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- A dynamic simulation model of a farm business

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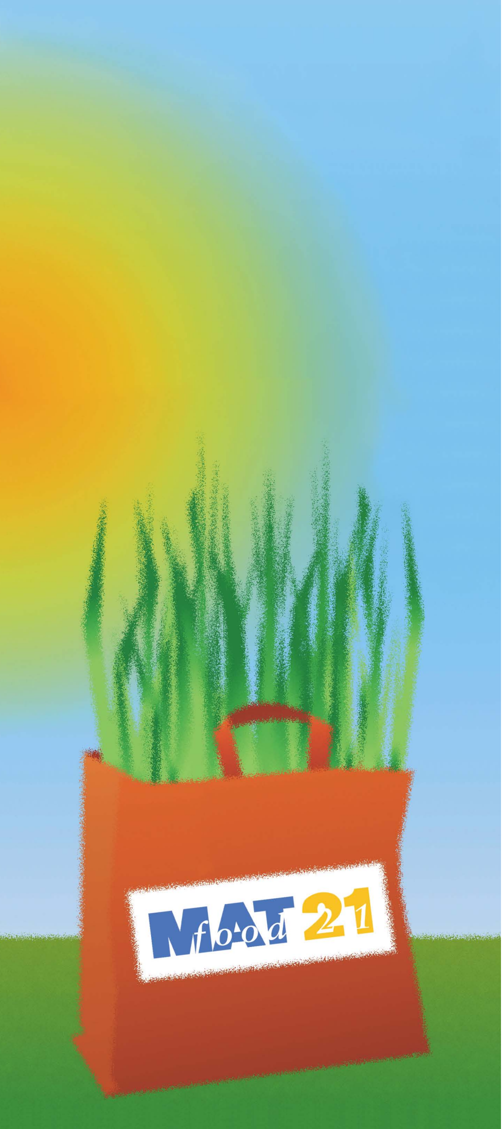

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PREFACE

This study was carried out as an inter-disciplinary research project between the Department of Social and Economic Geography at Umeå University and the Department of Biometry and Engineering (Formerly Agricultural Engineering) at SLU Uppsala.

The basic hypothesis of the work was that microsimulation techniques, mainly used in migration studies, combined with material/substance flow models, could form an integrated model of farm production. This model could be used to investigate how different decision strategies of farmers affect the organic sustainability of the production.

The present work demonstrates that this approach seems to work well and should be seen as a first step in the development of such integrated models. Interesting further development has been identified.

There were three main participants in this study: Urban Lindgren, a human geographer responsible for the decision modelling sections; Kalle Mäkilä, a computer scientist who did the microsimulation programming; and agronomist Helena Elmquist, who worked with the physical flow model. The physical flow model “SALSA“ was constructed by Helena Elmquist together with a biologist, Ingrid Strid Eriksson.

I would like to thank everyone involved for their engagement in the work, including Einar Holm and Sture Öberg who together with myself initially formulated the project.

Thomas Nybrant
Leader of the Systems Analysis and Economics sub-programme in FOOD 21.

CONTENTS

SUMMARY

This report describes an interdisciplinary study combining social sciences and natural sciences in an integrated simulation model. The integrated dynamic simulation model consists of the interplay between the decision-making farmer, the physical flows at the farm and the structural conditions that influence the business. The central question studied here concerned the energy use, environmental impacts and business economics of various decision models in comparison to different levels of environmental concern, costs and revenues.

A basic feature of the simulation model is that human decision-making is integrated with the physical flows at the farm. As a decision-maker in the model, the farmer is allocated different attributes and subjected to various constraints. For example, different levels of knowledge are attributed to him via the decision models, as are variations in acceptance of environmental loadings. Moreover, he has to cope with different levels of prices and subsidies. Three pre-specified crop rotations are implemented and whenever monoculture is employed, the farmer encounters yield reductions.

Emissions to the air and water are connected to soil and plant processes, but also to the production-related choices made by the farmer. Yields, emissions and energy use for the farm production are calculated using a physical flow model – the SALSA model (*S*ystems *A*na*L*ysis for *S*ustainable *A*gricultural production). Simulation outputs are evaluated in terms of their environmental impacts using life cycle assessment methodology. The outputs are expressed as potential contributions to eutrophication, global warming, and acidification, as well as primary energy use per hectare and per kilo product.

The model results show that from an economic point of view, the farmer can choose between two relatively sustainable strategies: either he specialises in organic production or he continues with conventional cultivation and uses large amounts of pesticides and fertilisers. The worst strategy is to combine conventional cultivation with minimal use of pesticides and fertilisers. These findings can be explained by higher prices for organic products and additional financial support via the common agricultural policy (CAP) to organic producers. It seems clear that the conventional farmer's potential to improve his economic situation by making 'better' production-related choices (the difference between the purely rational farmer reflecting the best possible solution and the bounded rational farmer reflecting the everyday situation) is much more confined compared to specializing in organic production. The importance of public spending on farming via subsidies is too extensive in

this respect. The economic potential of improved production-related choices is likely to be less than that related to the differences between the subsidies provided to conventional and organic farmers. Differences in crop prices also play a role in this context. Given the crop prices and yield reductions applied, the results of the simulation model suggest that it is beneficial to the farmer to continue with the pre-specified crop rotations.

Looking at the environmental variables, it turns out that there is no clear-cut divide between the organic and conventional farming scenarios. If conventional and organic feed production systems are to be compared, the system boundary needs to be expanded to include livestock production and upstream inflow of nitrogen. Regarding crops, there are considerable differences in terms of their environmental effects. In terms of emissions and energy use from a production perspective (emissions/energy use per hectare), rye, barley and oats prove to generate less environmental loading compared to wheat, spring oilseed rape and spring turnip rape. However, if the amounts of loading are related to the crop yield, (emissions/energy use per kg product), a somewhat different pattern appears. For example, rye and barley turn out to perform much worse in terms of eutrophication, whereas winter wheat and spring wheat perform much better in this respect. Moreover, rye appears to have a small environmental impact irrespective of the method of calculation (kg/ha or kg/kg). Another conclusion from the study was that the choice of using RME instead of ordinary diesel did not reduce the environmental impact, which is a consequence of the emissions occurring during the production of artificial fertiliser.

1. INTRODUCTION

Since the 1960s, there has been a gradual increase in awareness of environmental problems and much work has been done on defining goals for sustainable development (Carson 1963, Meadows *et al.* 1972, WCED 1987). Today there are a number of fields of research with varying specialisations, for example, eco-restructuring, industrial metabolism, industrial ecology and life cycle analysis (Ayres 1989, Frosch & Gallopoulos 1989, Erkman 1994, Udo de Haes 2002). Most studies in environmental research are, however, contributions from the sphere of the natural sciences, whereas social sciences have just recently begun to show an interest (Landberg 1990, Anderberg 1996). This development is positive and much can be gained from integrating a scientific and technological perspective with a perspective imbued with the attitudes and behaviour of interacting individuals and their social institutions. Such a development is also justified by an increasing awareness of environmental and socio-economic interdependencies.

Here, we argue that environmental problems are the cumulative outcomes of local actions and that sustainable development is very much dependent on co-ordinated human actions throughout the landscape. The failure of such a development so far is conceivably related to the tyranny of small decisions (Kahn 1966), *i.e.* local harmless actions that give rise to unforeseen cones-quences on the macro scale. We are approaching the carrying capacity of the planet (some would argue that we already have exceeded the limits in some respects) and are facing a choice where we either can continue along the present path till the problems force us to change direction, or develop theories and methods in order to delimit the impacts of local actions (Hägerstrand 1989).

There are a vast number of sources that contribute to environmental influence and one of them is agriculture, which is the empirical setting of this study. Obviously, the decisions made by the individual farmer are extremely important, since the farmer has access to the land he owns and can decide how and what to cultivate and how to manipulate the soil. The structural conditions formed by the world around him are admittedly an important factor, but his right of possession to the property is an effective impediment to the actions of other people. The production-orientated decisions made at the farm have environmental impacts at different geographical scales. Locally in the neighbourhood, impacts can be more or less observable to the farmer. Residues from chemical treatments appearing in groundwater and yield losses due to soil compaction or degradation of soil fertility are a few examples thereof. Monoculture cultivations make various sorts of weed and diseases more resistant, which in turn increases the need for intense chemical treatment. At the regional scale a number of problems can be observed: eutrophication due to nitrate and phosphate, soil degradation, loss of species diversity, pesticide residues in the groundwater. Moreover, emissions of CO_2, CH_4 and N_2O, all of which are greenhouse gases, have a potential influence on the greenhouse effect, and the use of energy from limited fossil resources has global effects as well. These impacts are, however, far away from the activities at the farm and difficult for the farmer to grasp.

Consequently, increased insights about the decision-making process at the individual farm are one crucial contribution to the understanding of accumulated pollution patterns and the advancement towards sustainable development. Within the literature the intersection of chemical, biological and anthropogenic systems is identified as an important field of investigation. Since the Brundtland Commission's report *Our Common Future* (WCED, 1987), sustainable development has occupied a place on the global agenda. As regards food production, ecological, economic and social criteria of sustainability must be fulfilled (Öborn *et al.* 2002.) From this point of departure, we have developed a dynamic simulation model that represents the interplay between the decision-making farmer, the physical flows at the farm and the structural conditions that influence the farm business. The farmer has values, attitudes and preferences, which along with economic factors, subsidies and legislation determine the annual choice of production at the farm. Different choices consequently bring environmental impacts such as eutrophication, global warming and acidification. The central question refers to the partial impacts of these factors on environmental loadings and economic performance at the farm. More specifically, what are the impacts on pollution and the economics of the business of various decision principles in *comparison* to different levels of environmental concern, costs and revenues?

1.1 Aim and scope

The main aim of the study was to integrate a model on the physical flows at the farm with a model representing the decision-making farmer and the structural conditions influencing the business. A further aim was to analyse factors affecting farm finances and environmental loadings. In particular, the study focused on the economic and environmental consequences of variations in four different dimensions, *i.e.* prices of input and output goods, subsidies, the farmer's choice of using different amounts of fertilizers, pesticides and type of fuel, and the farmer's skills in making production allocation choices to obtain best profit. The figure below shows the conceptual framework of the integrated simulation model.

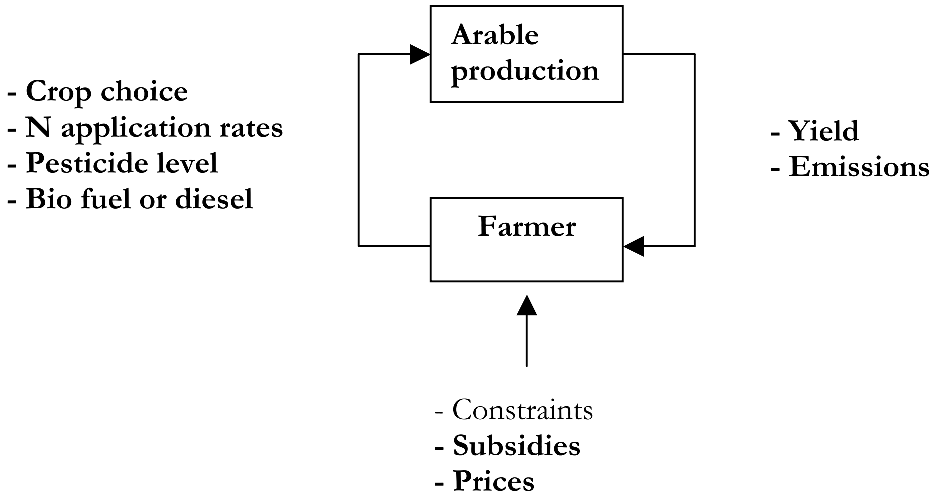

Figure 1. A conceptual model of the integrated simulation model.

1.1 System boundary for SALSA arable production

Setting the system boundaries is a main concern when carrying out environmental systems analysis. This study concentrates on the environmental effects for grain production at farm level. The life cycle thinking from cradle to farm gate was the main idea employed during construction of the system boundaries (Wrisberg & Udo de Haes 2002). However, small flows and flows of lesser importance were excluded. Cradle refers to resource production at the farm, whereas gate means the dried yield delivered to the purchaser. The farm production system investigated is illustrated in Figure 2. The farm system can be divided into two parts, the first being the core system, which consists of activities on the farm such as management and soil/plant processes. The other sub-system is an extended system where production of resources and transport of the grain from the farm to the mill are included.

The flows were analysed from the production of resources (fertilizer, fuel, electricity) via the processes and activities on the farm (machine operations, crop growth, soil and plant emissions, soil storage changes) to the finished products ready to be delivered to the wholesaler. To enable the current system status and results of environmental load to be measured with respect to sustainability, the substance flows were analysed and categorised according to their impacts on global warming, eutrophication, acidification and resource use.

Production of machinery and buildings was not included in the model due to difficulties in allocating the use of machinery and buildings between activities on the farm and also in time. The machine use was nearly the same in all the studied scenarios so there was no great difference between the cases investigated. Small flows from production of biocides, medicines and washing detergents were omitted due to their minor importance. Dynamic effects from weather impacts on crop yield were left out, in order to focus on management-related effects.

