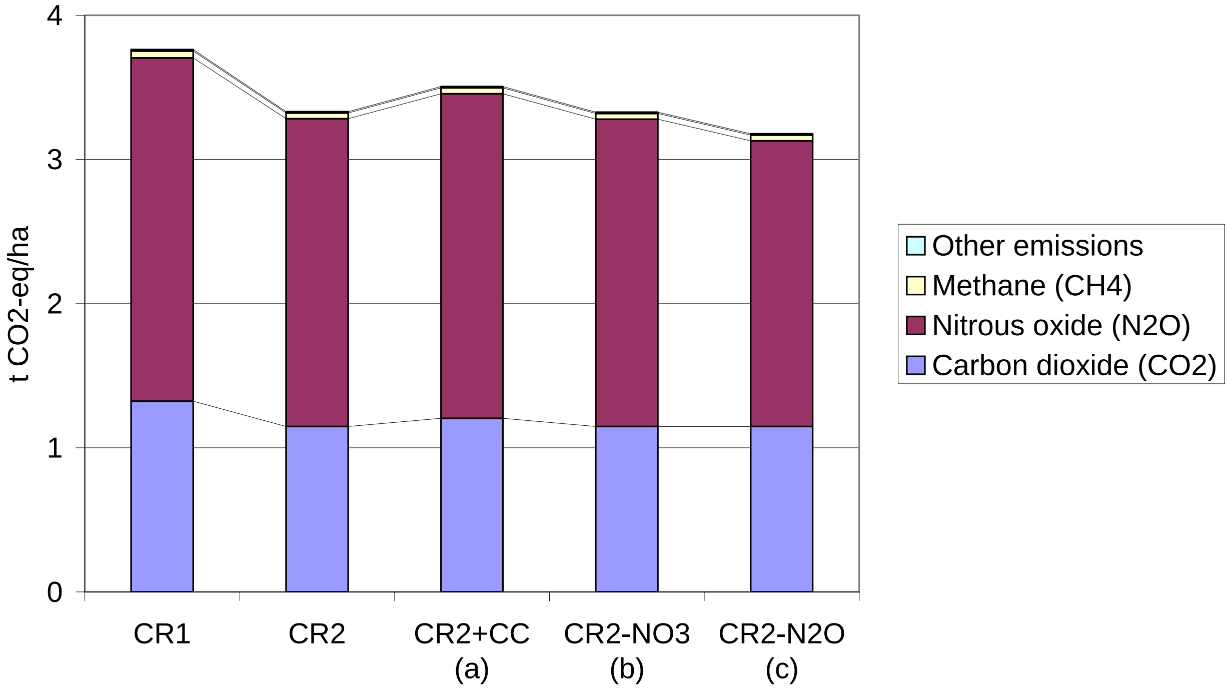

Fig. 9: Sensitivity analysis for the global warming potential over 100 years for Saxony-Anhalt (D): CR1 = crop rotation 1 without grain legumes, CR2 = crop rotation 2 with grain legumes, CR2+CC = CR2 with catch crop (option a), CR2-NO_3 = CR2 without increased N mineralisation after incorporation of pea crop residues (option b), CR2-N_2O = CR2 without N_2O emissions induced by symbiotic nitrogen fixation (option c).

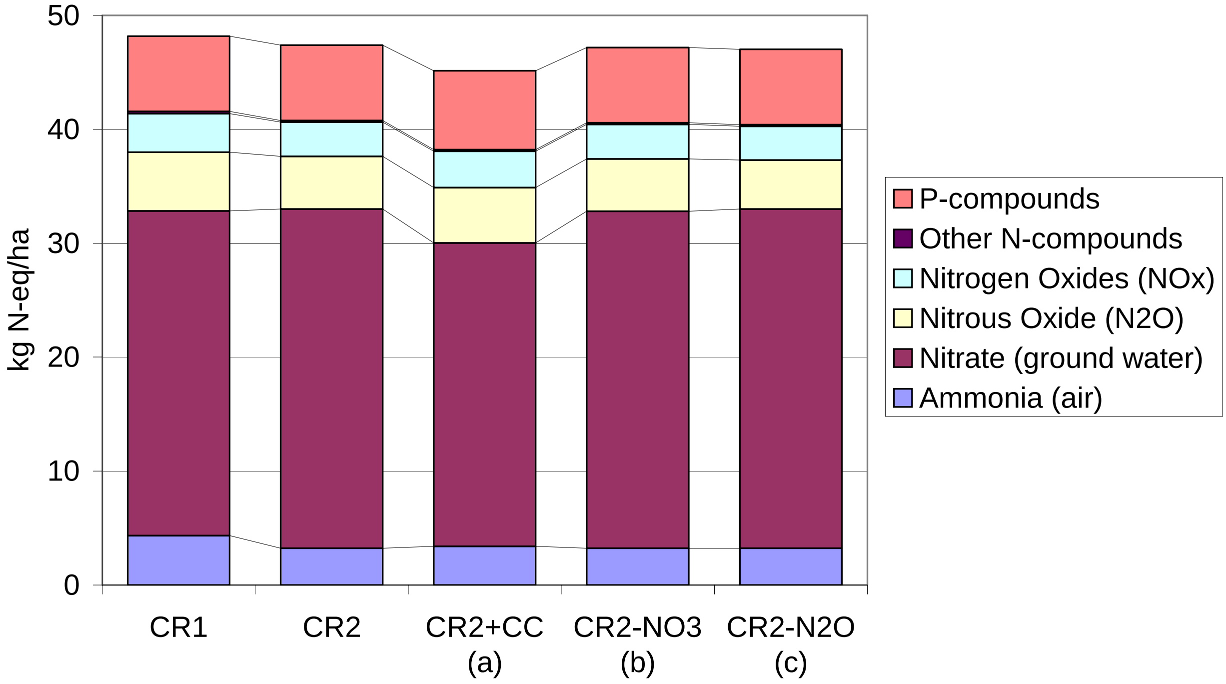

Fig. 10: Sensitivity analysis for the eutrophication potential (combined potential of N and P) for Saxony-Anhalt (D): CR1 = crop rotation 1 without grain legumes, CR2 = crop rotation 2 with grain legumes, CR2+CC = CR2 with catch crop (option a), CR2-NO_3 = CR2 without increased N mineralisation after incorporation of pea crop residues (option b), CR2-N_2O = CR2 without N_2O emissions induced by symbiotic nitrogen fixation (option c).

It has to be borne in mind that the IPCC method considers emissions of nitrous oxide after the incorporation of crop residues as well. This applies for all crops, but as pea straw has a higher N content than cereal straw, this effect is relatively more important. This factor remained unchanged in the sensitivity analysis.

6.1.3 Barrois (F)

Please note that in Barrois a 4-year crop rotation was extended to a 5-year rotation by the inclusion of (winter) peas.

Resource Management

The energy demand is reduced by 11% in the crop rotation with grain legumes (Fig. 11). The difference is only due to the lower use of N fertilisers in this case; unlike in Saxony-Anhalt, the same soil tillage was assumed in Barrois for both crop rotations.

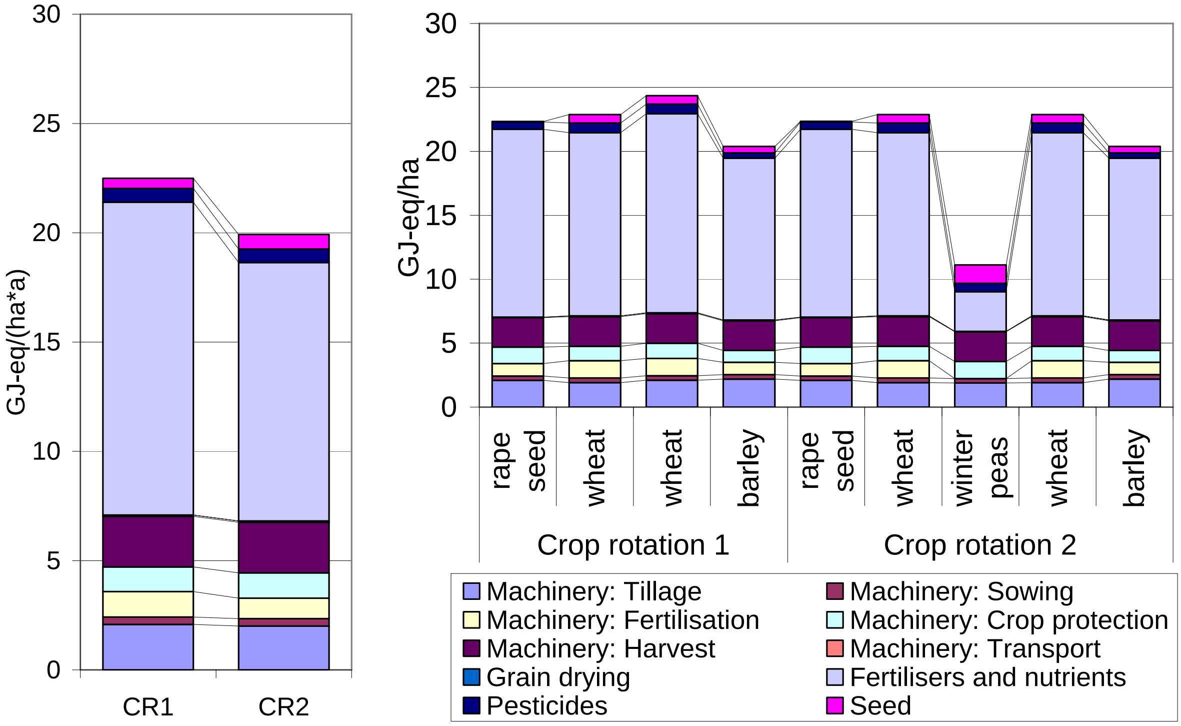

Fig. 11: Demand for non-renewable energy resources of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Barrois (F).

The global warming potential is reduced by 8% in the alternative crop rotation (Fig. 12). The same explanations hold as for Saxony-Anhalt (see Fig. 5).

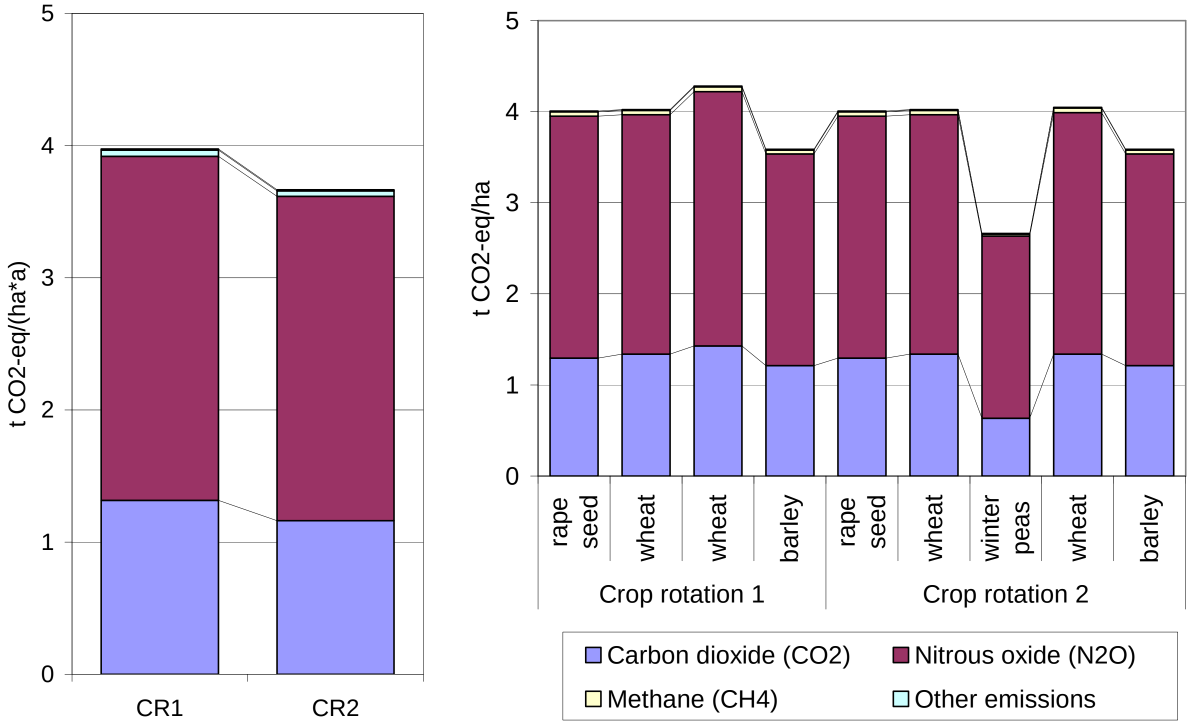

Fig. 12: Global warming potential over 100 years of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Barrois (F).

Nutrient Management

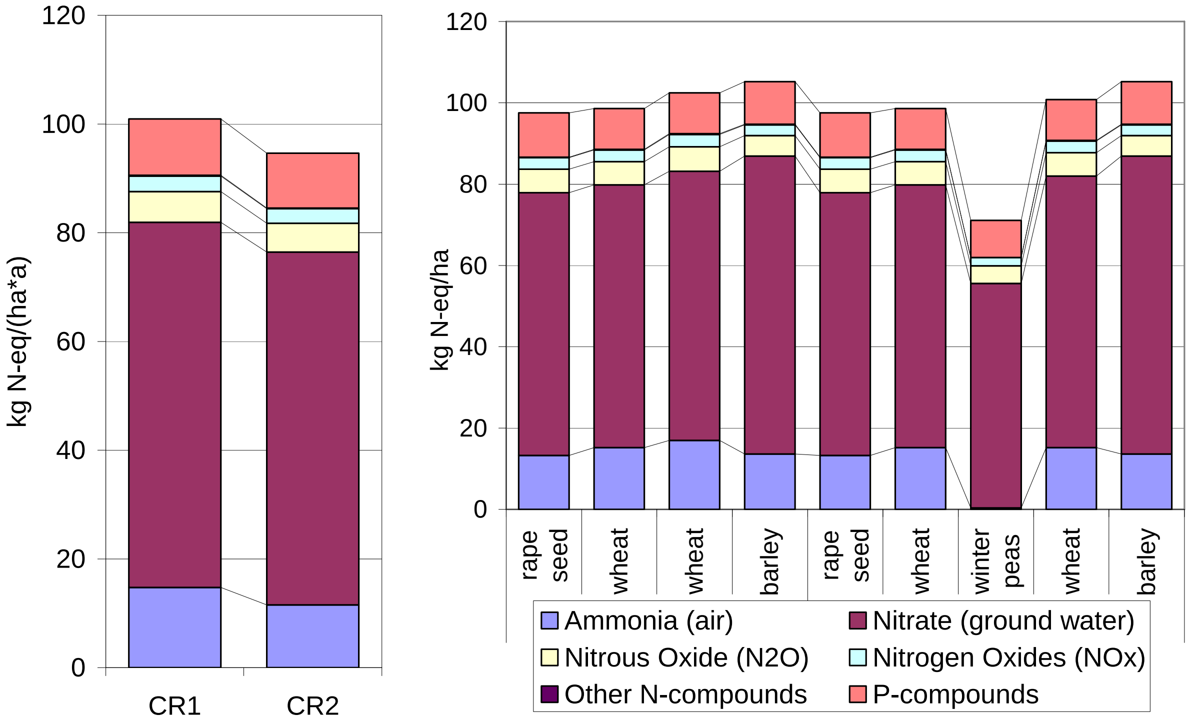

Fig. 13: Eutrophication potential (combined potential of N and P) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Barrois (F).

The level of the eutrophication potential for the two crop rotations is generally higher in Barrois (Fig. 13) than in Saxony-Anhalt. This is explained by the higher risk of nitrate leaching due to more precipitations in winter. The difference in the eutrophication potential between the two crop rotations is in favour of CR2 (-6%) and greater than in Saxony-Anhalt. This is explained by the fact that winter peas were sown in Barrois, which already take up a certain amount of nitrogen in autumn (see also Vocanson *et al*. 2006). Compared to spring peas, winter peas leave the soil bare for a shorter period than spring peas.

Pollutant Management

The terrestrial ecotoxicity potential (according to EDIP97, Fig. 14) is dominated by fungicides, followed by insecticides. Herbicides make only a small contribution. The main contributors to terrestrial ecotoxicity are the fungicides carbendazim (rape seed), propiconazol (cereals) and chlorothalonil (peas) as well as the insecticides lambda-cyhalothrin and cypermethrin. Overall this impact is decreased by 7% in CR2.

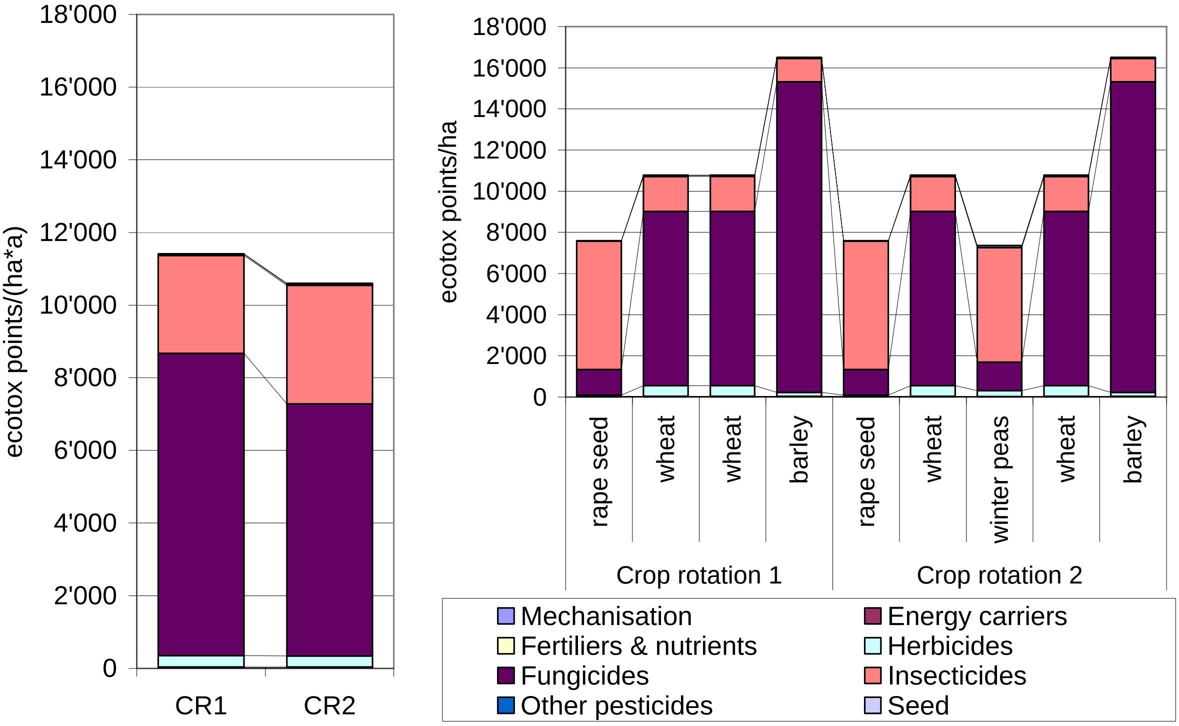

Fig. 14: Terrestrial ecotoxicity potential (EDIP) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Barrois (F).

Summary of the Results

The overview of the results reveals a favourable assessment of the crop rotation with peas (Tab. 7), similarly to what has been observed for Saxony-Anhalt. The same tendency is observed as well when we assess the results in relation to the three different functional units.

Tab. 7: Overview of the environmental impacts of the crop rotation without (CR1) and with (CR2) grain legumes in Barrois (F) for the three functional units. See Tab. 5 for an explanation of the colour coding.

	per ha and year			**per € gross margin 1**			**per GJ gross energy yield**		
Summary of the impacts:	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**
energy demand [GJ-eq]	2.25E+1	1.99E+1	89%	3.54E-2	3.05E-2	86%	2.33E-1	2.17E-1	93%
global warming potential [t CO2-eq]	3.97E+0	3.67E+0	92%	6.25E-3	5.62E-3	90%	4.12E-2	3.99E-2	97%
ozone formation [kg ethylene-Eq]	6.69E-1	6.29E-1	94%	1.05E-3	9.63E-4	92%	6.93E-3	6.84E-3	99%
eutrophication, combined potential N & P [kg N-eq]	1.01E+2	9.47E+1	94%	1.59E-1	1.45E-1	91%	1.05E+0	1.03E+0	98%
eutrophication, separate N potential [kg N]	9.06E+1	8.45E+1	93%	1.43E-1	1.30E-1	91%	9.39E-1	9.20E-1	98%
eutrophication, separate P potential [kg P]	1.43E+0	1.40E+0	98%	2.25E-3	2.14E-3	95%	1.48E-2	1.52E-2	102%
acidification [kg SO2-eq]	4.44E+1	3.63E+1	82%	6.99E-2	5.56E-2	80%	4.60E-1	3.95E-1	86%
terrestrial ecotoxicity EDIP [points]	1.14E+4	1.06E+4	93%	1.80E+1	1.62E+1	90%	1.18E+2	1.15E+2	98%
aquatic ecotoxicity EDIP [points]	4.70E+3	4.09E+3	87%	7.40E+0	6.26E+0	85%	4.87E+1	4.45E+1	91%
terrestrial ecotoxicity CML [points]	1.09E+3	8.78E+2	80%	1.72E+0	1.34E+0	78%	1.13E+1	9.55E+0	84%
aquatic ecotoxicity CML [points]	2.74E+3	2.22E+3	81%	4.31E+0	3.40E+0	79%	2.84E+1	2.41E+1	85%
human toxicity CML [points]	9.90E+2	8.56E+2	87%	1.56E+0	1.31E+0	84%	1.03E+1	9.32E+0	91%
Functional units				508	653	103%	97	92	95%
				€/(ha*year)			GJ/(ha*year)		

6.1.4 Vaud (CH)

In the Swiss region of Canton Vaud, grain maize was replaced by peas and soya bean, respectively. The reason for choosing two different grain legumes lies in the legislation: the farmer must allow an interval of at least six years between two pea crops (DZV 1998). Grain maize was replaced because this crop has the lowest gross margin of the crops in CR1.

Resource Management

The energy demand in CR1 is largely dominated by grain maize (Fig. 15). Maize grains are harvested at a humidity of 32% and must be dried to 14%, which requires a huge amount of energy. Therefore it is clear that replacing grain maize causes a significant reduction in energy demand.

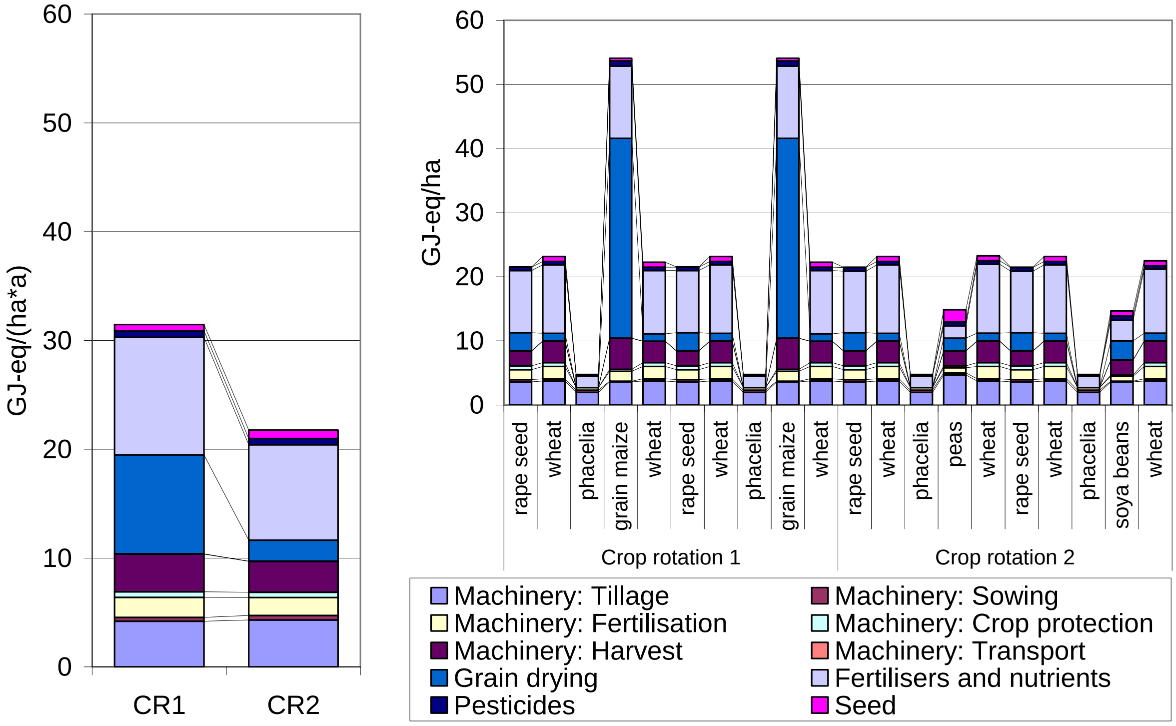

Fig. 15: Demand for non-renewable energy resources of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Canton Vaud (CH).

Grain drying is less significant for global warming than for energy demand, since this process mainly causes emissions of CO_2 and not of N_2O. Therefore, the differences between the two crop rotations are smaller for this impact category (Fig. 16).

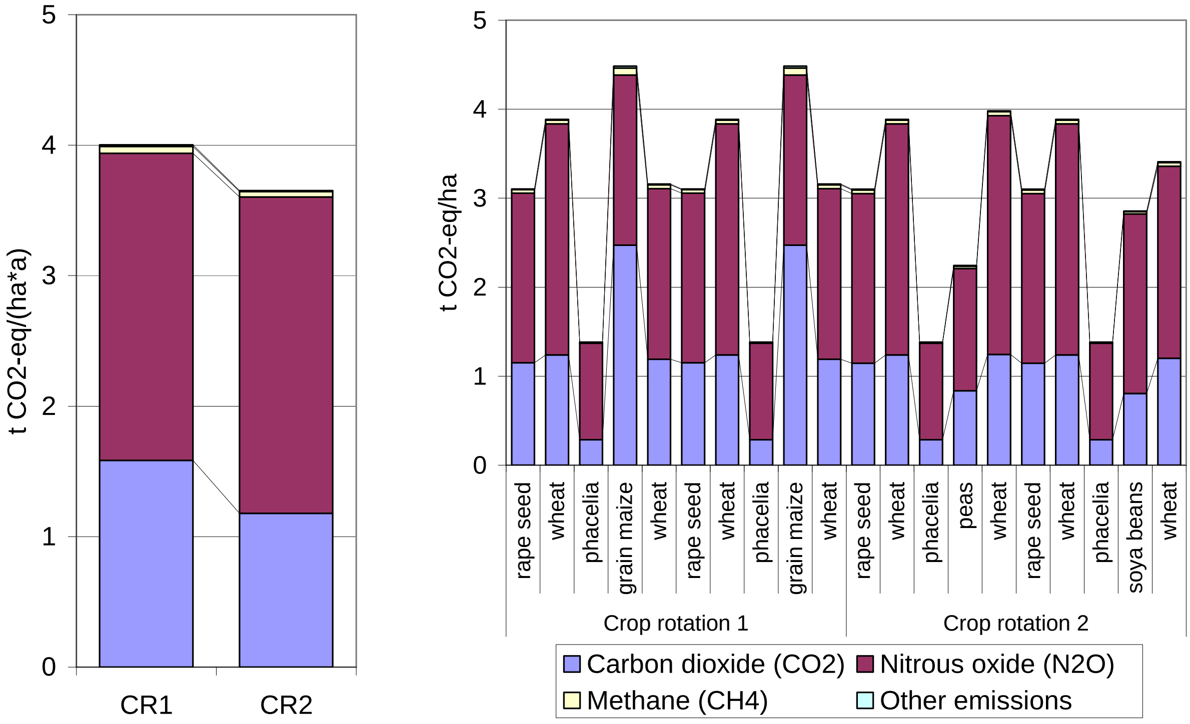

Fig. 16: Global warming potential over 100 years of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Canton Vaud (CH).

Nutrient Management

The eutrophication potential (Fig. 17) is increased by 10%, mainly due to a higher risk of nitrate leaching. In fact, nitrate leaching in this case is increased by 20%, whereas the other

N emissions are reduced. The following factors explain this different finding compared to the other regions:

- Both CR1 and CR2 include catch crops (*Phacelia*) before the spring-sown crops (grain maize, peas and soya bean). Therefore nitrate leaching is comparatively low in CR1.
- Nitrate leaching after grain legumes is potentially increased due to the factors mentioned above (see Fig. 6).
- The period between the harvest of peas or soya beans and sowing the following wheat crop is longer than is the case for grain maize, which is harvested very late.

Under these conditions, we find an increase in nitrate leaching and in the eutrophication potential.

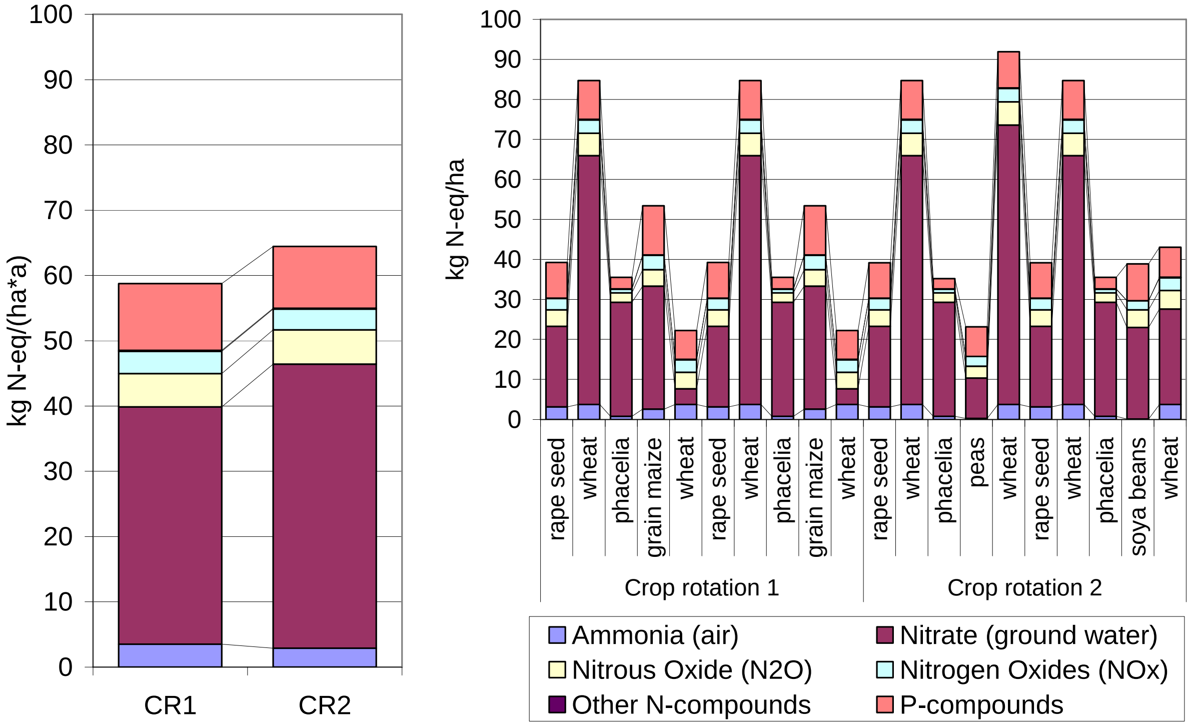

Fig. 17: Eutrophication potential (combined potential of N and P) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Canton Vaud (CH).