A tricky problem turned out how to allocate emissions from slurry production and slurry spreading between the arable farm and the pig farm from which the slurry originates. If all is allocated to the pig farm the slurry is a free resource not giving any environmental contributions from the system at all and if it shall be allocated between the system there is no obvious way how to allocate them. To avoid getting stuck with this difficulty, we first tackled this problem with the assumption that only slurry spreading belongs to the organic production system. However, this assumption is a question of concern because most of the grain production is used for animal feed. There is no easy way to allocate the slurry production and slurry spreading between the two systems, but in order to focus on the arable farm economy slurry storage was placed outside the system boundary and slurry spreading was included in the organic system. The result of different system boarders were later analysed in a sensitivity analysis.

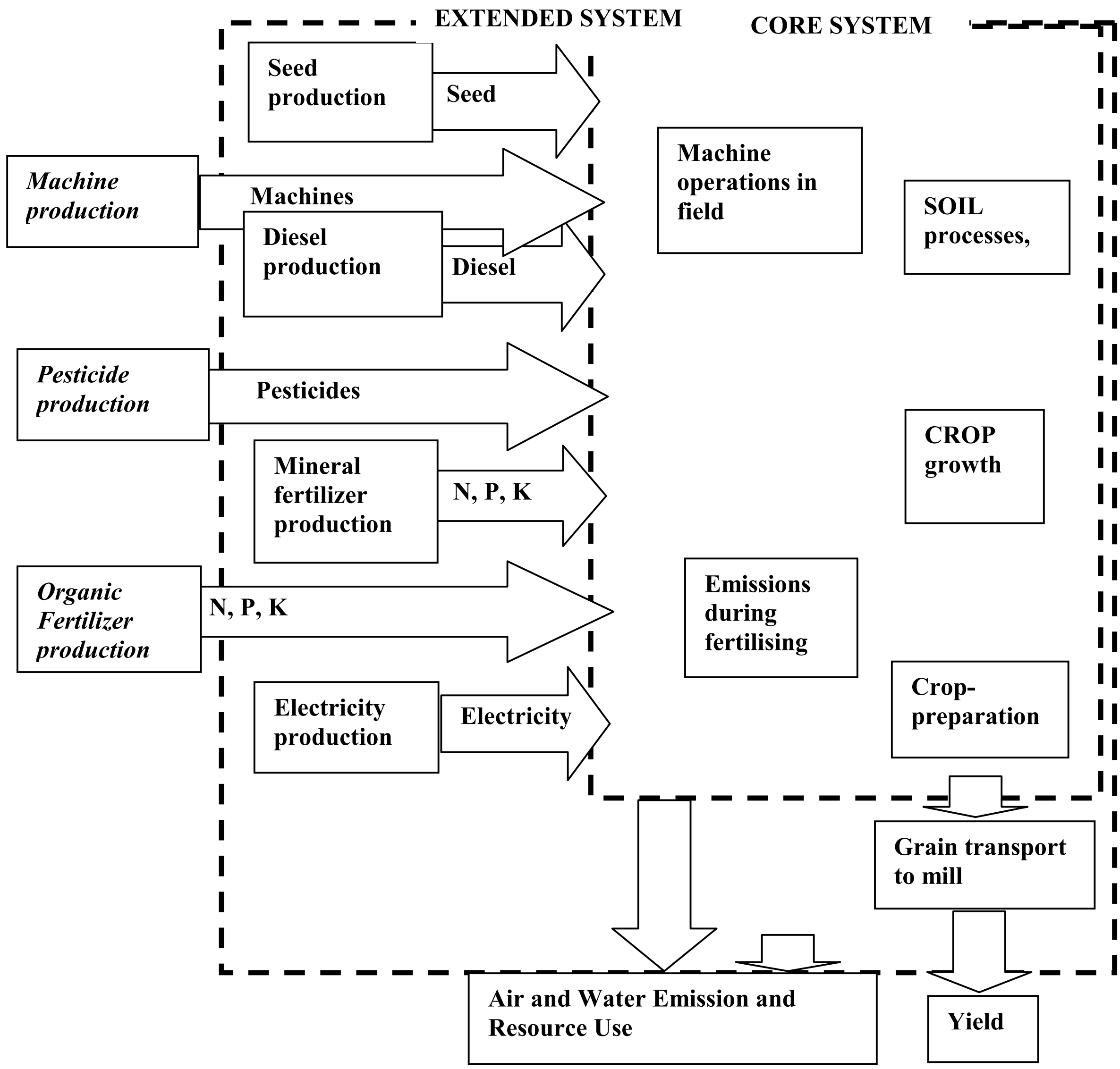

Figure 2. Flow chart of the SALSA arable physical flow model, which represents the agricultural production system. The core system is the farmer's management activities and soil/plant processes on the farm. The extended system includes production of inputs and grain transport from the farm.

The remainder of the report is divided into four chapters dealing with the methodological background of environmental systems analysis and micro-simulation (Chapter 2), a presentation of farm data used for simulation (Chapter 3) and a presentation of the simulation models (Chapter 4). In the fifth chapter the results of the simulations are presented, followed by a discussion of their implications.

2. METHODOLOGICAL BACKGROUND

The modelling development in this study is based on the interaction between two different modelling approaches – Environmental Systems Analysis (ESA) and microsimulation. The Environmental Systems Analysis used in this study originates from the sciences of using computer-aided modelling to study the physical flows on farm level and LCA methodology for environmental impact analysis. Microsimulation is a modelling approach designed for representing the behaviour and actions of individual agents.

2.1. The background of Systems Analysis

2.1.1. Systems Analysis and Systems thinking

A system is an assembly of parts that have been put together to achieve a specified goal or purpose that is to be studied. According to Bertalanffy, the so-called founder of systems theory, a system is "is a whole of elements in interrelation, connection with one another". So phenomena are to be studied in all their complexity; as opposed to the mechanistic viewpoint, which explains reality by mechanical simplification (Csáki 1985). Aguilar (1973) describes systems analysis as the process of separating or breaking up a whole system into its fundamental elements or component parts. It involves a detailed examination of the system in order to understand its nature and to determine its essential features. Systems analysis is based on systems thinking, which means that more effort is devoted to the system as a whole, the structure of the system and the interaction between different parts in the system than to studying separate parts (Gustafsson *et al.* 1982).

The evolvement of systems analysis was a reaction against a reductionistic science approach. In Checkland (1999) systems thinking is mentioned as an attempt to avoid the reductionism of natural science. The concept of "holistic thinking" became institutionalized in the 1950s. The mathematically expressed general theory of systems became central as a metalevel language to solve problems in many disciplines. From the general systems, many different model concepts have evolved and models have been developed as analytical tools to study system characteristics or for management purposes (Wrisberg & Udo de Haes 2002). However, some have criticized systems theory for its inability to deal with *"the inventiveness of human society"* (Mannion & Bowlby 1992 p.6). In the social sciences, there are often no clear theories on how social and economic systems are interrelated, which means that models are based on questionable assumptions and connections.

Farming systems are characterised by the fact that Man is attempting to control biological systems in an uncertain environment to achieve some goal, which is predominantly economic in nature, *i.e.* a bio-economic system. The degree of control varies considerably and both weather and prices constitute two major sources of uncertainty for management. The management component of a farming system is a dynamic function of goals, information feedback and control. The objectives of systems research may be to predict the behaviour of a system or, more commonly, to improve control over existing systems or to design new systems. With the development of system theories, a new trend opened in the solution of practical problems and scientific investigation using mathematical models. The use of computer models has been beneficial since the human mind is not capable of handling very complex models.

2.1.2. Systems Analysis and mathematical modelling of physical flows

Today many mathematical models are used to describe systems behaviour under different conditions. Simulation is an attempt to examine relationships in conditions approaching those of the real world, and to explore the probability of the predicted behaviour of the phenomenon being investigated under real conditions (Csáki 1985).

The idea of using mathematical and statistical theories and methods on practical problems other than physical or technical systems is not new. The concept has been used for many applications in the course of history, from military planning to regulation of industrial processes by signal analysis, where the need for such methods has increased during the industrialization process (Gustafsson *et al.* 1982). A classic example is from the early part of the 20th Century, when the mathematician Volterra created a dynamic model to explain how the interaction between predator and prey could drive sustained oscillation. During World War II, the optimization technique became important in operational research because of the need to allocate scarce resources to the various military operations and to the activities within each operation in an effective manner. In the post-war boom, industry became interested in using this technique and the computer revolution made the development of computer-aided systems easy (Hillier & Lieberman 1990).

The organization IIASA (International Institute for Applied Systems Analysis, a non-governmental, non-profit, global change research institute, has played an important role in the development of applied systems analysis since it works with methods and tools useful for environmental, economic, technological and social developments. The institute was set up in 1972 to be a platform for cooperation between the Eastern and Western hemispheres. (http://www.iiasa.ac.at/).

Models are categorised due to their characteristics. A model can be deterministic if it works with exact relationships with derived variables or stochastic if it works with uncertainties or probability distributions. If the relationship between variables in a model is direct or momentary, the system can be denoted as static, while if the variables in the system change even without external influences the system can be denoted as dynamic. Models are used for understanding, prediction of the future or for control of a system. Simulation languages became available for users other than mathematicians when complex mathematical relationships of differential equations started to be expressed as state-boxes and flow-arrows in graphical programme languages (Haefner 1996).

A systems analysis project contains a number of steps: statement of the objectives of the model; translation of the objectives into hypotheses; mathematical formulations of the system; verification of the computer algorithms; calibration or experimentation of the model; analysis and evaluation of the model where the model should be validated against independent data sets; and finally analysis of results (Haefner 1996).

2.1.3. Modelling the agro-ecosystem

Mathematical models have been developed in a relatively great variety for the solution of agricultural problems (*e.g.* Dent & Andersson 1971, Csáki 1985) and the list of relevant publications from recent decades is lengthy. These computer models have been built in order to explain the behaviour of the farm system without setting up physical experiments. Factors influencing production and economic returns have been the main scope of such models, where environmental impacts, machinery planning and socio-economic interaction have also been studied. Several methodologies for studies of environmental impacts, which can be applied to agricultural systems, have also been developed.[1] There is not always a clear methodological divergence between them since they overlap in various ways.

[1] Several models for studying various environmental impacts of Swedish farm production have been constructed, with different aims and on different levels. Nitrogen leaching can be studied on a daily basis by SOIL-N (Jansson *et al.* 1987), from general data by SOILndb (Johnsson *et al.* 2002) or from a more plausible rule-of-thumb approach by Farmmodel (Hoffman *et al.* 1999), Pesticide and phosphorus leaching can be estimated using the

The first alarming report by the Club of Rome in 1972 pointed out the need for a system change if the world were to avoid the threat of ecological collapse and a total shortage of resources by the end of the twentieth century (Meadows *et al.* 1972, Meadows *et al.* 1992). Their predictions did not come true, but in the work to find new strategies and instruments to manage fossil resources and to map the metal and nutrient flows for a region, the substance and material flow analysis methodology emerged. Material Flow Accounting (MFA) is a tool to for analysing regional metabolisms, which gives an opportunity to understand how society physically interacts with the environment. Substance Flow Analysis (SFA) analyses the substance flow in a designed system. Burström (2000) emphases the role of material flow analysis, MFA and environmental monitoring as important tools for describing and understanding the socio-ecological constitution and conditions.

Nutrient balances or nutrient budgets of farm production have been increasingly used for nutrient management and as a basis for environmental policymaking (JTI 2001, Oenema *et al.* 2003). The element balances and fluxes on farms provide valuable knowledge about risks for element accumulation, while depletion of soils and emissions to water and air can also be identified.

The energy analysis term and energy methodology were the theme of an international conference in 1974, held by the International Federation of Institutes for Advanced Studies (IFIAS 1974). The concept of budgeting energy by accounting for all different inflows of energy in the process was called energy analysis. One branch of energy analysis was termed process analysis, where the energy use was traced backwards and summed up contributions from all individual inputs for a specific commodity during the whole production chain. The production chain can be divided into levels, where the first level includes the fuel used in the last stage of the manufacturing process, the second adds energy use for production and transportation of fuels and material used in the process, and the third level includes energy use for production of raw materials and manufacture of machines used in the process and so on (see Figure 3).

Macro-model (Jarvis 1994). A model for prediction of the yield decreases due to soil compaction was developed by Arvidsson and Håkansson (1991). Emissions of global warming gases are estimated by a model developed by IPCC (2001). Nitrogen retention is estimated by a model developed by SMHI and IVL (2001). There are several models for feed plan estimations where the composition is optimised for economic benefit and animal need.

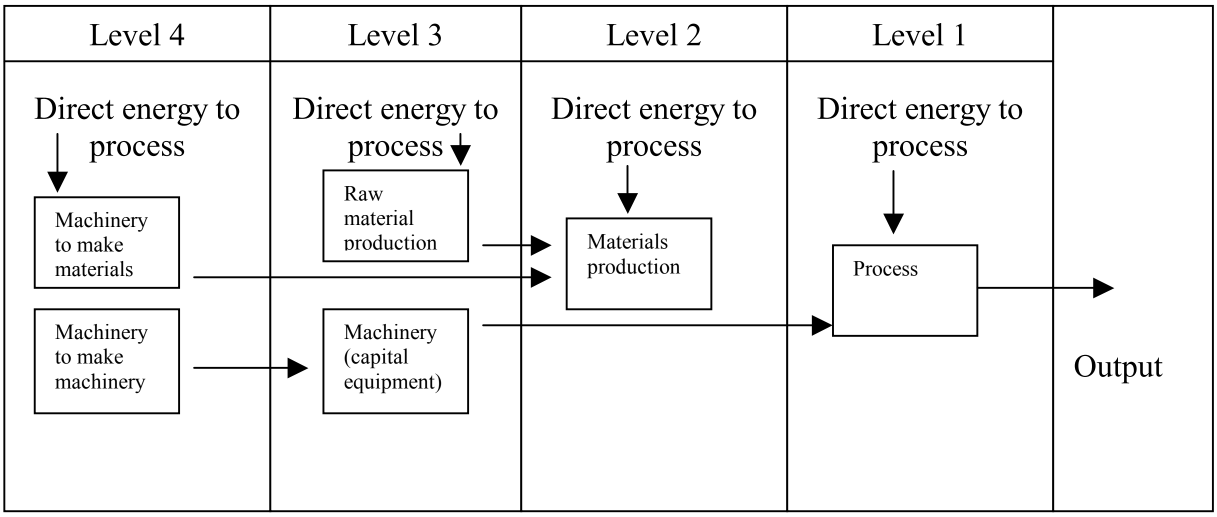

Figure 3. Energy levels used in the process energy analysis.

Life Cycle Assessment (LCA) is a method for studying the potential environmental impact of a product or service throughout its entire life cycle, from raw material to waste disposal (Lindfors *et al.* 1995, ISO 1997, 1998, 2000, Guinée *et al.* 2001). The first LCA analysis was made at the end of 1960s, mainly as an energy account for chemical processes and production systems. During the energy crisis in 1970s, the need for energy analysis increased and later the LCA methodology developed to also include environmental load issues because of the increased interest for environmental questions (Lindahl *et al.* 2001).

Life cycle thinking is today a concept that is used in many analytical tools for environmental design (Wrisberg & Udo de Haes 2002). The LCA methodology is now standardized in the ISO-standards 14 000 series (ISO 1998, 2000). LCA is typically a steady state, rather than a dynamic, approach (Guinée *et al.* 2001). A Life Cycle Assessment should include definition of goal and scope, inventory analysis, impact assessment and interpretation of results (ISO 1997).

However, there is not a clear-cut distinction between LCA, systems analysis or environmental systems analysis, since all three share a similar methodology of goal and scope definition and methods to set system boundaries and they can also be performed as model simulations. However in LCA, human behaviour is not considered and studies are often based on different scenarios. In the present study, human decision-making was introduced by a dynamic way into the integrated model.

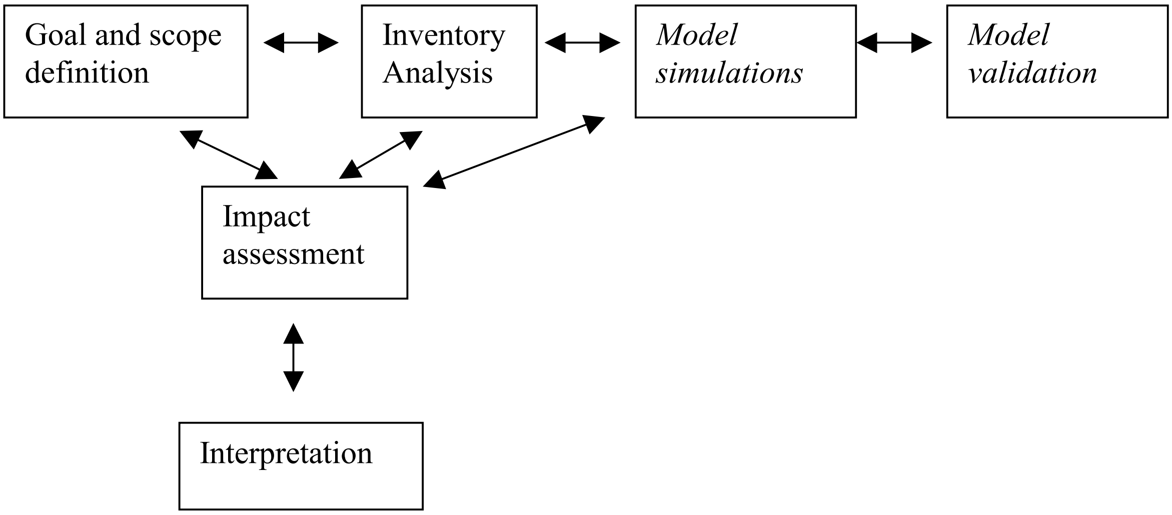

Figure 4. The structure of the SALSA arable model simulations combined with LCA methodology (modified after Gustafsson et al. 1982 and ISO 1997). The arrows indicate the interactive process during the study.

Environmental systems analysis (ESA) comprises methods, tools and approaches for the systematic study of interactions between technical, economic, social and ecological systems, particularly for assessment of human activities, processes and products from environmental and sustainability points of view (von Malmborg 2003). Experiences from environmental systems analysis modelling of waste handling and municipal wastewater using the model ORWARE (Eriksson *et al.* 2002) show the advantage of using computer models for systems analysis when comparing the environmental load from different waste systems.

2.1.4. Microsimulation modelling

The conceptual ideas behind the microanalytic modelling approach were originally developed by Guy Orcutt, and presented in his article titled *A new type of socio-economic system* (Orcutt 1957). The central feature of the microanalytic approach is the identification and representation of individual actors in the socio-economic system and the way in which their behaviour changes over time. In principle, these actors can include individuals, households, businesses, farmers, corporations and so on. The shift of focus from sectors to the individual decision-making units is the basis of all microsimulation work. Knowledge of individual behaviour, other actors and decision-making units is integrated into the model and the consequences of many individuals' behaviour or responses to external influence are explored (Krupp 1986).

The major advantages of microsimulation models are connected to their potential to incorporate individual behaviour and microprocesses into the models and to use theories of individual behaviour. The heterogeneity of information can be fully represented in the model and maintained during the simulation. The output consequently contains a great variety of information about general and specific conditions at the micro level, information that can easily be aggregated up to the levels suitable for answering research and applied questions. This facilitates a detailed analysis of microprocesses or sequences of individuals' actions and provides opportunities for a more thorough understanding of the mechanisms behind the macroprocesses and of the consequences at aggregated or disaggregated levels.

During the past three decades, many operational microsimulation models have been developed. In a survey by Merz (1991), it was shown that 57 dynamic and static microsimulation models were implemented between 1960 and 1990. Some of the fields of application of the major models are:

1. Demographics, family formation, labour force participation and income development;
2. Distributional effects of pension reform policies, tax transfer policies, energy policies, national health policies, unemployment insurance policies, housing allowances and child allowances;
3. Economic effects of economic policies and tax regulations on businesses;
4. Urban housing markets, land-use development, residential energy use, shortening of work hours, shadow economies.

For a more thorough presentation of different microsimulation models see Holm *et al.* (2000).

3. DATA

3.1. Some notes on data

The purpose of the present project is to represent the real situation of a farm business. For that reason, the SALSA arable and SALSA mind models need appropriate data. Some of the settings for the simulations were obtained from a particular case, a real farm from which data on yield, crop rotation, resource use, machine pool, nitrogen application technique and application time, climate, field work, etc. were collected. Other data required were assumed to be normal practice and were collected from other sources. Economic data were obtained from the AGRIWISE database (AGRIWISE 2002). Hence, in cases where data from the farm were not regarded as representative for the area, generic values were used.

When the SALSA arable model was run, average data for the three years were used. For the SALSA mind model, data were used separately for each crop and field. Field data related to all three years. The major proportion of the empirical data originated from a farm business in the project "Odling i balans" (Interview Lars Törner), which cooperates with research projects undertaken at the Swedish University of Agricultural Sciences (SLU). The farm is located in the county of Uppsala, approximately 60 kilometres north-west of Stockholm. Individual data on field operations, diesel use, pesticide use, yield, work hours, nitrogen applications per field and crops were collected from three years of farming operations at the farm. In cases when the case farm had unrepresentative management practices, average data for the district were used. The reason for using some data from a case farm instead of using only average Swedish data was that production factors and emissions results, such as for example yield and nitrate leaching, depend on where the farm is situated.

3.2. Farm data

The total area of the case farm is 166.7 hectares, which is subdivided into 12 parcels of varying size (from 5.1 hectare to 25.7 hectare). The main crops produced on the farm are spring wheat, winter wheat, spring barley, oat, winter rye and spring oilseed rape. Sometimes spring turnip rape is also grown.

3.2.1. Production data

In order to get an idea of the farm's economic return, the yields produced on the case farm are presented below and compared with the standard yield from Statistics Sweden, see Table 1 (SCB 1997). The crop price data shown in Table 1 refer to the year 1999 and were obtained from AGRIWISE. Climate conditions control the production levels and lead to a large variation between years. However, average yield data was used in the present study, but the integrated model contains an option to include yield variation data in the simulations.

Table 1. Average production data at the case farm 1997-1999 and standard yields according to Statistics Sweden.

Crop	Average yield kg/ha	Standard yield [a] kg/ha	Prices conventional SEK/kg	Prices organic SEK/kg
Spring oilseed rape	2 390	1 677	1.75	3.66
Spring wheat	5 007	5 239	1.06	1.78
Spring barley	4 654	4 857	1.01	1.48
Winter wheat	6 013	5 691	1.12	1.56
Oats	4 541	4 869	1.06	1.39
Rye	4 079	4 674	1.03	1.16
Turnip rape	2 396	1 522	1.51	3.66

a) Standard yield for the area calculated from many years of production by Statistics Sweden

3.2.2. N-application rates

The yields of the case farm were the main guide for setting the normal fertilising level used for simulations. The normal application rates were then calculated according to Swedish Board of Agriculture recommendations (Jordbruksverket 1997), plus 12% extra N due to an investigation of how much farmers actually apply (Kihlberg 2002). This was set to the "normal" application rate of the farm in the SALSA simulations. Then two other application rates were calculated as one 20% lower and one 20% higher than the "normal" N application rate. In Table 2, actual nitrogen application rate used on the farm, and the normal application rate and the two other N application rates used for the SALSA simulations are presented, plus the slurry application rate used in SALSA arable for the organic production option. As can be seen in Table 3 the actual nitrogen application on the farm, from which data is gained from, is mostly slightly higher than our normal application rates which are used for simulations. This can be partly explained by the fact that seed grain is produced on the farm and the N application rates for optimum economic returns are larger for seed production.

Table 2. Nitrogen application rate (kg/ha) and slurry application rates (ton/ha) used for SALSA simulations. The 'normal' N application rate was according to SJV advice but included an extra 12%, while the two alternatives had 20% less and 20% more N than the normal alternative.

Crop	Normal nitrogen application rate kg/ha	- 20% nitrogen application rate kg/ha	+ 20% nitrogen application rate kg/ha	*Slurry application* -20% nitrogen *tonnes/ha*
Oilseed rape	108	87	130	*28*
Spring wheat	125 [a]	99 [c]	148	*33*
Spring barley	88	70	105	*23*
Winter wheat after cereal	120	100	147	*31*
Oats	85	68	102	*22*
Winter rye	69	55	83	*18*
Fallow	0	0	0	*0*
Winter wheat after fallow	114 [b]	90	135	*30*
Turnip rape	108	87	130	*28*

a) Residual fertility effect after rapeseed is 15 kg N/ha, the extra 12% is not assumed for spring wheat because spring wheat uses a new N-function response equation that does not fit into norm yield if extra N is applied.
b) Residual fertility effect from fallow is 30 kg N/ha that the winter wheat will benefit from
c) Spring wheat gets extra N due to an expectation of good protein quality.

Table 3. Nitrogen application rate on the case farm (kg / ha)

Crop	*Nitrogen at the case farm*[a] *kg/ha*
Oilseed rape	*131*
Spring wheat	*126*
Spring barley	*114*
Winter wheat after cereal	*143*
Oats	*96*
Winter rye	*132*
Fallow	*0*
Turnip rape	*121*

a) The nitrogen application rate used on the case farm is presented for reference and was not used for simulations.