Pollutant Management

The terrestrial ecotoxicity potential according to the EDIP method (Fig. 18) is much lower than that observed in Saxony-Anhalt and Barrois, due to the fact that fewer and apparently less problematic active ingredients are applied and the total pesticide quantities are smaller. Fungicides play a minor role – unlike in Saxony-Anhalt and Barrois – and the impact is dominated by herbicides and insecticides. The value for CR2 is 18% higher than the value for CR1, mainly due to the application of pirimicarb in peas. In rape seed the insecticide cypermethrin dominates. Further important active ingredients are the herbicides isoproturon in wheat and metolachlor in maize. The CML01 method comes to a different result: the impacts of the two crop rotations are at the same level. Therefore no clear conclusion can be drawn for the differences in ecotoxicity.

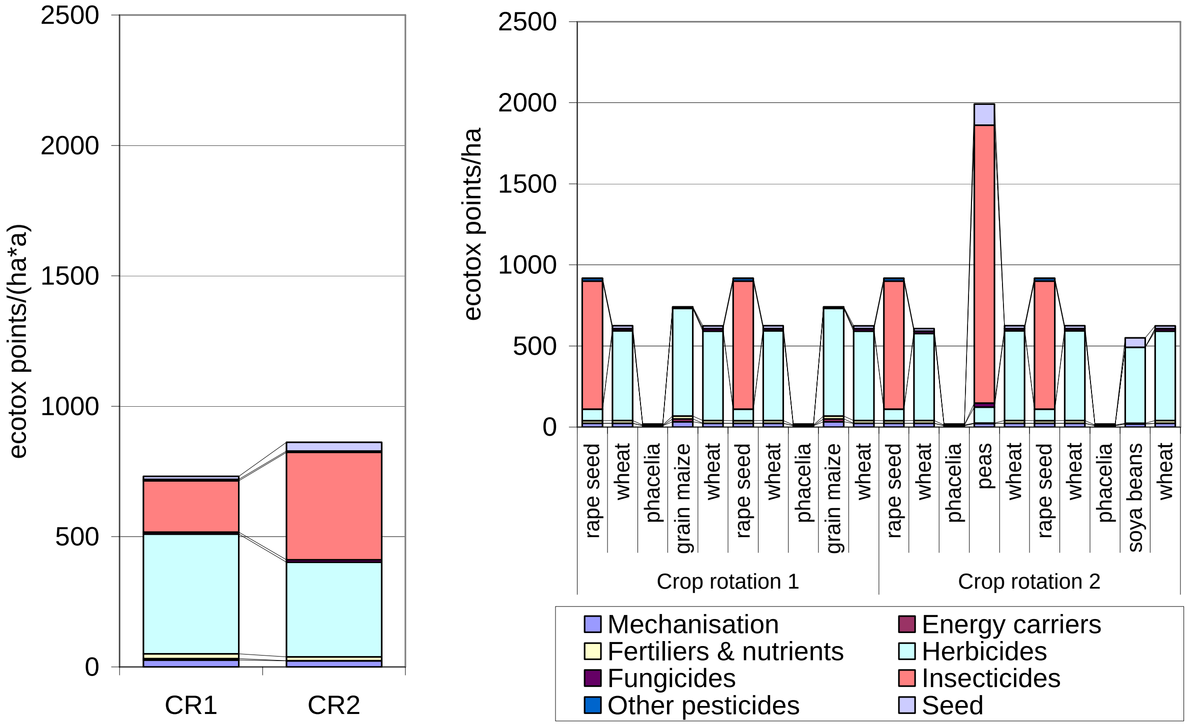

Fig. 18: Terrestrial ecotoxicity potential (EDIP) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Canton Vaud (CH).

Summary of the Results

The assessment results are different for Canton Vaud compared to the two regions analysed in Germany and France (Tab. 8). The impacts related to resource management are more favourable in CR2 than in CR1, due to the lower use of nitrogen fertiliser and lower energy demand for grain drying, with the exception of the assessment relative to the productive function, where global warming and ozone formation show unfavourable results. This is due to the much lower gross energy production in CR2 compared to CR1, since grain maize is a highly productive crop (average yield 9.3 t/ha). For nutrient management, the assessment is less favourable: due to a higher nitrate leaching risk, the eutrophication potential is significantly increased. Only for the acidification, favourable results were observed. The assessment is also unfavourable for terrestrial ecotoxicity (according to EDIP) and aquatic ecotoxicity (according to CML), but neutral for the other toxicity categories.

Tab. 8: Overview of the environmental impacts of the crop rotation without (CR1) and with (CR2) grain legumes in Vaud (CH) for the three functional units. See Tab. 5 for an explanation of the colour coding.

	per ha and year			**per € gross margin 1**			**per GJ gross energy yield**		
Summary of the impacts:	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**
energy demand [GJ-eq]	3.15E+1	2.19E+1	69%	2.31E-2	1.57E-2	68%	2.94E-1	2.51E-1	85%
global warming potential [t CO2-eq]	4.00E+0	3.65E+0	91%	2.93E-3	2.62E-3	89%	3.73E-2	4.20E-2	113%
ozone formation [kg ethylene-Eq]	8.54E-1	7.28E-1	85%	6.26E-4	5.22E-4	83%	7.96E-3	8.36E-3	105%
eutrophication, combined potential N & P [kg N-eq]	5.88E+1	6.44E+1	110%	4.30E-2	4.62E-2	107%	5.47E-1	7.40E-1	135%
eutrophication, separate N potential [kg N]	4.85E+1	5.50E+1	113%	3.56E-2	3.94E-2	111%	4.52E-1	6.31E-1	140%
eutrophication, separate P potential [kg P]	1.41E+0	1.31E+0	93%	1.03E-3	9.37E-4	91%	1.32E-2	1.50E-2	114%
acidification [kg SO2-eq]	2.04E+1	1.75E+1	86%	1.49E-2	1.25E-2	84%	1.90E-1	2.01E-1	106%
terrestrial ecotoxicity EDIP [points]	7.31E+2	8.62E+2	118%	5.36E-1	6.17E-1	115%	6.81E+0	9.90E+0	145%
aquatic ecotoxicity EDIP [points]	2.71E+3	2.61E+3	96%	1.98E+0	1.87E+0	94%	2.52E+1	3.00E+1	119%
terrestrial ecotoxicity CML [points]	6.89E+2	6.91E+2	100%	5.05E-1	4.95E-1	98%	6.42E+0	7.94E+0	124%
aquatic ecotoxicity CML [points]	2.10E+3	2.38E+3	113%	1.54E+0	1.70E+0	111%	1.95E+1	2.73E+1	140%
human toxicity CML [points]	1.33E+3	1.26E+3	95%	9.77E-1	9.04E-1	92%	1.24E+1	1.45E+1	117%
Functional units				1365	1396	102%	107	87	81%
				€/(ha*year)			GJ/(ha*year)		

Soil Quality

The results of the assessment of impacts on soil quality are shown in Tab. 9. No difference was observed between the two crop rotations for the nine parameters considered by the SALCA soil quality method (Oberholzer *et al*. 2006). It has to be borne in mind that despite the lack of organic fertilisers and clover grass, the crop rotation is quite optimised from the point of view of soil quality (high crop diversity, catch crops). Therefore these results cannot be generalised to the other regions analysed.

Tab. 9: Assessment of the potential impacts of management on soil quality of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes by the SALCA soil quality method in Canton Vaud. 0 means "neutral", i.e. soil quality is not changed by continuing this management over many years.

		CR1	CR2
Phy-sical	Rooting depth of soil	0	0
	Macropore volume	0	0
	Aggregate stability	0	0
Chemi-cal	Corg content	0	0
	Heavy metal content	0	0
	Organic pollutants	0	0
Biolo-gical	Eathworm biomass	0	0
	Microbial biomass	0	0
	Microbial activity	0	0

Biodiversity

The SALCA biodiversity method (Jeanneret *et al*. 2006) was only parameterised for Switzerland and was only applied in the Swiss case study.

Biodiversity points according to SALCA are higher for CR2 compared with CR1 because maize was replaced by a grain legume. Maize had a particularly low biodiversity potential because of the application of unselective herbicides (mainly atrazine). This positive effect would not have occurred had wheat been replaced, for example.

The biodiversity assessment is applied at crop level in this study. This includes the impact of management practices, but not the fact of increasing crop diversity.

Tab. 10: Assessment of the potential impacts of management on biodiversity of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes by the SALCA biodiversity method in Canton Vaud.

Biodiversity points	**CR1**	**CR2**
Total species richness		
Total aggregated	**7.1**	**7.3**
Flora arable land	13.1	13.9
Birds	5.6	5.6
Small mammals	4.3	4.5
Amphibians	1.7	1.7
Molluscs	2.2	2.2
Spiders	9.1	9.0
Carabids	10.3	10.5
Butterflies	7.6	7.6
Wild bees	4.2	4.4
Grasshoppers	7.5	7.5
Species with high ecological requirements		
Amphibians	1.5	1.5
Spiders	9.0	8.9
Carabids	10.1	10.2
Butterflies	7.6	7.6
Grasshoppers	7.4	7.4

Higher values mean higher species richness compared to reference CR1

favourable	🟩
very favourable	🟩

6.1.5 Castilla y León (E)

The production conditions in Castilla y León are quite different from the other regions. Firstly, the production intensity is relatively low and the yields are at a modest level (e.g. the wheat yield is only 2.9 t/ha). The quantity of inputs (fertiliser and pesticides) is relatively low. It was further assumed that fertiliser management is not changed in consequence of grain legumes, which corresponds to the current practice of the farmers in the region[3]. This means that the same quantity of N fertiliser is applied after peas as after a non-legume. According to consistent experimental results (summarised in von Richthofen *et al*. 2006), it should be possible to reduce the N fertiliser rates after a grain legume. This shows that an improvement potential exists in the cropping system in Castilla y León.

Furthermore, sunflowers are grown as an unfertilised break crop. The same holds for peas; this crop receives no fertiliser either. Therefore, no saving of fertilisers can be achieved, unlike the other regions.

---

[3] Personal communication P. Casta, ITA, Valladolid.

Resource Management

The low production intensity leads to a relatively low energy demand of about 10 GJ/ha per year, which is 2-3 times less than in the other regions. The energy demand is slightly higher (+4%) in CR2 (Fig. 19). This can be explained by the much higher seed demand of peas compared to sunflowers. Only 3.25 kg seed/ha is used for sunflowers, whereas 220 kg seed/ha is required for peas. Compared to the relatively low yields (sunflowers 1.03 t/ha, peas 1.24 t/ha) this difference is relevant.

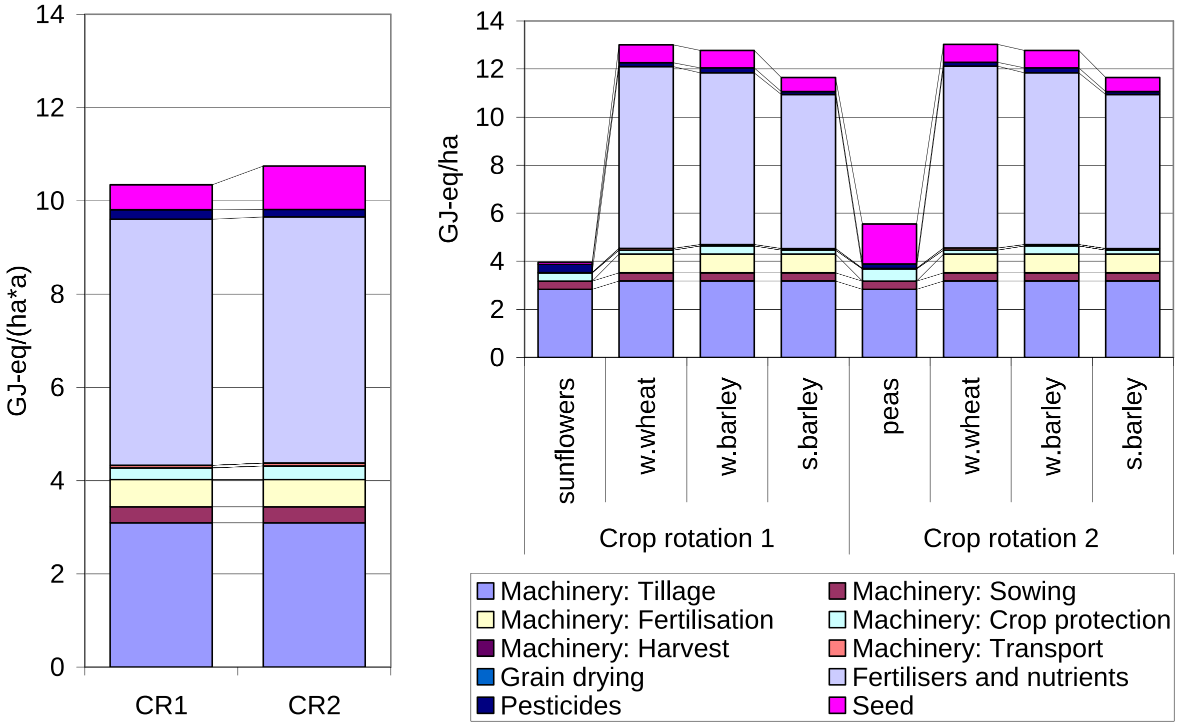

Fig. 19: Demand for non-renewable energy resources of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Castilla y León (E).

Concerning climate change (Fig. 20), the alternative crop rotation shows a higher impact. On the one hand, this is due to the higher energy demand, on the other hand, the higher nitrate leaching also plays a role, since it leads to induced emissions of nitrous oxide.