Fertilizing strategy was chosen according to common practice on the farm. This meant for mineral fertilizer one early application in spring and one extra application in the growing crop in early summer. Slurry was spread once in the growing crop in early summer with 20-37 ton/ha depending on the N need of the crop. Fertilizer was applied during spring for the alternative with low N application rates and once in spring and once in early summer for the normal and excess application rates. Calcium nitrate is commonly used in Sweden and also at the case farm. However, because it is a by-product of the production of other artificial fertilizers and information on the allocation of emissions between the fertilizers was lacking, calcium ammonium nitrate (*Suprasalpeter*) was assumed to be used for all applications. This is an artificial fertilizer, with half the N in ammonium form (NH_4) and half as NO_3. The slurry was assumed to be pig slurry bought from a farmer in the neighbourhood. The nutrient content in the slurry was assumed to be average for pig slurry, 3.3 kg NH_4-N/ton slurry (Steineck *et al.* 2000). Slurry spreading was assumed to be performed on one occasion with a band spreader technique, placing the slurry in the crops in June. This means that an average of 7% of the ammonia in the slurry will be lost during spreading using this technique (Karlsson & Rodhe 2002). The same nitrogen effect was assumed for both mineral and organic fertilizers, due to the fact that the organic fertilizer was spread with good equipment at a favourable time when there is large demand for nitrogen from the crops.

The economic value of slurry is equal to the nutrient content of N, P and K and the extra cost for spreading the slurry was also included in the simulations.

3.2.3. Pesticide, diesel and seed use

The number of sprayings and the use of biocide, diesel and seed are variables used for simulations. The case farm's average use of pesticides is presented in Table 4, together with the average values for Sweden. The case farm uses slightly higher doses than the average for Sweden except for one crop. Pressure from insects, fungi and weeds depends on weather conditions and on the field's management history. The farmer's choice of sprayings depends on the crop grown and where the farm is situated in the country.

Data on diesel consumption and numbers of passes for all machine activities were derived from the case farm except for numbers of sprayings, which were taken from the AGRIWISE database. The average fuel consumption per machine operation was used as in-data in the SALSA-arable model.

Diesel consumption at the case farm per crop and activity and numbers of passes for the activity during the three years 1997-99 are presented in Table 4. The average diesel consumption was 68 litre/ha for all crops in the three years. In a study by Gunnarsson & Hansson (2004) it was found that organic farmers use more stubble cultivations and inter-harrowing so therefore extra inter-harrowing was added to the organic alternative.

Table 4. Pesticide dose used on the farm and average use in Sweden (SCB 1999), total diesel use and amount of seed used during the period 1997 to 1999 at the case farm.

Crop	Biocide on the case farm kg active substance/ha	Biocide average [b] kg active substance/ha	Diesel l/ha [a]	Seed kg/ha
Spring oilseed rape	1.1	0.49	58	9
Spring wheat	0.6	0.90	67	248
Spring barley	1.0	0.89	60	187
Winter wheat	2.1	0.88	74	202
Oat	1.1	0.80	66	198
Rye	0.9	0.85	56	177
Fallow	1.0		1	0
Turnip rape	0.5	0.43	82	8

a) Differences in diesel consumption for the crops depend both on management choices and climate variations between years.

b) Average use per hectare on farmland treated with biocide.

Table 5. Diesel consumption (l/ha) at the case farm for different machine operations per crop and average numbers of passes (in brackets) for each operation per ha.

Crop	Ploughing (no.)	Harrowing (no.)	Soil levelling with float (no.)	Stubble cultiv. (no.)	Rolling	Sowing[a]	Mineral fertilising [a]	Herbicide spray [b]	Fungi and insecticide spray [b]	Harvest[c]
Spring oilseed rape	22 (0.5)	4.0 (2)	0	10 (1)	0	10 (1)	0	1 (1)	1 (1)	19 (1)
Spring wheat	30 (0.7)	4.2 (2.2)	5 (0.3)	9 (0.7)	0	10 (1)	0	1 (1)	0	19 (1)
Spring barley	26.9 (0.7)	3.4 (2.2)	5 (0.1)	10 (0.6)	0	10 (1)	0	1 ((1)	0	19 (1)
Winter wheat	24 (0.3)	4.0 (3)	6.2 (1.7)	8.9 (1.5)	4 (0.5)	8 (1)	3 (2)	2 (2)	1 (1)	20 (1)
Oats	25.2 (0.8)	4.2 (2.2)	5 (0.3	10.2 (0.4)	0	9 (1)	0	1 (1)	0	20 (1)
Winter rye	21 (1)	1.5 (2)	5 (1.0)	0	0	9 (1)	1 (1)	2 (2)	1 (1)	16 (1)
Fallow	0	0	0	0	0	0	0	1 (1)	0	0
Spr. tur. rape	36 (1)	4.4 (2.5)	5 (1.0)		0	10 (1)	0	0	2 (2)	17 (1)
Av f. diff. operations	*26.4*	*3.7*	*5.4*	*9.6*	*4*	*9*	*1*	*1*	*1*	*19*

a) A combined seed drill was used at the case farm.
b) Data on average numbers of sprayings were obtained from a Swedish database (AGRIWISE 2002).
c) Differences in diesel consumption during harvest depend on yield differences.

Transport of grain from the farm to the mill was assumed to be by a 12 ton trailer that was fully loaded outward and returned empty. The transport distance from the farm to the mill where the dried grain was delivered was set to 25 km. The truck was assumed to drive with a velocity of 36 km/ha and the average diesel consumption for the truck transport was set to 14.9 litres/hour (Lindgren & Hansson 2002).

3.2.4. Drying of grain

In the district (mid-Sweden) where the case farm is situated, the water content in grain is generally between 18-22% but sometimes after long periods of dry weather there is no need for grain drying at all. Sometimes it also happens that the grain needs to be harvested with 30% water content, and then there is a large need for drying (Interview Gustaf Forsberg).

Water content during harvest (Table 6) was set according to average field trial data (Fältforskningsenheten 2003) and desired water content was set according to commodity. The water content at harvest is important since electricity and fuel are used for the drying. The grain was assumed to be dried using Swedish average electricity, which is mainly based on half hydropower and half nuclear power. Emission data for electricity production were taken from a Swedish report (Uppenberg *et al.* 2001). Drying costs per hectare for different crop were obtained from the AGRIWISE database (Table 6).

Table 6. Water content at harvest, desired water content, energy use for drying (simulated figures due to water content), diesel use at the farm and drying costs.

Crop	Water content during harvest, %	Desired water content, %	Electricity use, MJ/ha	Diesel use, l/ha [c]	Drying costs, SEK/ha
Spr. oilseed rape	14.7	8	50	69	335 [a]
Spring wheat	19.2	15	100	71	524
Spring barley	19.0	15	72	70	503
Winter wheat	20.0	15	131	72	696
Oats	18.0	15	61	71	503 [b]
Rye	19.0	15	79	72	503 [b]
Fallow	0	0	0	10	0
Turnip rape	15.2	8	53	73	335 [a]

a) Assumed to be 2/3 of the cost for drying of spring barley, depending on yield amount.
b) Assumed to be the same as spring barley.
c) Figures given for the base scenario, with 100 % pesticide, normal N application rate of mineral fertiliser. Transport included.

4. A MODEL FOR SIMULATING A FARM BUSINESS

4.1. Experimental conditions

The calls for reducing environmental loadings and changing direction towards more sustainable agricultural production require awareness of a wide range of fields. The integrated model was constructed to link the physical flows at the farm (the SALSA arable model) to structural preconditions like the economy and legislation, as well as to the farmer as a decision-maker. At this stage it is a one-person simulator (one farmer at one farm), which cannot obviously make use of the full potential provided by the microsimulation approach on population dynamics. After having learned more about the activities at one farm these experiences could, however, be used in a broader context where the farms in a region (*e.g.* parish, municipality, county, nation or any other region endowed with pertinent micro data) dynamically interact with other parts of society – people, businesses, organizations, institutions etc.

In brief, the integrated model consists of two sub-models (see Figure 5). The first of these represents the economic context of the farm and the mental process of the farmer in which he makes up his mind regarding production allocation (the SALSA mind model). The second attempts to emulate reality by calculating, as systematically as possible, the environmental impacts and the yield of the chosen production (SALSA arable model).

At the start the business is given a history of production, which from a technical point of view is needed for getting the system in steady state. Apart from the production history, there are a number of essential factors whose partial impacts on environmental loadings and economic return we would like to analyse. These experimental conditions will be discussed in the next sections.

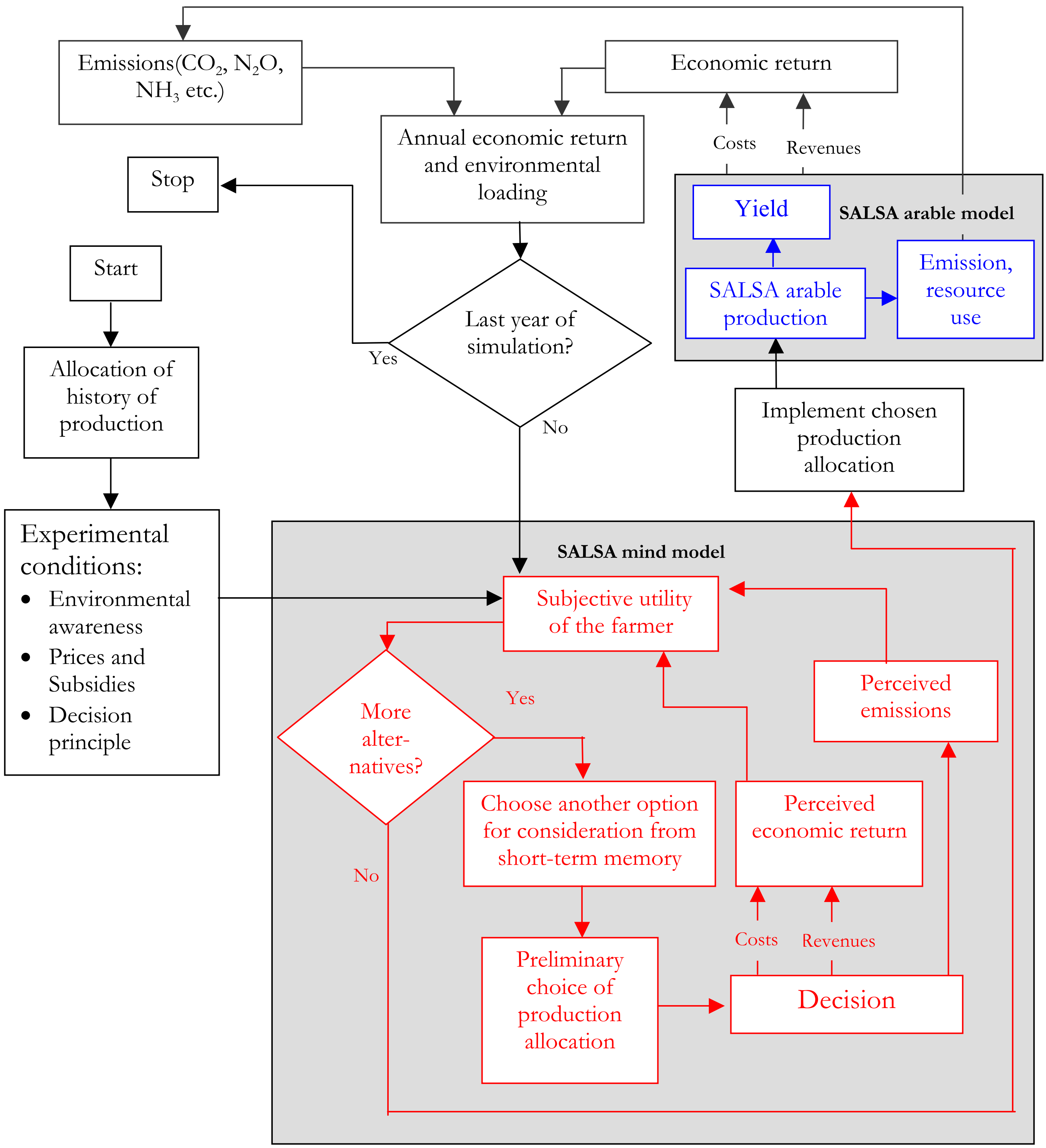

Figure 5. The flow chart of the integrated model consisting of the SALSA arable model and the SALSA mind model.

4.2. The SALSA mind model

4.2.1. Environmental awareness

Farmers undoubtedly pay different attention to environmental problems triggered by their production activities. This difference is not entirely related to different personal values about environmental protection, but also to different competitive strategies of the businesses. Some may specialize in organic production that attracts certain segments of the market, whereas others pursue large-scale mass production and strive for cost leadership. Both strategies can be profitable but they imply different uses of substances with environmental impacts. Here, environmental impacts can be brought about by three different inputs in crop production – pesticides, fertilizers and fuel.