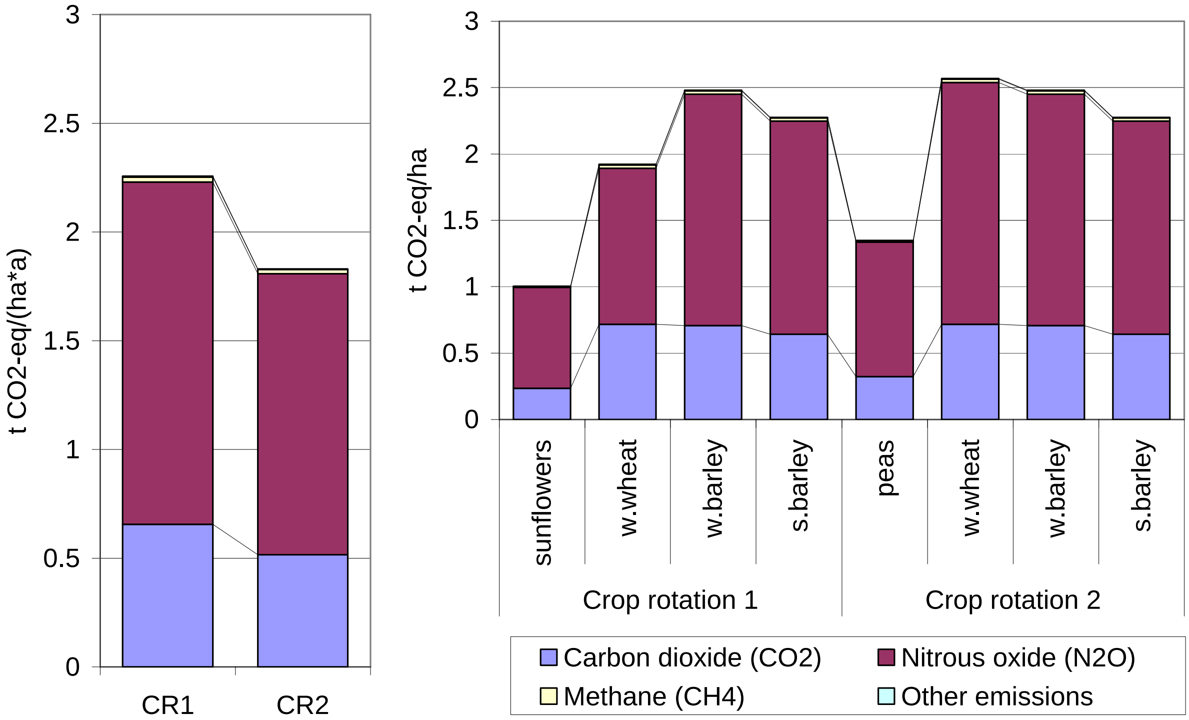

Fig. 20: Global warming potential over 100 years of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Castilla y León (E).

Nutrient Management

The alternative crop rotation causes a higher eutrophication potential (Fig. 21). The main difference lies in the risk of nitrate leaching. The latter is higher in CR2 due to the fact that the soil is covered for a shorter period by peas than by sunflowers. Furthermore, the risk of nitrate leaching is increased after the incorporation of pea crop residues. It should be noted that the period considered for each individual crop is not the same in the two crop rotations, due to different harvest dates. The calculation starts after the harvest of the preceding crop and ends with the harvest of the crop considered. Since sunflowers are harvested in October and peas as early as June, the period considered for wheat is much longer in CR2 than in CR1, leading to higher losses for the following wheat and lower losses for peas. For the whole crop rotation, this effect does not play a role.

It was debated whether a risk of nitrate leaching really applies in this region. As explained above, the factor was estimated on the basis of the precipitations during the winter months, which are 266 mm, a higher value than for Saxony-Anhalt (186 mm). Thus a certain amount of nitrate leaching is possible under these conditions.

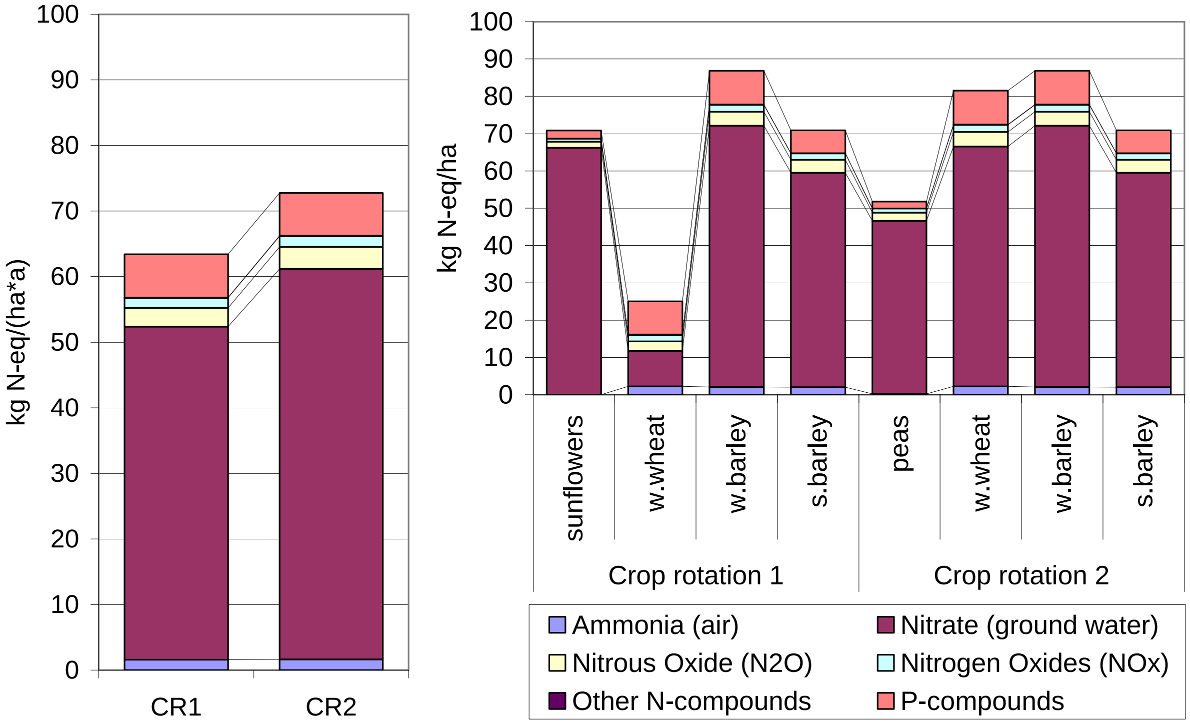

Fig. 21: Eutrophication potential (combined potential of N and P) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Castilla y León (E).

Pollutant Management

The terrestrial ecotoxicity potential (Fig. 22) is very low, compared to the other regions, due to the fact that only few pesticide applications occur. The value for CR2 is slightly higher than the value for CR1, which is completely explained by the larger quantity of seed and the insecticides (mainly pirimicarb) used during its production.

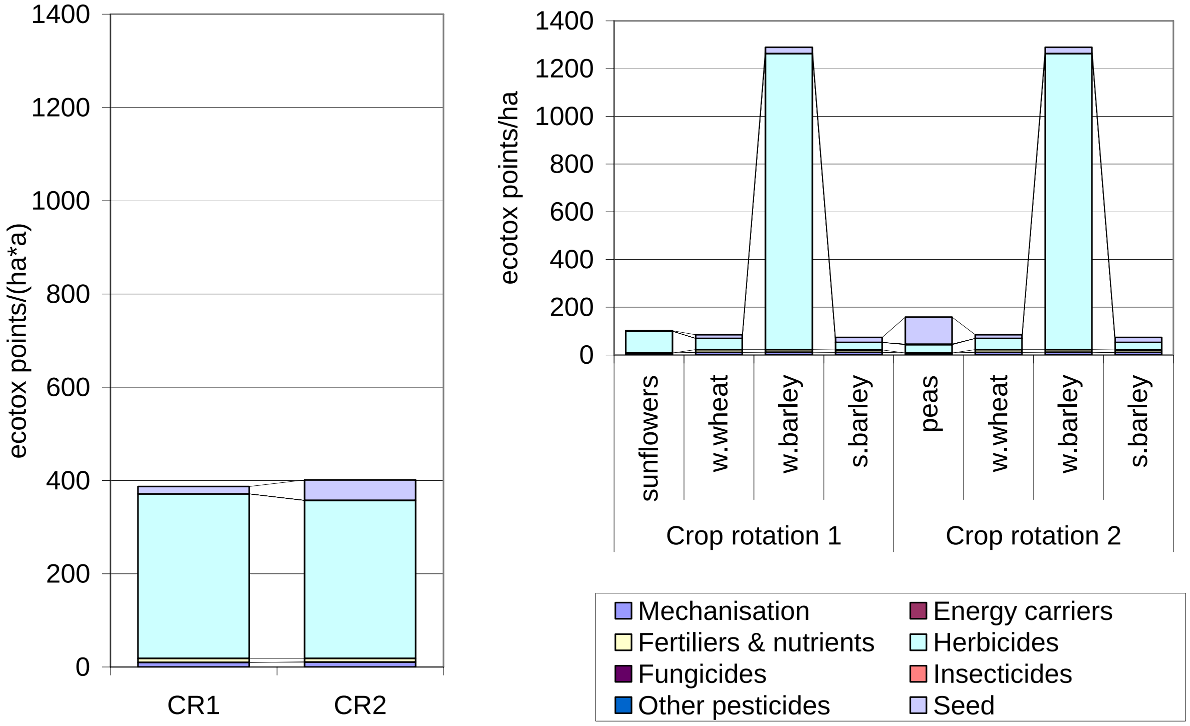

Fig. 22: Terrestrial ecotoxicity potential (EDIP) of crop rotation 1 (CR1) without grain legumes and crop rotation 2 (CR2) with grain legumes in Castilla y León (E).

Summary of the Results

On the whole, the introduction of peas into the crop rotation in Castilla y León leads to higher impacts for global warming, ozone formation and eutrophication (Tab. 11). Aquatic ecotoxicity seems to be lower; the other impacts are unchanged.

It appears from this example that there is no advantage in introducing a grain legume into a low-input crop rotation, especially when a break crop (in this case sunflowers) is replaced by a grain legume.

Unlike in the other regions, the assessment for the productive function is the same as for the land management and financial functions. This is because the gross energy production is the same in both crop rotations.

Tab. 11: Overview of the environmental impacts of the crop rotation without (CR1) and with (CR2) grain legumes in Castilla y León (E) for the three functional units. See Tab. 5 for an explanation of the colour coding.

	per ha and year			**per € gross margin 1**			**per GJ gross energy yield**		
Summary of the impacts:	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**	**CR1**	**CR2**	**CR2 in % CR1**
energy demand [GJ-eq]	1.03E+1	1.07E+1	104%	4.90E-2	5.03E-2	103%	2.56E-1	2.68E-1	105%
global warming potential [t CO2-eq]	1.92E+0	2.17E+0	113%	9.08E-3	1.02E-2	112%	4.75E-2	5.41E-2	114%
ozone formation [kg ethylene-Eq]	3.35E-1	3.54E-1	106%	1.58E-3	1.66E-3	105%	8.28E-3	8.85E-3	107%
eutrophication, combined potential N & P [kg N-eq]	6.34E+1	7.28E+1	115%	3.00E-1	3.41E-1	114%	1.57E+0	1.82E+0	116%
eutrophication, separate N potential [kg N]	5.68E+1	6.62E+1	117%	2.69E-1	3.10E-1	115%	1.41E+0	1.65E+0	118%
eutrophication, separate P potential [kg P]	9.08E-1	9.01E-1	99%	4.29E-3	4.22E-3	98%	2.24E-2	2.25E-2	100%
acidification [kg SO2-eq]	9.38E+0	9.77E+0	104%	4.44E-2	4.57E-2	103%	2.32E-1	2.44E-1	105%
terrestrial ecotoxicity EDIP [points]	3.87E+2	4.01E+2	104%	1.83E+0	1.88E+0	103%	9.57E+0	1.00E+1	105%
aquatic ecotoxicity EDIP [points]	3.33E+3	2.47E+3	74%	1.58E+1	1.16E+1	73%	8.24E+1	6.17E+1	75%
terrestrial ecotoxicity CML [points]	6.81E+0	1.09E+1	160%	3.22E-2	5.09E-2	158%	1.68E-1	2.71E-1	161%
aquatic ecotoxicity CML [points]	1.02E+2	9.32E+1	92%	4.80E-1	4.37E-1	91%	2.51E+0	2.33E+0	93%
human toxicity CML [points]	3.28E+2	3.42E+2	104%	1.55E+0	1.60E+0	103%	8.11E+0	8.54E+0	105%
Functional units				211	214	101%	40	40	99%
				€/(ha*year)			GJ/(ha*year)		

6.1.6 Overview of the Results for all Case Studies

In summary of the results shown above, the relative effects of introducing grain legumes into the crop rotations of the four case study regions are shown in Tab. 12 to Tab. 14.

Tab. 12: Overview of the relative effects of the introduction of grain legumes into crop rotations in the four regions for the functional unit hectare per year. See Tab. 5 for an explanation of the colour coding.

		Results per ha and year			
	CR2 in % of CR1	Saxony-Anhalt (D)	Barrois (F)	Vaud (CH)	Castilla y Leon (E)
Resource management	energy demand	86%	89%	69%	104%
	global warming potential	89%	92%	91%	113%
	ozone formation	90%	94%	85%	106%
Nutrient mana-gement	eutrophication	98%	94%	110%	115%
	acidification	83%	82%	86%	104%
Pollutant management	terrestrial ecotoxicity EDIP	63%	93%	118%	104%
	aquatic ecotoxicity EDIP	102%	87%	96%	74%
	terrestrial ecotoxicity CML	99%	80%	100%	160%
	aquatic ecotoxicity CML	96%	81%	113%	92%
	human toxicity CML	85%	87%	95%	104%

Tab. 13: Overview of the relative effects of the introduction of grain legumes into crop rotations in the four regions for the functional € gross margin 1. See Tab. 5 for an explanation of the colour coding.

		Results per € gross margin 1			
	CR2 in % of CR1	Saxony-Anhalt (D)	Barrois (F)	Vaud (CH)	Castilla y Leon (E)
Resource management	energy demand	82%	86%	68%	103%
	global warming potential	85%	90%	89%	112%
	ozone formation	86%	92%	83%	105%
Nutrient mana-gement	eutrophication	94%	91%	107%	114%
	acidification	79%	80%	84%	103%
Pollutant management	terrestrial ecotoxicity EDIP	61%	90%	115%	103%
	aquatic ecotoxicity EDIP	97%	85%	94%	73%
	terrestrial ecotoxicity CML	95%	78%	98%	158%
	aquatic ecotoxicity CML	92%	79%	111%	91%
	human toxicity CML	81%	84%	92%	103%

Tab. 14: Overview of the relative effects of the introduction of grain legumes into crop rotations in the four regions for the functional GJ gross energy. See Tab. 5 for an explanation of the colour coding.

		Results per GJ gross energy			
	CR2 in % of CR1	Saxony-Anhalt (D)	Barrois (F)	Vaud (CH)	Castilla y Leon (E)
Resource management	energy demand	92%	93%	85%	105%
	global warming potential	95%	97%	113%	114%
	ozone formation	96%	99%	105%	107%
Nutrient management	eutrophication	106%	98%	135%	116%
	acidification	89%	86%	106%	105%
Pollutant management	terrestrial ecotoxicity EDIP	68%	98%	145%	105%
	aquatic ecotoxicity EDIP	109%	91%	119%	75%
	terrestrial ecotoxicity CML	106%	84%	124%	161%
	aquatic ecotoxicity CML	103%	85%	140%	93%
	human toxicity CML	91%	91%	117%	105%

6.2 Comparison of Feed Formulas

In this chapter the results of the potential environmental impacts for the feed formulas are presented. It begins with detailed results from selected impact categories, i.e. energy demand, global warming potential, eutrophication and terrestrial ecotoxicity, and closes with a summary of the results of all the impact categories assessed.