Weeds, pests or diseases in different forms are a serious threat to harvests. Uncontrolled growth of weed plants, especially in conjunction with certain weather conditions, may cause severe damage to the annual yield. To control weeds, the farmer can employ either mechanical or chemical methods. In general, mechanical methods are relatively expensive and not frequently used by farmers producing on large areas. Therefore, weed and pest control is carried out by means of biocides. Within the model, the farmer can decide whether to use no biocide at all, half-dose or full manufacturer's recommended dose for the respective substrate. The dose recommended by manufacturers is often sufficiently strong to have the desired effect. The same result can, however, be obtained by using half the recommended dose combined with utilizing better technical spray equipment and employing improved spreading strategies (Jordbruksverket 2002).[2]

The successful cultivation of crops is also very much dependent on the supply of nutrients. Different crops have different abilities to respond to various levels of nitrogen application. The usage of fertilizers in these calculations was restricted to three levels linked to three different amounts of nitrogen fertilizer (see section 'N-application rates' for further descriptions). The 'normal' level used was the Swedish Board of Agricultural recommendation estimated from the economic optimum (Jordbruksverket 1997) plus 12% extra, which has been shown to be a normal application rate in practical farming (Kihlberg 2002). The highest level refers to 20% above normal practice for that crop, which according to the leaching model provides extra nitrogen leaching. Below the recommended dose we used a level that was 80% the 'normal' application. This situation is similar to that in

[2] German farmers can get environmental subsidies on three levels; no uses of pesticides at all, low level fertilizer application, and both.

sensitive areas for nutrient loadings in Denmark, where farmers get subsidies for keeping N application rates below the economic optimum. In our calculations, the 80% of normal application rate level was also compared with a scenario where slurry was used instead of artificial fertilizer.

The third input in crop production that gives rise to environmental impacts is fuel for machines. Within the model the farmer can choose between using diesel or RME (rapeseed methyl ester) produced from rapeseed oil. The RME can be used as fuel instead of diesel in normal tractor motors. Unlike diesel, RME produced from rapeseed oil is a renewable fuel that presumably has a lower impact on environmental loadings. Solar energy is converted into biomass with an energy exchange of 5.7 for winter oilseed rape cultivation (Hovelius 1997). Rapeseed oil combustion does not add any fossil carbon dioxide to the atmosphere, and thereby reduces the contribution to the greenhouse effect. However, from a broader point of view in which the production process of rapeseed oil is taken into account, the difference in environmental influence between diesel and rapeseed oil is not as clear. Sixty-four per cent of energy input in rapeseed cultivation originates from nitrogen fertiliser manufacturing and 20% comes from fuel used during machine operations (Hovelius 1997). There are two contributing factors: the usage of biofuel requires more land for cultivation (rapeseed) and, thereby, also more fertilizers that affect emissions of greenhouse gases and eutrophication; the production of fertilizers generates wide-ranging emissions of nitrous oxide (via the transformation of ammonia to nitric acid), which is a much more potent greenhouse gas than carbon dioxide. Thus, assigning relative environmental impacts to diesel and RME is not as clear-cut as it might seem in the first place. However, the reason for not drawing on this finding in the experimental design is that it is an interesting experiment to analyse and, moreover, biofuel seems to be a more environmentally friendly alternative at a first glance.

In order to systematize the combinations of accepted environmental loadings and different uses of inputs with environmental influence we constructed a matrix showing possible alternatives (Table 7). A farmer who does not pay any specific attention to environmental loadings will be open to all of the 24 possible alternatives, whereas the colleague who strives to implement environmentally friendly production and tries to minimize emissions will have only two conceivable options.[3] Between these extremes, there is a medium level, which is surrounded by two others that represent behaviour deviating from the medium. The distribution of levels of accepted environmental

[3] Alternative 1 in Table 6 makes use of organic fertilizers, which qualifies for an environmental subsidy.

loadings across combinations of production inputs is carried out by a weighting procedure, in which the different combinations of input levels are given summed values as a function of their constituent parts.[4]

To clarify the ideas behind this part of the experimental design it may be illustrative to provide an example. Let say that we would like to reproduce a farmer who has no clear view about the problems related to environmental issues. Perhaps he has not thought about it or he cannot make up his mind – indeed, the extensive use of certain chemicals increases the yield on average, but it may also have a negative impact on the environment. His position may be viewed as to what extent he can accept using certain inputs in production, which here means not tolerating more than *medium* along the scale of accepted environmental loadings. This implies that only a restricted number of combinations is relevant for him (numbers 1 - 7, 9, 10, 13 - 15 and 16, 17).[5] Throughout the simulation the perceived environmental and economic outcomes of the annual choices (see Figure 5) are compared to the actual outcomes.

Another aspect of the model is crop rotation. Based on empirical data and recommendations (aiming to avoid diseases and insect attacks) given by experts (Interview Maria Wivstad), the three predefined crop rotations shown in Table 8 were implemented in the model. Each year the farmer can choose between either holding on to the predefined rotations or making changes. The different parcels in the model follow any of these rotations in different sequences in order to avoid synchronization between parcels and crop rotation.

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[4] The five levels of accepted environmental loading are a result of discussion with experts from LRF (Interview Jan Ekswärd) and own assumptions.

[5] It could be argued that the acceptance of medium levels of environmental loadings delimits the alternatives to numbers 4 - 7, 9, 10, 15 and 17, 18. However, we would rather look upon the scale as limit values that correspond to personal belief or business strategy. The absolute doses of pesticides and rates of fertilizers are very much related to other circumstances (*e.g.* weather) and sometimes it is appropriate to use lower levels without necessarily changing personal position or business strategy. In this study average weather is assumed and it provides average nitrogen application rates of fertilizer and doses of pesticide per hectare and year. From this point of view it seems reasonable to include all alternatives, which do not exceed the limit values defined for each of the five categories (*limited*, *little*, *medium*, *much* and *unlimited*).

Table 7. Different alternatives for accepted environmental loadings.

Option	Herbicide and pesticide (biocide)	N Fertilizer	Bio-fuel	Accepted environmental loadings Eco. prod.	Limited	Little	Medium	Much	Unlimited
1	0% of rec.dose	80% of norm. rate*	Yes	X	X				
2	‘-‘	80% of norm. rate	‘-‘		X				
3	‘-‘	Normal rate	‘-‘			X			
4	‘-‘	120% of norm. rate	‘-‘				X		
5	50% of rec.dose	80% of norm. rate *	‘-‘			X			
6	‘-‘	80% of norm. rate	‘-‘			X			
7	‘-‘	Normal rate	‘-‘				X		
8	‘-‘	120% of norm. rate	‘-‘					X	
9	Recommended dose	80% of norm. rate *	‘-‘				X		
10	‘-‘	80% of norm. rate	‘-‘				X		
11	‘-‘	Normal rate	‘-‘					X	
12	‘-‘	120% of norm. rate	‘-‘						X
13	0% of rec.dose	80% of norm. rate *	No	X		X			
14	‘-‘	80% of norm. rate	‘-‘			X			
15	‘-‘	Normal rate	‘-‘				X		
16	‘-‘	120% of norm. rate	‘-‘					X	
17	50% of rec.dose	80% of norm. rate *	‘-‘				X		
18	‘-‘	80% of norm. rate	‘-‘				X		
19	‘-‘	Normal rate	‘-‘					X	
20	‘-‘	120% of norm. rate	‘-‘						X
21	Recommended dose	80% of norm. rate *	‘-‘					X	
22	‘-‘	80% of norm. rate	‘-‘					X	
23	‘-‘	Normal rate	‘-‘						X
24	‘-‘	120% of norm. rate	‘-‘						X

* In these alternatives the farmer uses organic fertilizers.

Table 8. Three crop rotations where the crop sequence is set to avoid diseases and insect attacks.

Order	Crop rotation 1	Crop rotation 2	Crop rotation 3
1	Spring turnip rape	Spring oilseed rape	Spring oilseed rape
2	Winter wheat	Spring wheat	Spring wheat
3	Fallow	Oats	Fallow
4	Spring wheat	Spring barley (early)	Winter wheat
5	Oats	Winter rye	Oat
6	Spring barley (early)	Fallow	Spring barley (early)
7	Winter rye	Winter wheat	Winter rye

If the farmer chooses to leave the predefined crop rotation for economic reasons and systematically focuses on crops with high returns, such behaviour is restricted by reductions in yield. Concentrating production towards monoculture is punished by variously diminished yields. The model recognises which crops are being cultivated on the different parcels during the previous four years. The reduction in yield caused by monoculture varies across crops (Bingefors *et al.* 1978, Fogelfors 2001). For example, the cultivation of winter wheat two years in a row reduces the yield in the second year by 15%. For spring wheat, oats, barley, rye, and oilseed crops, the figures amount to 10%, 5%, 5%, 5% and 13%, respectively (see Table 9). In cases where the farmer continues on the path of monoculture by cultivating the same crop for another year, the reduction in yield is even greater; another 50% reduction in the third year and another 25% reduction in the fourth year. For example, cultivating spring wheat two years in a row gives a 10% reduction. If this crop is further used in the third year the reduction amounts to 15% (10 + 5). The cultivation of the same crop a fourth time during the period will further reduce the yield by 2.5% (in total a reduction of 17.5%). The crops of farmers who are engaged in organic production are more exposed to insect attacks and diseases since pesticides cannot be used. This motivates additional reductions in yield for this group of farmers when they pursue monoculture.

Table 9. Percentage yield reduction in the first year due to preceding crop or monoculture.[6]

Previous crop	Spring rape, %	Spring wheat, %	Oats, %	Spring barley, %	Winter rye, %	Winter wheat, %
Spring rape	13%	No data	No data	No data	No data	No data
Spring wheat	No data	10%	3%	10%	3%	17%
Oats	No data	1%	5%	1%	1%	1%
Spring barley	No data	5%	3%	5%	3%	5%
Winter rye	No data	3%	3%	3%	5%	3%
Winter wheat	No data	10%	3%	10%	3%	15%

Beside these restrictions related to crop rotation, there are some logistical constraints regarding the succession of crops. Due to restrictions in time and constraints on use of machinery, some combinations are impossible without extensive investment in additional machinery and equipment (Interview

[6] The yield reduction effect on spring and winter wheat is compared with if they are placed at the most favourable place in the crop rotation *i.e.* after fallow or an oil crops. The other three cereals are often placed after another cereal but spring rape is placed after a cereal.

Alfredo de Toro). The following crop sequence was excluded as a result of these reasons; Spring oilseed rape cannot be followed by winter rye, spring turnip rape, winter wheat. Spring wheat cannot be followed by winter rye and winter wheat, and spring turnip rape cannot be followed by spring oilseed rape.

The reducing effect of a bad preceding crop is assumed after Fogelfors (2001) and Bingefors *et al.* (1978). The main concept is that wheat and barley are the most sensitive crops among cereals. Rye and especially oats can act as a cleaning crop between other more sensitive crops. The repeated mono-culturing is assumed to increase by the same figure as the numbers of repeated years. Reasonably, the negative effect of growing the same crop year after year causes more damage where half or no biocide is used. For the scenarios with half dose biocide and no biocide at all, the reducing yield effect is multiplied by an increasing factor.

4.2.2. Prices and subsidies

Apart from site-specific data, information about various prices and subsidies is also needed. Such material was collected from AGRIWISE, provided by SLU. For each parcel, costs related to machinery, sowing, fertilizers, pesticides, drying and transport from the farm to the mill were calculated using current prices. Slurry was equally priced to fertilizer. As regards equipment, a proposed set of machinery appropriate for a 150-hectare conventional type-farm was employed. The set consists of, for example, two tractors of different size, a reversible plough, a cultivator, a seed drill, a combine harvester and a machine workshop (AGRIWISE). The annual total machinery costs (TMC) were estimated by the following calculation[7]:

$$TMC = CC + MC + FLC + TIC \quad \text{(eq. 1)}$$

$$CC = D + IC \quad \text{(eq. 2)}$$

$$D = RV / EL \quad \text{(eq. 3)}$$

$$MC = a * RV / b * OT \quad \text{(eq. 4)}$$

$$FLC = c * FC * FP * OT \quad \text{(eq. 5)}$$

$$TIC = RV * d \quad \text{(eq. 6)}$$

[7] Parameter estimates are taken from the database for agricultural planning AGRIWISE.

where:
CC = Capital costs
MC = Maintenance costs
FLC = Fuel and lubrication costs
TIC = Tax and insurance costs
D = Depreciation per year
IC = Interest charge
RV = Replacement value
EL = Economic lifetime (years)
OT = Operating time (h)
FC = Fuel consumption (l/h)
FP = Fuel price (price/l)
a, b, c, d = Parameters accounting for varying characteristics of different machinery.

Another item of expenditure is land rent. We did not differentiate between owning land and renting land, because from an economic point of view there are costs related to both. If the farmer owns the land on which cultivation is carried out he gives up income from leasing out the land to any other farmer, and if he rents he has a direct expenditure to the landowner. In Sweden, tenancy costs show great regional variations and the level set in the model (750 SEK per hectare and year) is related to the region of study.

Labour cost is another expenditure to take into account, but we had no empirical site-specific information on number of workers, working time and salaries. However, labour costs were approximated by assuming the average gross salary for agricultural workers (100 SEK/h). On top of the salary social security costs (52.8% of the salary) were added. The working time was in broad terms divided into driving machines and carrying out tasks not requiring machine support. As there are site-specific data on the annual amount of fuel used for each parcel, it is possible to calculate the number of machine hours (given the allocated machine equipment) needed to consume this fuel. Consequently, we have an estimate of working time related to driving machines.

In order to obtain an idea of the amount of non-machine work, we departed from one of the basic assumptions of the modelling work, namely that the modelled farm is entirely specialized in grain cultivation and belongs to the category of reproductive family farms.[8] Full-time work was formally set to 1 700 hours per year, and in the simulation expansion (driven by increased machine hours) it was possible to have up to 1.5 full-time work. Further growth was considered to create large-scale dependence on hired labour,

[8] A reproductive family farm receives its income only from agricultural production. The input of working hours is mainly provided by family members (Djurfeldt & Waldenström 1996).

which would bring the business into another category of farm. Nevertheless, the amount of non-machine work was set to the difference between full-time work and the amount of machine hours calculated from empirical data. In the case of increased machine hours, reflecting enhanced production, non-machine work increased proportionally.

On the income side there are two sources – yield and subsidies. There is a vast array of different grants to agriculture. For simplicity, we focused on two forms of subsidy: Area subsidy and Environmental subsidy. The Area subsidy is the most important form of grant. The amount varies regionally and differs between cereal (≈2 000 SEK per hectare and year in the region of study) and oilseed plants (≈2 100 SEK). For environenmental subsidies are 70% higher for cereals and about 100% for oilseed plants. The Environmental subsidy is intended for farmers who choose to undertake organic cultivation without mineral fertilizers and pesticides. Within the model there are only two combinations of production inputs that meet with these requirements, combinations 1 and 13 in Table 7. No mineral fertilizers or pesticides were used. Here, fertilizer refers to organic fertilizer, which is purchased on the market. The cost varies between 1 300 SEK per hectare and year for cereals and 2 200 SEK for oilseed plants.

The difference between the sum of income (yield returns and subsidies) and the sum of expenses (labour, tenancy, capital, pesticides, fertilizer and sowing costs) constituted the gross profit of the business. Tax effects were not taken into account. All factors that influenced costs and revenues could be subjected to experimentation.

4.2.3. Decision-making

Decision-making is a field of enquiry connected to a wide range of disciplines within the social sciences. Throughout the post-war period, contributions from economics, psychology, political science, sociology and planning have extended the understanding of the decision-making process of individuals and organizations (*e.g.* Simon 1947, 1976; Lindblom 1959, 1979; Etzioni 1967, Dror 1968, Cohen *et al.* 1972, Brunsson 1985). Multidisciplinary fields such as organization theory and policy analysis form meeting-places for scholars with various backgrounds. Within the policy analysis tradition, systems analysis (together with operations research and cost-benefit analysis) provides a methodological framework for quantitative analyses (Premfors 1988). However, although systems analysis provides a powerful tool for policy analysis, it needs to be complemented by models on the decision-making process. Here we draw on some of the different decision models frequently referred to in the literature.

A general feature of model building is related to abstraction and complexity of real life phenomena and processes. The representation can be carried out with a wide variety of resolution – from theory-derived abstractions to full empirical heterogeneity. Where to locate on this continuous scale is partly a philosophical matter, but also determined by resources at hand. Had we access to physical, socio-economic and behavioural data related to farm businesses and farmers, we would have been able to take these empirical differences into account. Studies on, for example, how farmers make decisions and their ideas about landscape and environment protection indicate that they approach these issues in many different ways (*e.g.* Nitsch 1982, Stenseke 1997, Djurfeldt & Waldenström 1998, Beedell & Rehman 1999, Jansson 2000). Without data about real-life decision-making among farmers, we have no information about the variation in socio-economic characteristics and behaviour – choice of either traditional or green production, planning tools or rules of thumb etc. In certain respects this circumstance is not a major problem, since our model is designed to simulate one single farm.

Nevertheless, the literature provides different attempts to categorize various models of decision-making. Following Hogwood & Gunn (1986) a distinction can be made between ideal-type models, descriptive and normative models. At a first glance, the ideal-type and normative models may seem to be rather similar, but the variety of conceivable prescriptions found within the normative category is not the same thing as ideal types or mental constructs related to real-life entities. Authors indeed have different opinions about the decision-makers' capability for making rational decisions, as is manifested in numerous models, but these considerations should not be confused with the idea of pure rationality. Analogously, the concept of perfect competition in economics is neither referred to as a correct description of the real world nor necessarily as something to arrive at. It is rather employed as a construct for improving the understanding of the real world by means of analysing deviations from the ideal type.

How would decisions be made if the decision-maker were capable of strict rationality? Simon (1957) and Lindblom (1959) offer models that differ in their views on values and pre-specification of objectives. Simon argues for introducing values after the stages of information gathering, option identification and consequence assessment, since such a procedure would hinder the decision-maker from overlooking relevant courses of action.

However, to some people it may seem rather peculiar to aimlessly gather every single piece of information hoping to find a few precious grains that fit the relevant contextual situation. As an alternative, the rational decision-maker should, according to Lindblom, start by specifying his objectives before looking for options. This procedure seems more pertinent taking our managerial application into consideration. The farmer most likely has an overall purpose with his operation. Some would say that maximizing profit is the most important aim, whereas other would suggest varying non-monetary considerations related to, for example, lifestyle and environmental protection to be more important than pure profitability. Taking Lindblom's ideal-type rationality model as a starting point, we define the first decision-making model to be implemented in the integrated model.

Model 1: Pure rationality.

The farmer

- defines and rank his values,
- specifies objectives compatible with these values,
- identifies all relevant options,
- calculates all the consequences of these options,
- chooses the option or combination of options that maximize the values.

The simple utility function used is: U = *f*(profit, environmental concern)

The farmer's comprehensive purpose of the activity is to maximize profit, but various degrees of environmental concern are also elaborated on in the experiments. Restrictions on environmental loadings are expressed in terms of kg CO_2, O_2, and SOX -equivalents per kg product. Given the farmer's environmental preferences shown in Table 7, alternatives implying higher environmental loadings are excluded. The monetary outcomes of all alternatives are calculated and the best possible option is chosen.

Despite the attractive theoretical properties of the ideal-type model, it is difficult to disregard its unrealistic and impracticable characteristics. The lack of behavioural realism is certainly a major weakness, which is revealed by its low degree of confirmation due to unfulfilled assumptions (Lane 1993). Moreover, the role played by values is perhaps even more problematic, because it is difficult to make value judgements of profits, environmental concerns or socio-psychological motives on anything other than a personal or subjective basis. If we accept the limitations arising from manifold values and acknowledge that there is no absolute rational way of resolving a problem, then we approach descriptive models of decision-making. It is assumed that strict rational behaviour is impossible due to restricted logical and economic capabilities. Unlike 'economic man' the real-life 'administrative man' settles for a level of performance that meets reasonable expectations.

The descriptive model by Simon (1957) points out why fully rational decision-making is unattainable. One obvious limitation lies in the human powers of cognition and calculation. People do not have the skills and the value consistency needed for being strictly rational. In addition, being rational in the pure sense implies heavy costs, not least related to information scanning and consequence evaluation of all options. Another important circumstance refers to situational limitations. People are more or less influenced by the past, which is reflected in strong vested interests in the present. By drawing on the ideas of Simon (1957), we used the principles of 'administrative man' when formulating the second decision-making model used in the integrated model.

> Model 2: Bounded rationality.
>
> The farmer is not capable of optimising decisions, he rather settles for a 'satisfying' behaviour drawn on experience, and he applies the same utility function as the rational farmer. The skilled bounded rational farmer is assumed to consider crop sequence, different levels of pesticides doses and N-fertilizer application rate, and whether to use diesel or biofuel (these decisions pertain to all parcels at the farm). We also assume that he has the cognitive capacity to consider the combinations of the 24 alternatives (pesticides 3; fertilizers 4; and fuel 2). In addition to income, the farmer is assumed to have various opinions about environmental protection in line with the principles presented in Model 1. The farmer does not evaluate all possible alternatives of production allocation, but a limited set of alternatives. For each parcel the farmer chooses between the "allowed" (given the levels of accepted environmental loadings) alternatives of pesticides and fertilizers. In 50% of the decisions he settles for the levels used in the previous year. In 50% of the decisions a randomly chosen alternative is compared with the levels used the year before. The perceived most profitable alternative of the two is selected. Normally, the farmer cultivates the following crop of the rotation, but in every second decision a comparison is made to a randomly chosen crop. The perceived most profitable one is chosen.

When moving further away from the ideas of pure rationality towards models meant for more real-life resemblance, Lindblom's (1959) descriptive (as well as normative) model of incremental decision-making may serve as a point of departure. Originally the model was designed for reflecting policy-making within government, but some of the principles can be applied in a managerial context as well.

A characteristic of the decision-maker is that he sometimes avoids thinking through or spelling out his objectives. Such behaviour might be justified as conflict avoidance. Usually the farmer does not make decisions entirely on his own - family members, advisors and neighbours are to a different extent consulted in these matters. For example, studies on investment in machinery report that these decisions cannot fully be understood from an economic point of view (Jacobsen 1997). Tractors not yet economically worn out are replaced due to considerations such as 'fear of repairs', 'outmoded design' and 'need for larger machine'. These empirical results hint at non-economic reasons related to available new technology and style, which create a need for replacement (Marell Molander 1998). This type of consideration may not be accepted by others involved in the decision-making process and may partly explain why objectives are formulated indistinctly in order to avoid conflicts.

Another characteristic of the decision-making process, according to Lindblom, is that changes in the operation tend to be made by small steps. These incremental adjustments are brought about on the basis of what is known, and by doing so restricting major negative consequences of sweeping changes. Such a procedure is very much along the lines of the conservative-type farmer, who relies on traditional knowledge and experience. As a feature of a descriptive model, however, critics have commented on its shortcomings by referring to situations when it is pointless to merely carry out incremental adjustments. Fundamental changes in the socio-economic environment (*e.g.* deregulation of agriculture, changed agricultural policy within the European Union) of the farm business would definitely alter its conditions. A continued strategy of business as usual would most likely be unsuccessful and result in decreased profitability or even closure. However as long as conditions remain more or less the same, incremental decision-making could work by means of its remedial properties of fixing things that do not work. Implicit in the model lies the characteristic of handling small malfunctions as they emerge rather than extensively looking for expansive possibilities.

This discussion suggests that a distinction needs to be made between routine and unique decisions. Simon (1960) refers to programmed and non-programmed decisions in connection to economic considerations. It is unnecessarily expensive to undertake systematic analysis of well-known and repetitive problems. Resources should rather be directed towards situations where complex and novel decisions have to be made. Etzioni's (1967) mixed-scanning strategy combines a thorough exposition of intricate decision problems, whereas perfunctory matters can be handled incrementally. Fundamental decisions should be made by investigating as many options as possible open to the decision-maker, but with the omission of detailed assessment so that an overview is possible.

According to Simon (1960) fundamental decisions need some sort of intelligent and adaptive problem-orientated activity, which cannot fully be met by different calculation devices. In a study on Swedish farmers, Öhlmér *et al.* (1998) found that very few use planning tools such as budgeting or computer models. Rather it seems that they try to form cognitive situation-specific images and make categories and scenarios. Due to uncertainties and changing conditions, written plans are not used to any large extent, unless the decision refers to, for instance, a major investment that may jeopardize the existence of the business. In accordance with the ideas of incremental decision-making, farmers tend to introduce new production or marketing activities step by step to be able to avoid heavy financial losses in the event of failure.

Lindblom (1959) also points out that decision-makers seldom regard problems as being solved once and for all. They keep coming back to similar problems over and over and try to reinterpret why failures occur. This hints at the difficulties of perceiving the decision process as a linear sequence of steps (exemplified in the pure rationality model). It has been shown that in real-life decision-making there are factors such as delays, interruptions and feedbacks, which distort the idea of a linear process. Öhlmér (1997) suggests that within each of the phases (problem detection, problem definition, analysis and choice, and implementation) there are looping sub-processes in which the farmer searches for information, makes plans, analyses options and checks choices.

Given this structure, new information can be collected and revisions can be made throughout the entire decision process. The process in which the farmer invests in a new combine harvester, for example, may start by the continuous reading of journals and magazines or a visit to various trade fairs, which make him conscious about new models and their performance. He gathers more information by talking to different people and tries to decide whether such an acquisition is a good idea or not. Does he need the top of the line model or is it better to settle for the basic model? The outcome of these considerations decides which options need to be further scrutinized. If the farmer is 'quantitative' he may check whether the budget allows the top model and, if necessary, change aspiration levels. However, to have chosen a final alternative is not the same as implementation. Once again he might talk to advisors, neighbours and other trusted people, and check their opinions. Thereafter he has to gather financial resources, which often means negotiations with the bank about interest rates, period of repayment and other loan conditions.

This example clearly indicates the temporal extension of the decision process. Weeks, months or even years make be required between problem detection and successful implementation, which is a circumstance not easily handled within the modelling framework. Apart from the representation of the daily growth of crops, decisions concerning crop sequence, the use of fertilizers and pesticides are made once a year. This means that the complexity of the decision-making process is encapsulated in a discrete point in time. The conventional method of population ageing by employing annual transition probabilities and rules has weaknesses related to the interdependence of various events and the intricacy of individual choices. An alternative to such a method (time-driven simulation) would be to use event-driven simulation, in which changes in processes (*e.g.* the decision process of buying a new combine harvester) are identified as they occur (Holm *et al.* 1989). By means of previous events new points in time can gradually be scheduled. The use of event-driven simulation is beyond the scope of this study, but it seems nevertheless to be a promising simulation methodology when modelling the decision-making process in further detail.