6.2.1 Detailed Results from Selected Impact Categories

Energy Demand

The energy demand of soya crop production is lower than its replacement consisting of a combination of peas, rape seed and soya beans (Fig. 23). But the larger proportion of cereals in the soya formulas mean a higher energy demand for cereals per kg feed in these formulas. The total impact of the production of the raw materials is similar for PEA and SOY for all three-phase feeds. Their contribution to the total impact is between 66% and 74% for the pea formulas and between 62% and 67% for the soya formulas.

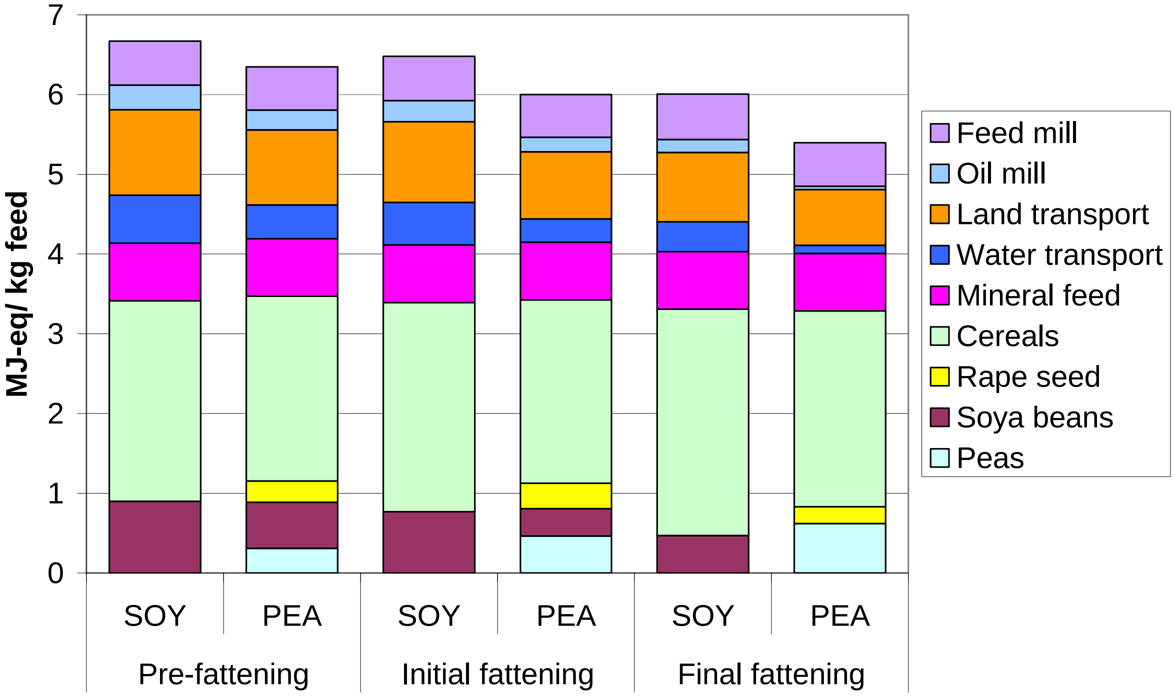

Fig. 23: Results for the six feed formulas for the impact category energy demand shown in MJ-equivalents per kg feed. SOY: Feed formulas based on soya bean meal and cereals; PEA: Feed formulas based on peas, rape seed meal, soya bean meal and cereals (see Tab. 2 for details of feed composition).

The main difference for the energy demand results from transport. Soya from Brazil is increasingly produced in the vast interior parts of that country. Therefore soya beans are hauled by lorries over long distances (930 km) from the production sites to the ports on the banks of a tributary of the Amazon. There, the beans are loaded on to barges and shipped to an Amazon floating port (1270 km), where they are loaded on to transoceanic ships for their journey to Europe (9500 km). From the European port to the feed mill they are again shipped by barge (300 km); whereas peas are transported over 300 km by lorry, rape seed is hauled 150 km by lorry and 320 km (as meal) by barge. This explains why the transport of soya beans produces perceptibly greater environmental impacts than peas and rape seed from Europe. There are greater differences in the transport by water between the feed alternatives than in transport by road. Still, the environmental impact of road transport is more significant compared to water transport. It is often claimed that transport by ship does not contribute much to the energy demand due to a good ratio between tonnage times distance to fuel consumed. However, one should not overlook the point that when transport distances differ greatly, water transport has a detectable effect on the energy demand of the system assessed. The share of transport amounts to 15% to 25% of the total energy demand.

Feed and oil mill processing are of minor importance overall. Together they account only for 11% to 13% of the total impact.

Overall, for energy demand the resource use of the PEA alternatives is reduced by 5% to 10% compared to SOY (Tab. 15), which is considered to be an improvement in the environmental impacts (Tab. 5).

Global Warming Potential

The results for the global warming potential show that the production of soya has a lower environmental impact than the feed components replacing it have in the pea formulas (i.e. peas, soya, rape seed meal, Fig. 24). Still, the total impact of the soya formulas is higher than of the pea formulas. This is due to the greater quantities of cereals used in the soya formulas compared to the pea formulas. Similarly to the energy demand, transport has a greater impact in soya formulas than in pea formulas. The significance of raw material production is even greater in this impact category than for the energy demand, ranging from 80% to 88% of the total impact.

In total, the impact on global warming potential of the PEA feeds is between 4% and 8% less than the SOY feeds (Tab. 15). This reduction is an improvement in the environmental impacts compared to SOY (Tab. 5).

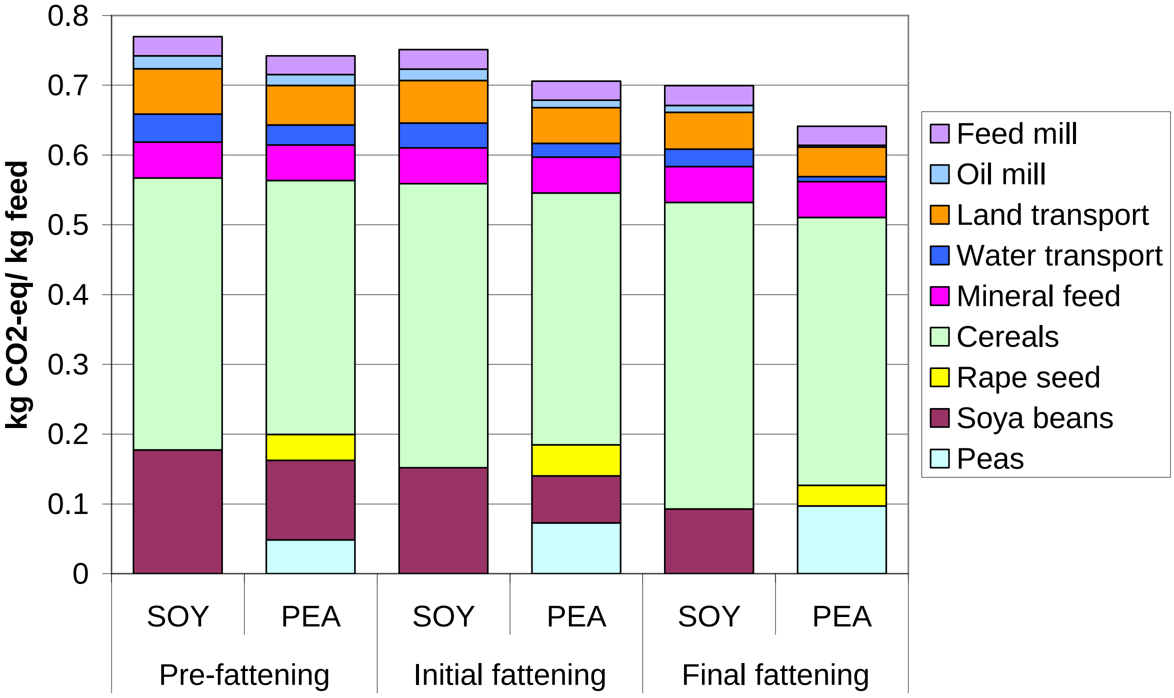

Fig. 24: Results for the six feed formulas for the impact category global warming potential over 100 years shown in kg CO_2-equivalents per kg feed. SOY: Feed formulas based on soya bean meal and cereals; PEA: Feed formulas based on peas, rape seed meal, soya bean meal and cereals (see Tab. 2 for details of feed composition).

Eutrophication

The production of peas, rape seed and soya beans as a replacement for soya beans has higher environmental impacts for the category eutrophication than soya bean production alone. Because the share of cereals is larger in the soya formulas, the total impact of the production of raw materials is higher in the soya than in the pea formulas. Raw material production accounts for 96% to 98% of the total impact (Fig. 25). Transport and processing are of minor importance.

The potential N eutrophication is similar for both formulas, but with a tendency to a favourable impact for the pea alternative (Tab. 15). The reason is that in the soya formulas the cereal share is bigger than in the pea formulas, because peas partly replace cereals as an energy supply. Whereas peas and soya beans are grown without the application of N fertiliser, rape seed, wheat and barley received 113 kg N/ha, 175 kg N/ha and 135 kg N/ha respectively in this study; per kg produce this corresponds to 32 g, 24 g and 17 g N. So with the higher proportion of cereals in the soya formulas, there is more N fertilisation per kg feed in the soya formulas.

Contrary to the potential N eutrophication, the potential P eutrophication of pea feeds is similar or has an unfavourable environmental impact compared to soya feeds (Tab. 15). The reason lies again in the share of cereals in the two feed alternatives. Rape seed (17 g), peas (14 g) and soya beans (11 g) received more P fertiliser per kg produced than wheat (8 g) and barley (8 g). The pea feed formulas with a lower share of cereals than the soya alternatives therefore have more P fertilisation per kg feed than the soya feeds.

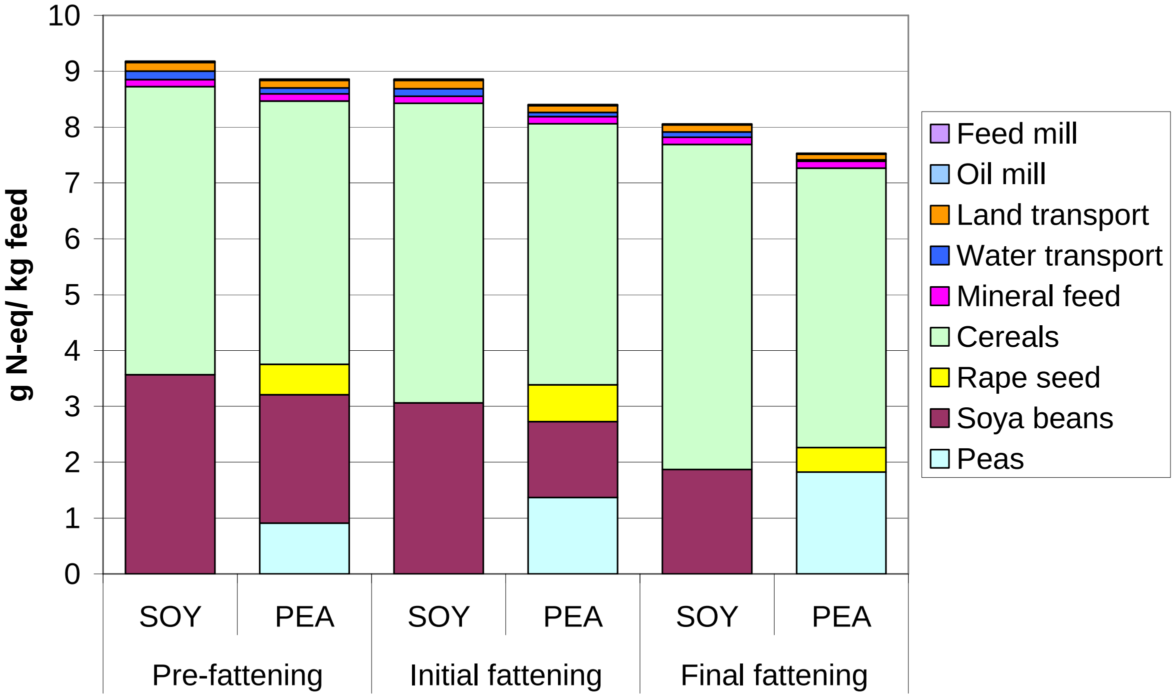

Fig. 25: Results for the six feed formulas for the impact category eutrophication shown in g N-equivalents per kg feed. SOY: Feed formulas based on soya bean meal and cereals; PEA: Feed formulas based on peas, rape seed meal, soya bean meal and cereals (see Tab. 2 for details of feed composition).

The impact of the PEA formulas for the combined N and P eutrophication is between 4% and 7% lower than for the SOY formulas (Tab. 15). This small difference is considered to be within the range of similar results (Tab. 5).

Terrestrial Ecotoxicity

The pea formulas have slightly lower impacts on terrestrial ecotoxicity assessed with EDIP (Haushild & Wenzel 1998) than the soya formulas (Fig. 26). The impact of soya bean production is lower than that of the soya substitutes. But for terrestrial ecotoxicity this is not important, as the protein feed ingredients account for only 0.4% to 7% of the total impact. The dominant impact originates from the cereal production (92.4% to 99.6% of total impact).
According to EDIP the impact on terrestrial ecotoxicity is reduced by 2% to 6% for the PEA feeds compared to the SOY feeds (Tab. 15). However, when applying the assessment classes shown in Tab. 5 the results are considered to be similar.
Contrary to other impact categories, the impact level increases from pre-fattening feed through initial to final fattening feed (Fig. 26), due to the increasing share of cereals in the formulas.

When comparing the standard EDIP method to the alternative CML method (Guinée *et al.* 2001), the results are dramatically changed. Contrary to the results for EDIP, the PEA formulas with CML have a seven- to nine-fold higher impact on terrestrial ecotoxicity than the SOY formulas (Fig. 27).
Both the standard EDIP method and the alternative CML method apply high impact factors to pesticides compared with heavy metals. Within the process of manufacturing pig feed almost all the pesticides are applied for crop production. Of the pesticides used for the five crops in this study, only two seem to have an environmental relevance, when applying the EDIP method: propiconazole (a fungicide used in cereals) with a range of 81% to 87% of the total impact and lambda-cyhalothrin (an insecticide used here in all crops but soya beans) with a range of 12% to 18% of the total impact. The non-use of an environmentally harmful pesticide in soya bean cultivation is the reason for the very low impacts of soya beans. As

the soya feeds contain a higher proportion of cereals, their environmental impacts are higher than those of the pea feeds (Fig. 26).