Model 3: Incrementalism.

The farmer only considers making limited annual changes in production. The allocation of pesticides, fertilizers and fuel is mostly the same year by year, but in every tenth decision a comparison is made to another allocation. The alternative is chosen only if it is more profitable and implies an incremental change in the levels of pesticides, fertilizers or fuel (*e.g.* changing fertilizer from 80% to 100% of normal rate). Leaving the crop sequence is only considered if any other crop is more profitable than the following one in the sequence.

The characteristics of the descriptive incremental model make it closer to real-life decision-making than the two former ones. However, these models represent different kinds of formal rationality, which are based on analytical procedures that dissect a complicated reality into manageable problems. There is an obvious risk that researchers, as outsiders, impose on the farming community a rationality that they do not share. Based on empirical studies of Swedish farmers, Öhlmér (2000) contends that farmers use intuitive rather than analytical decision-making strategies. Calculations of magnitudes and consequences are replaced by judgements and comparisons to similar situations experienced previously. Cursory information about tendencies often serves as a sufficient source for decisions.

Moreover, the varying views on money and profitability could serve as a good example of different rationalities. Within the decision models referred to, profitability is expressed more or less explicitly as the most important driving force for continued operations at the farm. By referring to numerous studies

Nitsch (1990) argues that *"Swedish farmers' primary motivation in farming does not stem from monetary profit. More basic to motivation are factors such as family appreciation, freedom in making decisions, room for creativity, pleasure of working outdoors, and working close to nature"* (p. 68). Admittedly, he recognizes the importance of a sound economy, but farmers often express the opinion that money is merely the means of upholding a desired lifestyle.

Supported by evidence from empirical research on management in small manufacturing firms, Nitsch (1990) believes that decision-making cannot be regarded as a separate activity, which is isolated from other activities within the business. Decision-making is an integral part of daily life at the farm and is formed by the synthesis of information, experiences, and visions. The experienced farmer has developed a coordination skill, which is an essential element of adaptive rationality. Adaptive rationality, unlike formal rationality, takes into account the unpredictability of weather, biology, legislation, market conditions and other factors that affect the operations at the farm. *"Farm management is not a matter of doing everything correctly. Rather it is a matter of getting approximately the rights things done under the specific prevailing conditions on a farm. … it is a matter of making a totality run in a satisfactory manner"* (ibid, p. 69). The coordination skill is a tacit knowledge acquired throughout years of learning in daily life, and makes the farmer capable of applying all the elements needed to run the business.

According to this line of thought, decision-making cannot be understood as a separate part of the farm. More accurately, decision-making is interwoven with the contextual situations of the farm, which is so multifaceted that it does not allow the use of simplifications and pre-determined rules. However, this perspective draws on methodologies somewhat different from those used here and it can be questioned whether knowledge about decision-making can *only* be achieved through in-depth analyses of people within the system, but it rightfully stresses the importance of distinguishing between internal and external rationality. It has to be borne in mind that the applied decision models impose a rationality in which rational behaviour is primarily to prefer more money. Immaterial values such as those mentioned by Nitsch (1990) are often underrated or even neglected. One possible way of getting closer to the farmer within the methodological framework used here could be to involve him in the elaboration of the systems analysis model and let him run simulations. This was not carried out at this stage of the project, but would most likely provide new insights and suggestions for alternative solutions.

Before leaving the discussion on decision-making we would like to add one more model, which serves as a reference point to the others. It would be beneficial to get an idea of how the outcomes on profitability and environmental loadings of the pure rationality, bounded rationality and incremental models differ from a decision model governed by pure chance. In the Garbage Can model proposed by Cohen *et al.* (1972) flows of opinions, problems and solutions are mixed and the outcome of the decision-making process is very much a result of the timing and the logistics of the contributions made by all the people involved. The fundamental idea is to create a broad basis for decision-making by facilitating many different solutions to emerge. However, the degree of empirical support is a matter of controversy, as some think that the model over-emphasizes the irrational components of behaviour (Lane 1993).

> Model 4: Garbage Can.
>
> Given the level of accepted environmental loadings, the amounts of pesticides and fertilizers are randomly chosen, as is the crop. However, the logistical constraints regarding crop sequence are kept.

To sum up, the decision models presented above are four different ways of representing farmers' decision-making. The bounded rational model and the incremental model are intended to provide a best characterization of real life decision-making, whereas the pure rational model and the Garbage Can model should be regarded as models for comparison. The model driven by pure rationality stands for an ideal situation showing what it could be like if more were known about the economic consequences of actions taken. On the other hand, the Garbage Can model, which is essentially driven by chance, represents a decision-maker with very limited knowledge about how to run a farm. This model demonstrates the outcomes of letting anybody make decisions about production allocation at the farm without any knowledge of running a farm. From this point of view, these two decision models can be regarded as extreme references, whose outcomes may be compared to the outcomes of the two other more realistic decision models.

So far we have described the experimental conditions regarding environmental issues, prices and subsidies, and decision-making. Now we continue along the path in Figure 5. In the SALSA mind model, the integrated model reproduces the process where the farmer makes up his mind about which production option to carry out. This part draws very much upon the decision-making principles and the experimental conditions discussed above. For each of the twelve parcels, the outcome provides a set of crops, fertilizers and pesticides to be implemented. The chosen production allocation is sent on to the energy and substance flow model, SALSA arable, which carries out the analysis of the physical flows and their consequences for the environment. In the SALSA mind model, the evaluation of different production alternatives is performed by using slightly distorted results from the SALSA arable model. This procedure is justified by the notion that farmers cannot exactly foresee the "true" outcomes. On the other hand, it is not reasonable to assume that their perceived notions of production alternatives deviate strongly from the "true" results. Therefore we settled for using distorted results from the SALSA arable model.

4.3. SALSA arable model description and equations

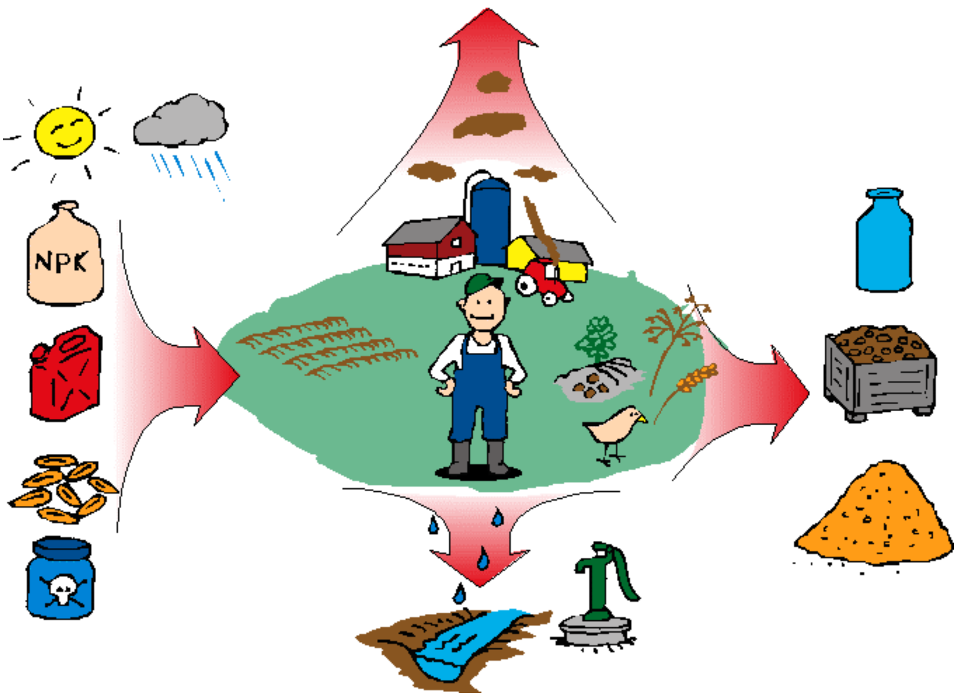


Figure 6. The farmer's decision on amount of resources and types of activities gives effects on the yield and causes environmental impacts on air, soil and water bodies. Illustration Kim Gutekunst.

4.3.1. Main characteristics

Environmental load and farm production were calculated using a model; the SALSA arable model (Systems AnaLysis for Sustainable Agriculture). The SALSA model is a tool for environmental systems analysis of agricultural production at farm level. The model can be described as an energy and substance flow analysis model (SFA) for analysis of different scenarios, complemented by life cycle assessment methodology for evaluation of the environmental impact. The main principle of the physical flows model is illustrated in Figure 7.

The model was built for handling the substance flows and energy use relevant in respect of the studied impact categories: eutrophication, global warming, acidification and energy use. The amount of cultivated area per functional unit[9] can also be calculated. The functional unit in the SALSA arable model can be one specific amount of one crop's yield, for example 1 000 kg winter wheat or it can also be the production on a specific area, for example 6 000 kg barley produced on one hectare. It is also possible to study the production on a whole farm for a single year or for several years or to study a set of crops that fulfils a feed mix.

The environmental impacts from different parts of the system are presented separately, which enables a comparison between sub-systems in order to find the sources behind the highest impacts. Key environmental issues can then be highlighted and by testing different scenarios conflicting goals can be found. The model is made for analysis and comparison of several scenarios in order to visualise the effect from different management practices.

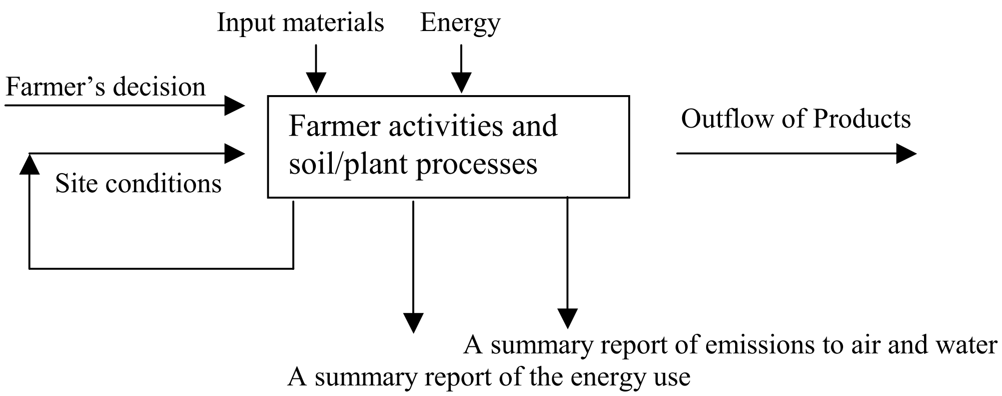


Figure 7. The principle for simulating the substance and energy flows for farm production by the SALSA arable model.

A farm system may be described as a set of sub-systems organised as a chain of activities taking place during refinement of raw materials to farm products. Each of the sub-systems interacts with other sub-systems (internal effects)

[9] Functional unit is used for specification of the performance characteristics of the study. The functional units primary purpose is to provide a reference to which the input and output data of environmental loads and resource use are normalized (ISO 1998).

and the surrounding environment (external effects), either in a static or dynamic manner. Internal effects occur when a process affects the state of a system, thus influencing the future behaviour of the system. One example of internal interaction at a farm is the release of nitrogen from crop residues to the following year's crop, which provides a benefit to the following crop in a crop rotation or leads to nutrient leaching during seasons without crop growth. Other examples of internal interactions are soil compaction, which leads to a reduced yield for the following crops for several years, and the pathogen pressure on crops, which depends on the frequency with which a crop is repeatedly grown in a crop rotation. The flow of nutrients from animal husbandry to crop production via manure applications to soil is an internal effect at integrated farms, as is the feed flow and its effect on animal production. The external impact of farm production refers to emissions and use of resources. The system gives rise to both external effects on the surrounding environment and to internal effects affecting the productivity of the system.

The model is built for Swedish farm production from a life cycle perspective, assessing the physical flows from manufacturing of input materials up to production and delivery of the products to the purchaser. Environmental loads from all parts of the production chain are then recorded and categorised into environmental impacts according to ordinary life cycle assessment methodology (ISO 1998, Guinée *et al.* 2001). The impact categories chosen in this study were selected due to their relevance for the agricultural sector's environmental impact and limited to impacts possible to describe with a physical flow model. The effects on biodiversity and landscape aesthetic values were therefore not considered in this study.

The SALSA arable model described in this report is part of a modelling approach that also includes the models SALSA pig (pig meat production) and SALSA cattle (milk and cattle meat production). The animal production models can each be simulated together with arable production in order to study the environmental effect of feed choice or to study other interactions between arable and animal systems (Figure 8).