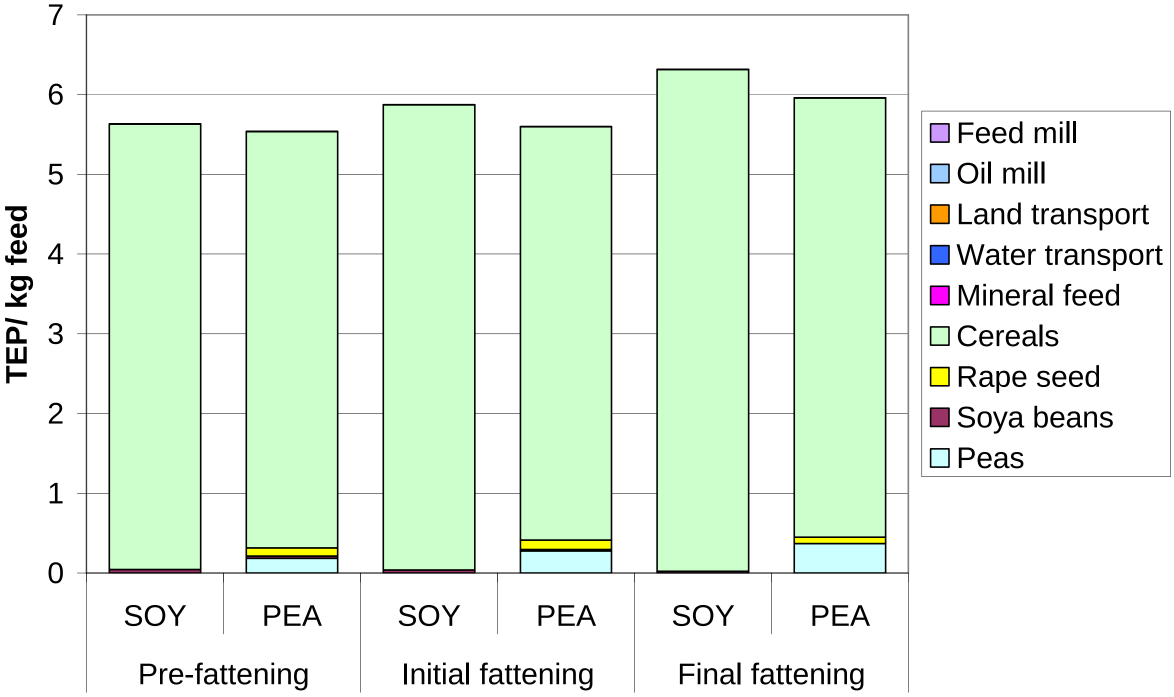

Fig. 26: Results of the six feed formulas for the impact category terrestrial ecotoxicity (EDIP) shown in TEP (Terrestrial Ecotoxicity Points) per kg feed. SOY: Feed formulas based on soya bean meal and cereals; PEA: Feed formulas based on peas, rape seed meal, soya bean meal and cereals (see Tab. 2 for details of feed composition).

When assessing the terrestrial ecotoxicity by the CML method, the following pesticides are of importance: unspecified pesticides, chlormequat chloride (plant growth regulator), fenpropidine (fungicide) and cypermethrin (insecticide). The first three are mainly applied in SOY feeds with a range of 73% to 74% of the total impact; cypermethrin is mainly used in PEA feeds, covering 85% to 89% of the total impact. Cypermethrin is applied only in rape seed, in small quantities, but in CML it has a very high impact factor. This is apparent from the yellow bar in the PEA formulas in Fig. 27. In EDIP the impact factor of cypermethrin is in a medium range. This explains the enormous difference between the results for the two methods.

Note that TEP do not have the same basis in EDIP and CML method (see chapter 4). Hence one cannot compare the absolute results of these two methods.

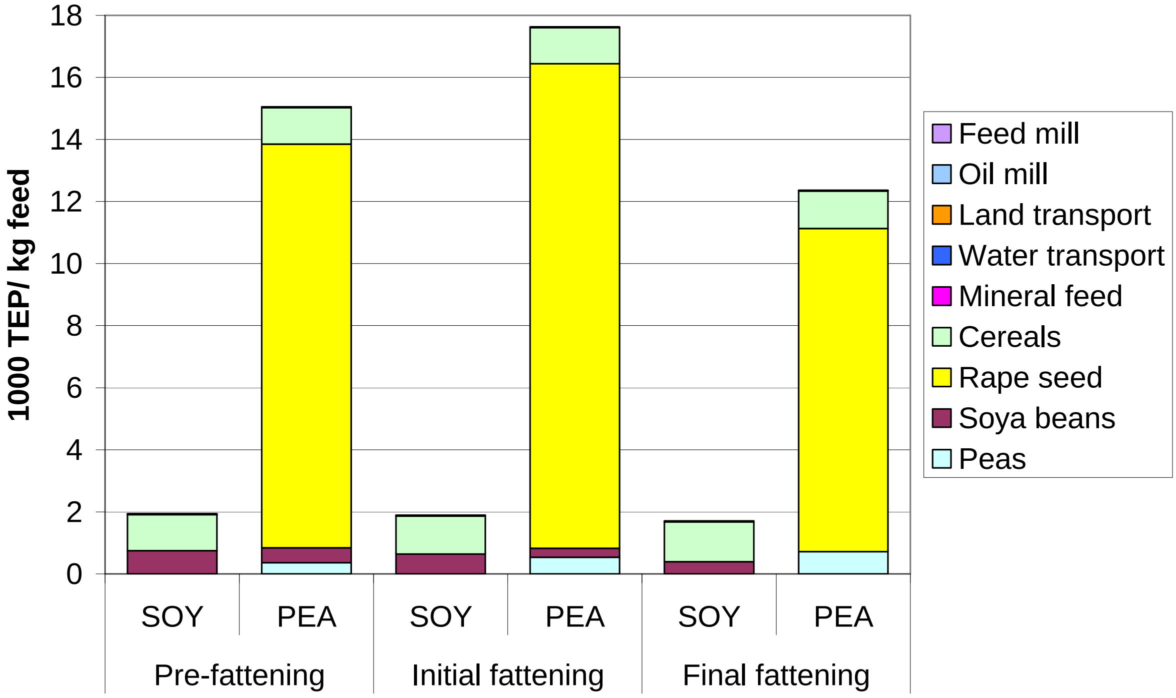

Fig. 27: Results of the six feed formulas for the impact category terrestrial ecotoxicity (CML) shown in 1000 TEP (Terrestrial Ecotoxicity Points) per kg feed. SOY: Feed formulas based on soya bean meal and cereals; PEA: Feed formulas based on peas, rape seed meal, soya bean meal and cereals (see Tab. 2 for details of feed composition).

6.2.2 Summary of the Results

For the three impact categories representing *resource management* (i.e. energy demand, global warming potential and ozone formation) the pea alternative has favourable environmental impacts compared to the soya alternative. The range of the results in these three categories is similar (Tab. 15).

Eutrophication and acidification represent *nutrient management*. Within these categories the results of the comparison between the pea and the soya alternative are not uniform (Tab. 15). For the three categories eutrophication (combined potential of N and P), eutrophication (separate N potential) and acidification, the environmental impact of the pea alternative is similar to the soya alternative with a tendency towards favourable, notably for initial and final fattening. The category eutrophication (separate P potential), being a subset of eutrophication (combined potential of N and P), has similar impacts for the two alternatives of the pre-fattening formulas, but unfavourable impacts for the initial and final fattening pea formulas compared to soya.

Regarding *pollutant management* when using the standard methods by EDIP (Haushild & Wenzel 1998) for ecotoxicity and by CML (Guinée *et al.* 2001) for human toxicity, the environmental impacts are similar except that for aquatic ecotoxicity according to EDIP there is a tendency towards unfavourable impacts for aquatic habitats. However, within pollutant management the results are clearly dependent on the choice of assessment method (see chapter on Terrestrial Ecotoxicity). In Tab. 15 the results of the alternative method CML are shown as well, where the environmental impact of the pea alternative is clearly very unfavourable compared to the soya alternative.

Overall, we can summarise that for all three formulas - pre-fattening, initial fattening and final fattening - the environmental impact of the pea alternative (PEA) is lower than that of the soya alternative (SOY) or there is at least a tendency for the environmental impact of the pea alternative to be lower, with the exception of higher values for ecotoxicity according to CML and potential P eutrophication (Tab. 15).

Tab. 15: Overview of the environmental impacts of feed formulas. Comparison of the pea (PEA) and soya (SOY) alternatives for three feed formulas (see Tab. 2 for details of feed composition).

	Pre-fattening			**Inital fattening**			**Final fattening**		
Summary of the impacts:	**SOY**	**PEA**	**PEA in % SOY**	**SOY**	**PEA**	**PEA in % SOY**	**SOY**	**PEA**	**PEA in % SOY**
energy demand [MJ-eq/ kg feed]	6.67E+00	6.35E+00	95%	6.48E+00	6.00E+00	93%	6.01E+00	5.40E+00	90%
global warming potential [kg CO2-eq/ kg feed]	7.70E-01	7.42E-01	96%	7.51E-01	7.06E-01	94%	7.00E-01	6.41E-01	92%
ozone formation [g ethylene-eq/ kg feed]	2.09E-01	2.00E-01	96%	2.01E-01	1.89E-01	94%	1.82E-01	1.68E-01	92%
eutrophication, combined potential N & P [g N-eq/ kg feed]	9.18E+00	8.86E+00	96%	8.86E+00	8.40E+00	95%	8.06E+00	7.53E+00	93%
eutrophication, separate N potential [g N-eq/ kg feed]	7.98E+00	7.59E+00	95%	7.70E+00	7.15E+00	93%	7.02E+00	6.37E+00	91%
eutrophication, separate P potential [g P-eq/ kg feed]	1.65E-01	1.75E-01	106%	1.59E-01	1.73E-01	109%	1.44E-01	1.60E-01	111%
acidifaction [g SO2-eq/ kg feed]	4.28E+00	4.06E+00	95%	4.20E+00	3.84E+00	91%	3.97E+00	3.49E+00	88%
terrestrial ecotoxicity EDIP [points/ kg feed]	5.63E+00	5.54E+00	98%	5.88E+00	5.60E+00	95%	6.32E+00	5.96E+00	94%
aquatic ecotoxicity EDIP [points/ kg feed]	6.11E-01	6.54E-01	107%	5.83E-01	6.41E-01	110%	5.08E-01	5.80E-01	114%
terrestrial ecotoxicity CML [points/ kg feed]	1.94E-03	1.51E-02	775%	1.90E-03	1.76E-02	929%	1.71E-03	1.24E-02	722%
aquatic ecotoxicity CML [points/ kg feed]	2.73E-02	5.89E-02	216%	2.68E-02	6.48E-02	242%	2.48E-02	5.21E-02	210%
human toxicity CML [points/ kg feed]	1.30E-01	1.33E-01	103%	1.28E-01	1.31E-01	103%	1.23E-01	1.24E-01	101%

In most impact categories there is a decrease of environmental impacts from pre-fattening through initial to final fattening feed, which is explained by the decreasing share of soya meal in the formula and the increasing share of cereals. The exceptions are terrestrial ecotoxicity by EDIP and aquatic toxicity by CML (Tab. 15).

6.2.3 Sensitivity Analysis of Allocation Factors for the Oil Extracting Process

A sensitivity analysis has been performed to assess the influence of the choice of allocation factors in the oil extracting process. The standard allocation, as described in 2.2.5 and shown in Tab. 3, is compared with an allocation procedure where the economic allocation (e.g. for electricity or waste) is replaced by mass allocation (Tab. 16).

Tab. 16: Allocation factors for sensitivity analysis of pig feed study. Changed factors are shown in colour.

Product / process	Unit	**Soya**		**Oil seed rape**		**Allocation**
		oil	meal	oil	meal	***mass***
soya	[kg]	18%	82%			mass
oil seed rape	[kg]			42%	58%	mass
hexane	[kg]	100%	0%	100%	0%	no allocation [4]
electricity	[MJ]	18%	82%	42%	58%	mass
fuel oil	[MJ]	18%	82%	42%	58%	mass
natural gas	[MJ]	18%	82%	42%	58%	mass
water	[m3]	18%	82%	42%	58%	mass
hexane emission in air	[kg]	100%	0%	100%	0%	mass
waste	[kg]	18%	82%	42%	58%	mass
sewage	[m3]	18%	82%	42%	58%	mass
transport lorry	[km]	18%	82%	42%	58%	mass
transport rail	[km]	18%	82%	42%	58%	mass
transport barge	[km]	18%	82%	42%	58%	mass
transport vessel	[km]	18%	82%	42%	58%	mass

---

[4] Hexane is solely used for the oil extracting process. Therefore it is fully attributed to the oil.

The use of mass allocation factors instead of economic ones for the process inputs and outputs of soya oil and rape seed oil extraction has led to minimal changes in the results for the different impact categories (see Appendix 3).

For most categories the changes were less than 1% when comparing the results of the standard allocation procedure to the results obtained with the mass allocation procedure for each feed formula and protein alternative. The maximum deviation was 2%.

When comparing the results for the PEA alternative with the SOY alternative of the corresponding formulas the results altered by a maximum of 1% (see Appendix 3).

Because of the minimal changes in the results, the interpretation and conclusions regarding the impacts remain the same.

7 Discussion

7.1 Grain Legumes in Crop Rotations

What is the effect of introducing grain legumes into European crop rotations? What changes in the environmental impacts are to be expected?
The answer depends on the following aspects:

- the considered crop rotations,
- the considered impacts and
- the considered function of the agricultural system.

7.1.1 Effect of the Crop Rotation

From the four case studies it seems that the advantages of introducing grain legumes are greatest in crop rotations with a large share of cereals and a high level of N fertilisation. Two effects have to be distinguished (Jensen 2006):

- the nitrogen effect of legumes and
- the break-crop effect.

Through symbiotic nitrogen fixation (SNF), legumes have several effects on the nitrogen cycle that influence the management practices (N fertilisation) and also the nitrogenous emissions (Fuhrer 2006). However, we should also consider that not all changes in nitrogenous emissions are related to SNF: e.g. the fact that an autumn-sown crop (winter wheat) is replaced by a spring-sown one (spring peas). In regions with cold winters, winter peas cannot be grown. The period of bare soil in winter leads to higher nitrate losses; this effect, however, has nothing to do with SNF and would also occur with other spring-sown crops.

The break-crop effect is not specific to grain legumes; this is a diversification of the crop rotation which corresponds to good agricultural practice. Savings of pesticides are an example of such a break-crop effect (Munier-Jolain & Collard 2006). In regions where crop rotations are quite diverse, like in Switzerland, there is no break-crop effect.

7.1.2 Considered Impacts

The main advantage of introducing grain legumes lies in the saving of resources, particularly fossil fuels. Manufacturing nitrogen fertiliser requires a massive use of fossil fuel (especially natural gas, Nemecek & Erzinger 2005). Legumes offer an excellent opportunity for reducing the use of fossil fuels. This advantage can be expected to become more important in the future, since fossil fuels will get more expensive and will be increasingly depleted. The reduction of the global warming potential is a further benefit of growing grain legumes. Increasing areas of grain legumes would therefore contribute to an improved balance of greenhouse gases. The ozone formation potential is reduced as well, with positive effects on human health and ecosystem quality.

Regarding nutrient management, the N emissions ammonia and nitrous oxide are reduced, thanks to the lower use of N fertilisers. As a consequence we find significantly reduced acidification potentials. On the contrary, nitrate leaching tends to be higher for the crop rotations with grain legumes. This is partly due to the fact that grain legumes fix nitrogen, and effects that are related to this property (higher nitrogen content in the biomass, lower N uptake from the soil, etc.). Partly this is also linked to other properties of the crop or its management, e.g. the pea’s relatively shallow root system, or the sowing and harvest dates (Carrouée *et al.* 2006). The total eutrophication potential is therefore approximately at the same level for the crop rotations compared.

Concerning pollutant management, we can expect advantages from the introduction of grain legumes into cropping systems that have a very large share of cereals. Such crop rotations sometimes resemble a monoculture and thus greatly profit from diversification, which helps the farmer to avoid or reduce problems with soil pathogens and weeds. This is not an effect specific to legumes.

Regarding biodiversity and soil quality, no relevant effect has been detected in the case study in Vaud, where the methods have been applied. The higher biodiversity potential which was calculated for the particular case study in Vaud cannot be generalised, since the result would have been different if another crop rather than maize had been replaced by a grain legume.

7.1.3 Considered Function of the Cropping System

The result of the assessment also depends on the considered function of the system. We get nearly identical results if we consider the land management or financial functions. The gross margins per ha differ by only a few percent in favour of CR2; in consequence the results are very similar.

A quite different picture emerges when we consider the productive function. The gross energy production is between 1% and 19% lower for the alternative crop rotation with grain legumes. The area productivity of grain legumes is clearly lower than that of cereals. The assimilation of nitrogen by *Rhizobia* requires energy, which is supplied mainly in the form of carbohydrates by the plant. Therefore we get higher protein production, but at the expense of diminished carbohydrate production. Gross energy is not the only possibility for assessing the productive function. In particular, it does not take the protein content of the product into account. One could imagine various other functional units that would more closely represent the nutritional value of the harvested products.

We have chosen not to do this and have opted for a different approach: the nutritional value of the products is evaluated at the level of the feed formula in the present study. This obviates the need for complicated constructs that are difficult to justify and to communicate.

7.2 Grain Legumes in Feed Formulas

What is the effect of introducing grain legumes into pig feed formulas? What environmental impacts can be expected? What are the main factors of those impacts?

The results show that the majority of the environmental impacts are reduced when the protein supply in pig feed formulas is shifted from soya bean meal produced in South America, as is the current practice, to grain legumes produced in Europe. These findings are similar to literature results for France (van der Werf *et al.*, 2005). In accordance with van der Werf *et al.* (2005) the pre-fattening feed for piglets has the highest impact values except for terrestrial ecotoxicity.

The energy demand of crop production does not differ much between the pea and soya alternatives. Van der Werf *et al.* (2005) found that almost 60% of the energy demand was due to crop production. This corresponds with our results, where the range is between 62% and 74%. The same concordance is found for feed manufacturing and transport. The main difference occurs from transport over land and water, as described in chapter 6.2. The results of the environmental impacts indicate the importance of such transport. Part of the negative impacts through transport is due to the rather poor transport infrastructure in Brazil (McVey *et al.* 2000). About 80% of Brazil's soya beans are hauled to the market by lorry. The railways offer no alternative, as they have been neglected for years and are in poor physical condition. River transportation is more promising, but still requires lorry transport over long distances to the barge loading facilities (as used in the present study).

Furthermore, from the results of our study we can assume that choosing feed ingredients from local production or even on-farm produce would lessen the energy demand even further. This confirms the results of Cederberg & Flysjö (2004), who found important advantages for on-farm produced feed, especially protein feed in respect to energy demand. Eriksson *et al.* (2005) as well as Sonesson & Baumgartner (2006) concluded that the

replacement of soya bean products by domestic protein sources has lower environmental impacts.
The use of peas as a protein source has advantages not only in terms of energy demand, due to less transport than in the case of soya beans, but also due to a reduction of fertiliser use for the following crops. In addition to replacing the protein delivered by soya bean meal, peas also cover parts of the energy requirements of the fattened pigs. As a consequence, the share of cereals is reduced in the PEA feeds.

Cereals have, as this study has shown, negative impacts compared with peas as regards energy demand, global warming potential and also eutrophication. This is mainly due to the use of mineral fertilisers, especially N fertilisers. Unlike cereals, peas receive no N fertiliser at all. The production of N fertiliser involves high energy consumption and energy is needed to transport the N fertiliser to the cereal farms. Half of the global warming potential impact is due to nitrous oxide (N_2O). It originates mainly from crop production where there are direct field emissions from the use of fertilisers and the indirect emissions from N fertiliser manufacturing. Eutrophication is dominated by crop production, which is in correspondence with the findings of other authors (van der Werf *et al.* 2005; Eriksson *et al.* 2005; Cederberg & Flysjö 2004). The main emission is nitrate (NO_3^-) into ground water at about 60%, followed by phosphates (PO_4^{3-}) into surface water at 10%, nitrous oxide (N_2O; 9%), nitrogen oxides (NO_x; 8%) and ammonia (NH_3; 5%) into the air. Nitrate, nitrous oxide and ammonia emissions are related to the use of N fertiliser.
The analysis of the results for terrestrial ecotoxicity has shown that crop production is the sole process contributing to this impact category, with cereals accounting for over 92% of the total impact. This result is in conformance with the findings of van der Werf *et al.* (2005). These authors, however, did not consider the impact of pesticides in their study. For terrestrial ecotoxicity only the heavy metals were assessed. The fungicides applied in cereal production have comparatively negative environmental impacts. However, the present study shows that the results for terrestrial ecotoxicity are very much dependent on the chosen method. The substitution of a single pesticide can alter the results completely.
Overall, by having a higher share of cereals in the SOY feeds the impacts of these formulas are greater than of the PEA ones, due not only to less transport of the protein source, but also to the higher impacts of cereals compared with peas. We conclude that using cereals from low input production would help to decrease the impact level of the pig feeds.

Whereas in this pilot study we focussed on the replacement of soya beans as a protein supply because of the long transport distances, other optimisation strategies can be followed in order to reduce environmental impacts, e.g. reduction of excess N and P by improved feeding (Dourmad *et al.* 2006). But the reduction of N excretion could result in a profound reduction in the proportion of peas in the diet. Therefore Dourmad *et al.* (2006) made an assessment at farm level using an optimisation model. They took into account the production of peas on the farm, its interactions with the production of other crops and the consequences for farm operations, e.g. less fertilisation. Even though the greater incorporation of peas into pig diets resulted in more N excretion per pig produced, the excess N per ha per year was reduced at farm level, mainly due to the reduced use of N fertiliser. However, the improved N balance at farm level seems highly dependent on the relation between pig production intensity and farm size. In a situation where only a limited part of the peas can be produced on-farm, the advantages for the farm N balance vanish (Dourmad *et al.* 2006).

Overall, crop production is the dominant process of the pig feed production. For the main impact categories it ranges between 51% and 99%. Hence it is of paramount importance to reduce the environmental impacts of crop production in order to obtain more environmentally sound pig feed.

The pilot study presented here gives interesting insights into the environmental consequences of replacing soya beans from Brazil by German-grown peas. Assessing at feed formula level seems more advisable than at single ingredient level, as it takes the share of the feedstuff in the diet into account. However, to assess the environmental impacts of pork production the system boundary has to be extended by including animal husbandry as well as the entire food chain all the way to the plate. This integrated approach should allow a better understanding of the consumption of pig meat by humans.

8 Conclusions and Outlook

Based on these four case studies at crop rotation level in Germany, France, Switzerland and Spain we conclude that the introduction of grain legumes into intensive crop rotations with a high proportion of cereals and intensive N-fertilisation is likely to reduce energy use, global warming potential, ozone formation and acidification as well as eco- and human toxicity per unit of cultivated area. The main reasons for this are a reduced application of N-fertilisers (no N to the grain legume and less N to the following crop), improved possibilities for using reduced tillage techniques and greater diversification of the crop rotation, which helps to reduce problems with weeds and pathogens (and therefore to reduce pesticide applications).

The nitrate leaching potential tends to be higher with grain legumes in general, an effect which is only partly related to symbiotic nitrogen fixation. Other parameters, like the short crop cycle and the shallow rooting of some grain legumes, play an important role as well. Nitrate leaching can be reduced by including catch crops or sowing winter grain legumes, where possible.

No differences were found for the impacts of crop management on soil quality and biodiversity; these impacts were studied in the Canton Vaud region only. In low-input crop rotations like the one in Spain, no significant changes in environmental impacts are to be expected, especially when a break-crop is replaced by a grain legume.

The analysis per gross margin 1 (financial function) led to slightly more favourable results for the grain legume crop rotations compared to the analysis per ha per year. Due to the lower yields of grain legumes compared with cereals, the advantages of grain legumes are smaller when considered per GJ gross energy of the harvested products (productive function). However, energy efficiency was higher in crop rotations with grain legumes.

Therefore, introducing grain legumes into European crop rotations offers interesting options for reducing environmental burdens, especially in a context of depleted fossil energy resources and climate change.

The LCA case study of pig feed formulas in North-West Germany has led to the following conclusions:

- Overall there is an environmental benefit from replacing soya beans produced in South America by grain legumes (and rape seed) produced in Europe.
- The greatest benefits are obtained for the impacts of resource management followed by the impacts of nutrient management. The least environmental benefit is seen for pollutant management. For ecotoxicity the results are very dependent on the pesticides applied and the choice of the assessment method. Generally it can be said that the larger the share of the crop production on the total impact, the smaller the environmental benefits from pea formulas compared to soya formulas.
- Crop production of the feed ingredients is the dominant process within the production of pig feed, with a minimum of 50% of the total impact of an impact category, followed by transport and production of mineral feed. Consequently, reducing the environmental impacts of crop production is of high importance. The processing of the feed ingredients in the feed and oil mills is of minor importance for all the main environmental impacts.
- Four factors have to be considered when assessing the environmental impacts of pig feed formulas: reducing the share of soya bean meal in the formulas, lessening the proportion of cereals in the formulas, minimising the transport of the feed ingredients, notably the protein concentrates, will improve the environmental impacts of pig compound feeds. In addition, a low ratio between the means of production applied and the yield level of the different crops is favourable for reducing the environmental impacts.

The LCA of feed formulas is a pilot study which gives first insights into the environmental effects of replacing South American soya beans by grain legumes produced in Europe in animal feed. Further and more extensive studies are needed to reach a better assessment of the use of animal feeds. The logical continuation is to extend the system boundary and include animal production and human nutrition. This will be done within the integrated project

GLIP (6th EU RTD framework programme, integrated project “New strategies to improve grain legumes for food and feed”, FP6-506223, see www.eugrainlegumes.org).

9 References

AEP (ed.) 2006. Grain legumes and the environment: how to assess benefits and impacts? 18.-19.11.2004, Zurich. AEP & FAL, AEP workshop, 226 p.

Basset-Mens C. & van der Werf H., 2005. Scenario-based environmental assessment of farming systems: The case of pig production in France. Agriculture, Ecosystems and Environment, **105**: 127-144.

Blonk H. & Effting S., 2001. Life cycle analysis of the pig meat production system to select improvement options for fodder production. In: Geerken T., Mattsson B., Olsson P. & Johansson E. (eds.). Proceedings of the International Conference on LCA in Foods. Gothenburg: SIK, VITO, 2001, 17-21.

Carrouée B., Aveline A., Biarnes V., Charles R., Crozat Y., Jensen E. S., Laurent F., Munier-Jolain N., Thévenet G. & Viaux Ph., 2002. Effets environnementaux des protéagineux dans les rotations de grandes cultures. Working document, UNIP, ITCF, INRA, ESA, Paris, 32 p.

Carrouée B., Bourgeais E. & Aveline A., 2006. Nitrate leaching related to dry pea in arable crop rotations. In: AEP (ed.), Grain legumes and the environment: how to assess benefits and impacts, 18.-19.11.2004, Zurich. AEP & FAL, 117-124.

Cederberg Ch. & Flysjö A., 2004. Environmental assessment of future pig farming systems - Quantifications of three scenarios from the FOOD 21 synthesis work. SIK - The Swedish Institute for Food and Biotechnology, Göteborg; SIK-rapport 723, 64 p.

Charles R. & Gosse G., 2002. Environmental impact related to nitrogenous emissions from crop of peas and wheat. Grain Legumes, **36**: 20.

Charles R. & Nemecek T., 2002. A standardised method to assess the environmental impact of grain legumes. Grain Legumes **36**, 18-19.

Charles R. & Vullioud P., 2000. Pois protéagineux et azote dans la rotation. Revue Suisse d'Agriculture, **33** (6): 265-270.

Crépon K., Cottrill B., Cechura L., Hucko J., Miguelañez R. & Pressenda F., 2005. Animal production sectors in seven European countries: Synthetic studies preceding the building of models simulating the raw materials supply of feed compounders. GLIP report. 80 p.

Crews T. E. & Peoples M. B., 2004. Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. Agriculture Ecosystems & Environment, **102**: 279-297.

Dourmad J.-Y., Dronne Y. & Baudon E., 2006. Evaluation of emissions from pig production with special emphasis on the feeding of peas. In: AEP (ed.), Grain legumes and the environment: how to assess benefits and impacts, 18.-19.11.2004, Zurich. AEP & FAL, 139-145.

DZV, 1998. Verordnung über die Direktzahlungen an die Landwirtschaft (Direktzahlungsverordnung, DZV). Bern, 46 p.

Eriksson I. S., Elmquist H., Stern S. & Nybrant T., 2005. Environmental systems analysis of pig production – The impact of feed choice. Int J LCA, **10** (2): 143-154.

Freiermuth R., 2006. Modell zur Berechnung der Schwermetallflüsse in der Landwirtschaftlichen Ökobilanz. Agroscope FAL Reckenholz, 42 p.

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Hellweg S., Hischier R., Nemecek T., Rebitzer G. & Spielmann M., 2004a. Overview and Methodology - ecoinvent data v1.1. Swiss Centre for Life Cycle Inventories (ecoinvent), Dübendorf; ecoinvent report 1, 75 p.

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Hellweg S., Hischier R., Nemecek T., Margni M. & Spielmann M., 2004b. Implementation of life cycle assessment methods – ecoinvent data v1.1. Swiss Centre for Life Cycle Inventories (ecoinvent), Dübendorf; ecoinvent report 3, 116 S.

Fuhrer J., 2006. Environmental aspects of the nitrogen cycle in legume-based cropping systems. In: AEP (ed.), Grain legumes and the environment: how to assess benefits and impacts? 18.-19.11.2004, Zurich. AEP & FAL, 85-91.

Gaillard G., Freiermuth R., Baumgartner D., Calanca P. L., Jeanneret P., Nemecek T., Oberholzer H. R., Prasuhn V., Richner W. & Weisskopf P., 2006. Methode zur Ökobilanzierung landwirtschaftlicher Systeme. Schriftenreihe der ART, in prep.

Guinée J. B., Gorrée M., Heijungs R., Huppes G., Kleijn R., de Koning A., van Oers L., Wegener Sleeswijk A., Suh S., Udo de Haes H. A., de Bruijn H., van Duin R., Huijbregts M. A. J., Lindeijer E., Roorda A. A. H. & Weidema B. P., 2001. Life cycle assessment - An operational guide to the ISO standards. Ministry of Housing, Spatial Planning and Environment (VROM) and Centre of Environmental Science (CML), Den Haag and Leiden, Netherlands.

Hauschild M. & Wenzel H., 1998. Environmental assessment of products. Vol. 2: Scientific background. Chapman & Hall, London, 565 p.

IPCC, 2001. Climate Change 2001: The Scientific Basis. In: Houghton, J. T. *et al.* (eds.), Third

Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). IPCC, Intergovernmental Panel on Climate Change, Cambridge University Press, The Edinburgh Building, Shaftesbury Road, Cambridge, UK.

Jeanneret P., Baumgartner D., Freiermuth R. & Gaillard G., 2006. Méthode d'évaluation de l'impact des activités agricoles sur la biodiversité dans les bilans écologiques – SALCA-BD. Agroscope FAL Reckenholz, Online at http://www.reckenholz.ch/doc/fr/forsch/control/bilanz/salca-bd.pdf, 67 p.

Jensen E. S., 1997. The role of grain legume N_2 fixation in the nitrogen cycling of temperate cropping systems. Risø National Laboratory, Roskilde.

Jensen E. S., 2006. Grain legume functions in crop rotations. In: AEP (ed.), Grain legumes and the environment: how to assess benefits and impacts, 18.-19.11.2004, Zurich. AEP & FAL, Paris, 49-54.

Köpke U., 1996. Symbiotische Stickstofffixierung und Vorfruchtwirkung von Ackerbohnen (*Vicia faba* L.). Verlag Dr. Köster, Berlin; Schriftenreihe Institut für Organischen Landbau.

McVey M., Baumel Ph., Wisner B., 2000, accessed 14.02.06. Brazilian soybeans – Transportation problems. http://www.extension.iastate.edu/agdm/homepage.html.

Menzi H., Frick R. & Kaufmann R., 1997. Ammoniak-Emissionen in der Schweiz: Ausmass und technische Beurteilung des Reduktionspotentials. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau, Zürich-Reckenholz; Schriftenreihe der FAL 26, 107 p.

Munier-Jolain N., 2002. The long-term impact of grain legumes on the environment: possibilities for reducing herbicides. Grain Legumes, **36**: 16-17.

Munier-Jolain N. & Collard A., 2006. Grain legumes and weed management in crop rotations: opportunities and methodologies for reducing environmental impacts of weed control. In: AEP (ed.), Grain legumes and the environment: how to assess benefits and impacts? 18.-19.11.2004, Zurich. AEP & FAL, 67-72.

Nemecek T. & Erzinger S., 2005. Modelling representative life cycle inventories for Swiss arable crops. Int J LCA, **10**: 68-76.

Nemecek T., Heil A., Huguenin O., Meier S. Erzinger S., Blaser S., Dux D. & Zimmermann A., 2004. Life cycle inventories of agricultural production systems - ecoinvent data v1.1. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.; ecoinvent report 15, 289 p.

Nemecek T., Huguenin-Elie O., Dubois D. & Gaillard G., 2005. Ökobilanzierung von Anbausystemen im schweizerischen Acker- und Futterbau. Agroscope FAL Reckenholz, Zürich; Schriftenreihe der FAL 58, 155 p.

Oberholzer H.-R., Weisskopf P., Gaillard G., Weiss F. & Freiermuth R., 2006. Methode zur Beurteilung der Wirkungen landwirtschaftlicher Bewirtschaftung auf die Bodenqualität in Ökobilanzen – SALCA-SQ. Agroscope FAL Reckenholz, Online at http://www.reckenholz.ch/doc/de/forsch/control/bilanz/salca-sq.pdf, 98 p.

Ostermayer A., Berger J., Detzel A., Knappe F., Vogt R. & Giegrich J., 2002. Ökobilanz für DL-Methionin in der Geflügelmast. ifeu GmbH, Heidelberg, 180 p.

Prasuhn V., 2006. Erfassung der PO_4-Austräge für die Ökobilanzierung - SALCA-Phosphor. Online at http://www.reckenholz.ch/doc/de/forsch/control/bilanz/publ9905.pdf, Zürich, 22 p.

Richner W., Oberholzer H.-R., Freiermuth R. & Walther U., 2006. Modell zur Beurteilung des Nitratauswaschungspotenzials in Ökobilanzen - SALCA-NO3. Unter Berücksichtigung der Bewirtschaftung (Fruchtfolge, Bodenbearbeitung, N-Düngung), der mikrobiellen Nitratbildung im Boden, der Stickstoffaufnahme durch die Pflanzen und verschiedener Bodeneigenschaften. Agroscope FAL Reckenholz. Online at http://www.reckenholz.ch/doc/de/forsch/control/bilanz/publ9905.pdf, 25 p.

Smith K. A., 2006. Nitrous oxide emissions from grain legume crops. In: AEP (ed.), Grain legumes and the environment: how to assess benefits and impacts, 18.-19.11.2004, Zurich. AEP & FAL, Paris, 93-98.

Schmid M., Neftel A. & Fuhrer J., 2000. Lachgasemissionen aus der Schweizer Landwirtschaft. FAL; Schriftenreihe der FAL 33, 131 p.

Sonesson U. & Baumgartner D., 2006. Environmental benefits of grain legumes for food and feed. In: Proceedings of the GL-Pro dissemination event, 3 May 2006, Brussels, Belgium, 85-94.

The Times Comprehensive Atlas of the World, 1999. 10th Edition, Times Books, London, United Kingdom. p. 544.

USDA 2006. Brazil Soybean Production Statistics. Retrieved on 15.02.2006 from http://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/Brazil/BrazilSoybean.pdf.

van der Werf H., Petit J. & Sanders J., 2005. The environmental impacts of the production of concentrated feed: The case of pig feed in Bretagne. Agricultural Systems, **83**: 153-177.

Vocanson A., Jeuffroy M. H., Grandeau G. & Le Fouillen B., 2006. Introducing winter pea in crop rotations: a solution to improve nitrogen budget? In: AEP (ed.), Grain legumes and the environment: how to assess benefits and impacts, 18.-19.11.2004, Zurich. AEP & FAL, 193-

195.

von Richthofen J.S., Pahl H., Nemecek T., Odermatt O., Charles R., Casta P., Sombrero A., Lafarga A., Dubois G., 2006. Economic interest of grain legumes in European crop rotations. GL-Pro report, WP3.

World Weather Information Service, 2006. Climatological information Cuiaba, Brazil. Retrieved on 15.02.2006 from http://www.worldweather.org/136/c01065.htm.

10 Appendices

10.1 Appendix 1: Origin of Feed Ingredients and Transport Distances for the Pig Feed Study

Feed ingredients/ Origin	Transport sections	Origin of transported goods	Transport distances (km)	Means of transport	Sources for origin or transport distances	Data sources of production inventory
peas Germany (Lower Saxony)	farm - cooperative	Uelzen District (or Helmstedt)	20	tractor	http://www.nls.niedersachsen.de/Tabellen/Landwirtschaft/nutzungen/sprungbild1.htm	von Richthofen J.S. *et al.* , 2006b
	cooperative - feed mill		300	lorry		
soya bean meal Brazil (Mato Grosso)	farm - cooperative	area around Sapezal	20	tractor		soya bean production inventory in Brazil (see Appendix 2)
	cooperative - inland port BR	Sapezal - Porto Velho	930	lorry	McVey, M., Baumel, Ph., Wisner, B (accessed 14.02.06). Brazilian soybeans - Transportation problems. http://www.extension.iastate.edu/agdm/homepage.html	
	inland port - ocean port BR	Porto Velho - Itacoatiara	970	barge	http://www.extension.iastate.edu/agdm/homepage.html	
	ocean port BR - port NL	Itacoatiara - Rotterdam	9500	ship	http://www.extension.iastate.edu/agdm/homepage.html http://www.distances.com	
	port NL - feed mill	Rotterdam - Münster	300	barge	Times Atlas of the World	
rapeseed meal Germany	farm - cooperative		20	tractor	http://www.ima-agrar.de/Dateien/Rapsanbau_.pdf http://www.statistik-portal.de/Statistik-Portal/de_jb11_jahrtab20.asp http://www.agranet.de/7245.php	von Richthofen J.S. *et al.* , 2006b
	cooperative - oil mill	Freyburg - Salzgitter	150	lorry	Times Atlas of the World	
	oil mill - feed mill	Salzgitter - Münster	320	barge	Times Atlas of the World	
barley North-West Germany	farm - cooperative		20	tractor	http://epp.eurostat.cec.eu.int/cache/ITY_OFFPUB/KS-AF-05-001/DE/KS-AF-05-001-DE.PDF	von Richthofen J.S. *et al.* , 2006b
	cooperative - feed mill		200 200	lorry barge	Times Atlas of the World	
wheat North-West Germany	farm - cooperative		20	tractor	http://epp.eurostat.cec.eu.int/cache/ITY_OFFPUB/KS-AF-05-001/DE/KS-AF-05-001-DE.PDF	von Richthofen J.S. *et al.* , 2006b
	cooperative - feed mill		200 200	lorry barge	Times Atlas of the World	
mineral feed Germany	plant - distribution centre		600	train	Frischknecht R. *et al.* , 2004	http://www.ecoinvent.ch; ecoinvent v1.2
	distribution centre - feed mill		100	lorry	Frischknecht R. *et al.* , 2004	

Conversion

1 mile (international)	1.609 km
1 nautical mile (international)	1.852 km

Basic information is taken from a report on a meeting between J.S. von Richthofen (proPlant GmbH) and H. Jebsen (Head of Feed Department, AGRAVIS AG), 03.02.05
Assumption: Feed mill is in Münster, North-Rhine Westphalia, North-West Germany

10.2 Appendix 2: Production Data used for Calculation of Soya Production in Brazil

Parameter	**Unit**	**Value**	**Remarks**	**Source**
Yield	kg/ha	2660	Average 1998-2002 for Brazil.	USDA 2006 (http://www.usda.gov/oce/weather/pubs/Other/MWCACP/Graphs/Brazil/BrazilSoybean.pdf).
Precipitation during the 6 winter months	mm	272	Cuiaba Station (Mato Grosso, BRA).	World Weather Information Service, (2006): http://www.worldweather.org/136/c01065.htm
Seed	kg/ha	70		Ostermayr *et al*. (2002)
P-fertiliser	kg P2O5/ha	30		
K-fertiliser	kg K2O/ha	30		
Lime	kg CaO/ha	275		
Herbicides	Glyphosate	540		Cederberg & Flysjö (2004)
	2,4-D	250		
	Cletodim	36		
	Lactofen	48		
	Oxasulfuron	22		
	Trifuralin	380		
	Imazaquin	70		
Insecticides	Monocrotofos	160		
	Profenofos	75		
Fungicides	Difenoconazole	50		

10.3 Appendix 3: Results of the Sensitivity Analysis for Altered Allocation Factors in the Oil Extraction Process

		Pre-fattening			**Initial fattening**			**Final fattening**		
Summary of the impacts:	Allocation procedure (see Tab. 16)	**SOY**	**PEA**	**PEA in % SOY**	**SOY**	**PEA**	**PEA in % SOY**	**SOY**	**PEA**	**PEA in % SOY**
energy demand [MJ-eq/ kg feed]	standard	6.67E+00	6.35E+00	95%	6.48E+00	6.00E+00	93%	6.01E+00	5.40E+00	90%
	mass	6.73E+00	6.46E+00	96%	6.53E+00	6.11E+00	94%	6.04E+00	5.46E+00	90%
	mass in % standard	100.9%	101.8%		100.8%	101.9%		100.6%	101.1%	
global warming potential [kg CO2-eq/ kg feed]	standard	7.70E-01	7.42E-01	96%	7.51E-01	7.06E-01	94%	7.00E-01	6.41E-01	92%
	mass	7.74E-01	7.49E-01	97%	7.54E-01	7.13E-01	94%	7.02E-01	6.45E-01	92%
	mass in % standard	100.5%	101.0%		100.4%	101.0%		100.3%	100.6%	
ozone formation [g ethylene-eq/ kg feed]	standard	2.09E-01	2.00E-01	96%	2.01E-01	1.89E-01	94%	1.82E-01	1.68E-01	92%
	mass	2.09E-01	2.01E-01	96%	2.01E-01	1.90E-01	95%	1.82E-01	1.69E-01	93%
	mass in % standard	100.3%	100.7%		100.3%	100.7%		100.2%	100.4%	
eutrophication, combined potential N & P [g N-eq/ kg feed]	standard	9.18E+00	8.86E+00	96%	8.86E+00	8.40E+00	95%	8.06E+00	7.53E+00	93%
	mass	9.18E+00	8.86E+00	96%	8.86E+00	8.41E+00	95%	8.06E+00	7.53E+00	93%
	mass in % standard	100.0%	100.0%		100.0%	100.0%		100.0%	100.0%	
eutrophication, separate N potential [g N-eq/ kg feed]	standard	7.98E+00	7.59E+00	95%	7.70E+00	7.15E+00	93%	7.02E+00	6.37E+00	91%
	mass	7.99E+00	7.59E+00	95%	7.71E+00	7.15E+00	93%	7.02E+00	6.38E+00	91%
	mass in % standard	100.0%	100.0%		100.0%	100.0%		100.0%	100.0%	
eutrophication, separate P potential [g P-eq/ kg feed]	standard	1.65E-01	1.75E-01	106%	1.59E-01	1.73E-01	109%	1.44E-01	1.60E-01	111%
	mass	1.65E-01	1.75E-01	106%	1.59E-01	1.73E-01	109%	1.44E-01	1.60E-01	111%
	mass in % standard	100.0%	100.0%		100.0%	100.0%		100.0%	100.0%	
acidifaction [g SO2-eq/ kg feed]	standard	4.28E+00	4.06E+00	95%	4.20E+00	3.84E+00	91%	3.97E+00	3.49E+00	88%
	mass	4.29E+00	4.08E+00	95%	4.21E+00	3.86E+00	92%	3.98E+00	3.50E+00	88%
	mass in % standard	100.3%	100.5%		100.2%	100.6%		100.2%	100.3%	
terrestrial ecotoxicity EDIP [points/ kg feed]	standard	5.63E+06	5.54E+06	98%	5.88E+06	5.60E+06	95%	6.32E+06	5.96E+06	94%
	mass	5.63E+06	5.54E+06	98%	5.88E+06	5.60E+06	95%	6.32E+06	5.96E+06	94%
	mass in % standard	100.0%	100.0%		100.0%	100.0%		100.0%	100.0%	
aquatic ecotoxicity EDIP [points/ kg feed]	standard	6.11E+05	6.54E+05	107%	5.83E+05	6.41E+05	110%	5.08E+05	5.80E+05	114%
	mass	6.12E+05	6.54E+05	107%	5.83E+05	6.41E+05	110%	5.08E+05	5.80E+05	114%
	mass in % standard	100.0%	100.0%		100.0%	100.1%		100.0%	100.0%	
terrestrial ecotoxicity CML [points/ kg feed]	standard	1.94E-03	1.51E-02	775%	1.90E-03	1.76E-02	929%	1.71E-03	1.24E-02	722%
	mass	1.94E-03	1.51E-02	775%	1.90E-03	1.76E-02	929%	1.71E-03	1.24E-02	722%
	mass in % standard	100.0%	100.0%		100.0%	100.0%		100.0%	100.0%	
aquatic ecotoxicity CML [points/ kg feed]	standard	2.73E-02	5.89E-02	216%	2.68E-02	6.48E-02	242%	2.48E-02	5.21E-02	210%
	mass	2.73E-02	5.89E-02	216%	2.68E-02	6.48E-02	242%	2.48E-02	5.22E-02	210%
	mass in % standard	100.0%	100.0%		100.0%	100.0%		100.0%	100.0%	
human toxicity CML [points/ kg feed]	standard	1.30E-01	1.33E-01	103%	1.28E-01	1.31E-01	103%	1.23E-01	1.24E-01	101%
	mass	1.30E-01	1.35E-01	104%	1.28E-01	1.33E-01	104%	1.23E-01	1.25E-01	102%
	mass in % standard	100.2%	101.3%		100.2%	101.5%		100.1%	101.0%	