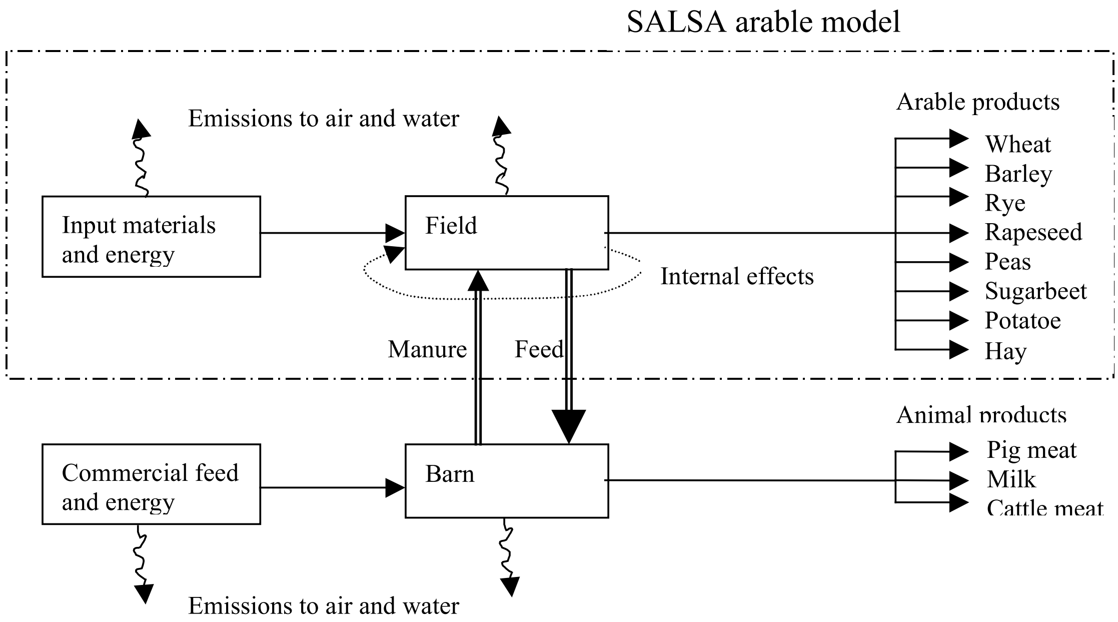


Figure 8. The main structure of the SALSA model for farm production, and a presentation of the agricultural products available for simulation of environmental impacts. The dotted line enclosures the SALSA arable model used in this study.

The main characteristics of the SALSA arable model and its components of farm activities and soil and plant processes are described in the following section. The results from each sub-model are summarised in a crop and activity/event specific vector denoted $\underline{S}$ (followed by an index). The $\underline{S}$-vectors consist of information on quantities of; H_2O, total N, NH_3, NH_4 NO_3, N_2O, organically bound N, P, K, SO_2, CO_2 of fossil origin and bio origin, CH_4, Cd, Zn and energy use. The SALSA arable model consists of several sub-models representing the following activities and processes:

<u>Production of input material:</u>

- $\underline{S}_{PMF}$, mineral fertilizer production
- $\underline{S}_{Seed}$ seed production
- $\underline{S}_{PriD}$ production of the energy carrier fossil diesel, *e.g.* the energy use is recalculated to primary energy

- $\underline{S}_{PriE}$ production of the energy carrier electricity, *e.g.* the energy use is recalculated to primary energy
- $\underline{S}_{PriG}$ production of the energy carrier natural gas, *e.g.* the energy use is recalculated to primary energy
- $\underline{S}_{PriO}$ production of the energy carrier oil, *e.g.* the energy use is recalculated to primary energy
- $\underline{S}_{RME}$ production of biodiesel, RME production

Farmer activities:

- S_{AMF}, S_{AOF} ammonia losses from applications of mineral and organic fertilizers
- $\underline{S}_{Fuel}$ tractor emissions from tillage and other machine operations in the field, harvesting and transport
- $\underline{S}_{dry}$ electricity use and fuel oil combustion in drying of grain
- $\underline{S}_{RSpre}$ electricity use during preparation of rapeseed oil

Soil, plant and recipient processes:

- $\underline{S}_{soil}$ processes in the soil and the crops causing direct air and water emissions
- S_{rec} processes emitting N_2O in recipients caused by nitrogen emissions of agricultural origin (indirect N_2O emissions).
- S_{Cair} ammonia emission from plants

Emissions and energy use for one crop per hectare and year $\underline{S}_{Crop}$ is then calculated as follows:

$$\underline{S}_{Crop} = \underline{S}_{PMF} + \underline{S}_{Seed} + \underline{S}_{RME} + \underline{S}_{AMF} + \underline{S}_{AOF} + \underline{S}_{Fuel} + \underline{S}_{dry} + \underline{S}_{REpre} + \underline{S}_{soil} + \underline{S}_{rec} + \underline{S}_{Cair} + \underline{S}_{\Pr i} \qquad \text{(eq. 7)}$$

Underlined S-variables consist of several substances forming a vector otherwise the variable is a scalar. Emission substances have a specific place in all the substance emission vectors $\underline{S}$ and the substance emissions and energy use from one farm is calculated as follows:

$$\underline{S}_{Farm} = \left(\underline{S}_{Crop1} * a_1\right) + \left(\underline{S}_{Crop2} * a_2\right) + \ldots \qquad \text{(eq. 8)}$$

where $\underline{S}_{Farm}$ is the emissions and energy use for growing the crops on the farm and a is the area (ha) on which the crops are grown. The emission of substances and energy use for a feed mix $\underline{S}_{Feed}$ is calculated as follows:

$$\underline{S}_{Feed} = \left(\underline{S}_{Crop1} * x_{feed1} / x_y\right) + \left(\underline{S}_{Crop2} * x_{feed2} / x_y\right) + ... \qquad \text{(eq. 9)}$$

where x_{feed1} is the amount of the crop in the feed mix and x_y is the yield per hectare of the crop.

In the impact assessment, the characterisation of substances into different environmental impact categories is done by multiplying the substance emissions $\underline{S}_{Farm}$ relevant for each impact category by the corresponding equivalency factor (see section 6.3, Environmental Impact) to assess the relative impact from different emissions as follows (for the example $\underline{S}_{Farm}$):

$$Eutro_{Farm} = \underline{W}_{Eutro} \circ \underline{S}_{Farm} \qquad \text{(eq. 10)}$$

$$Green_{Farm} = \underline{W}_{GWP} \circ \underline{S}_{Farm} \qquad \text{(eq. 11)}$$

$$Acid_{Farm} = \underline{W}_{Acid} \circ \underline{S}_{Farm} \qquad \text{(eq. 12)}$$

where $\underline{W}_{Eutro}$ is the equivalence row-vector for eutrophication, $\underline{W}_{GWP}$ is the equivalence row-vector for global warming potential, $\underline{W}_{Acid}$ is the equivalence row-vector for acidification and $\underline{S}_{Farm}$ is a column vector giving the emissions of the effecting substances. The $\circ$ -symbol is the inner product of the two vectors.

The energy use is presented as total use of primary energy *Primary EnergyUse* $_{Farm}$ and as the fraction of fossil primary energy *Fos. Primary EnergyUse* $_{Farm}$. See description in Appendix A.6.

The multiplication of the substance flows and the classification and weighting of the substances into the impact categories kg O_2-, CO_2 and SOx-equivalents and as MJ primary energy for a defined functional unit gives the result. The functional unit could be one individual crop or all crops on a farm, for a single or for several years, a farm, a feed mix etc. The classification of substances and equivalency factors used in the model are described in section Environmental Impacts.

Included in the model are also pre-simulation sub-models, used for calculation of input data, such as a suitable application rate for mineral fertilizer. Figure 9 gives a schematic description of the SALSA arable model as it is presented in the graphical simulation package SIMULINK.

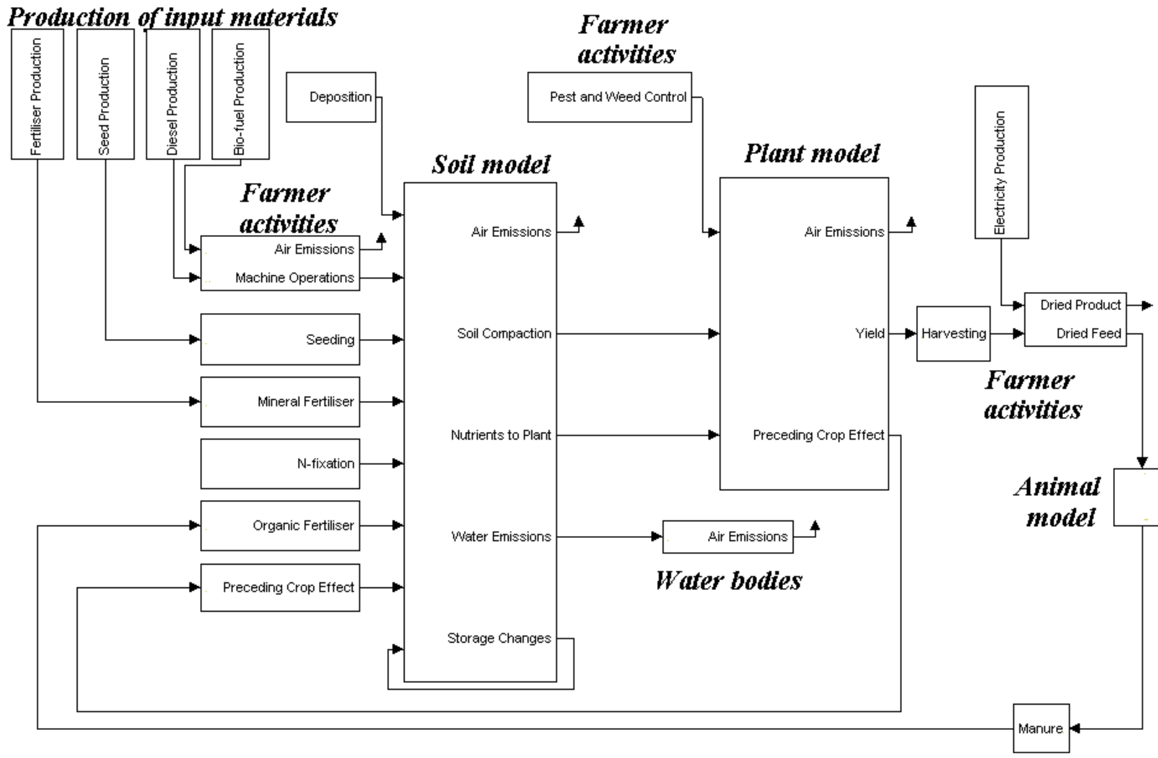


Figure 9. The SALSA arable model's top layer in the graphical interface SIMULINK, describing the physical flows related to production of input material, farm activities, soil, plant and recipient processes. The interface with SALSA pig and SALSA cattle is denoted 'Animal model'.

Other results that can be obtained from the simulations concern yield and soil status.

<u>Results of yield and soil status:</u>

- x_y yield response to N application rate
- p_{eff} yield decrease due to reduced pesticide applications
- c_{eff} yield losses due to soil compaction
- i soil nutrient status

4.3.2. Production of input materials

In the SALSA model, energy use and environmental load during production, transportation and distribution of seed, fertilizers, diesel, RME and electricity are included. The following sections describe those model parts.

Since the 1950s, Swedish agriculture has undergone large structural changes; production has changed to more specialized entities, management has become more mechanized and the use of artificial fertilizers has increased. The increased use of artificial fertilizers compensates for the large outflow of nutrients due to higher yields (Claesson & Steineck 1996). About 85% of nitrogen applied to crops is artificial fertilizer, but the major proportion of phosphorus and potassium, 60% and 75% respectively, is applied as organic fertilizers. On fertilized farmland in Sweden 105 kg N, 25 kg P and 85 kg K were applied on average per hectare during 2001 (SCB 2003).

The diesel consumption in agricultural production is about 100 litres per hectare and year, if the average annual diesel consumption per farm is divided by total annual cropped farmland in Sweden (SCB 2002b, 2003), where activities such as ploughing, harvest and grain drying are the largest sources of diesel consumption. Electricity used for drying grain in wet autumns can represent a considerable part of the farm's total energy use. The energy use can be recalculated to primary energy [10] to also include the production cost of the energy carrier.

According to LCA methodology, all relevant flows should be included. The production chain can theoretically be traced backwards in a large number of phases. The SALSA model calculates the environmental effects backwards including production of input materials and energy. This corresponds to include up to level 2 in a traditional energy analysis, called energy process analysis, Figure 3. The decision to stop at that level is based on two reasons. The first is that other authors have pointed out that a study including production of input materials and processes on the farm (the first and the second level) captures the largest environmental impacts. The second reason relates to the goal of the study to compare different farm management practices, where the same machinery equipment and buildings are assumed.

Emissions during production of fertilizers

Artificial fertilizer production is a highly energy-demanding process especially in the production of ammonia. The dominating energy carrier is natural gas. Air emissions of CO_2, N_2O, and NO_x occur during production and small amount of SO_X and HCl are also emitted. Nitrous oxide is generated during production of nitric acid, which is used for nitrate fertilizer production.

[10] Primary energy is a concept to include the energy embodied in the product. The direct energy use on the farm is multiplied by a factor to also include energy use for production and distribution of the energy source and efficiency losses during the energy converting processes. See Appendix A.6.

Therefore the amount used and the choice of artificial fertilizer, *i.e.* proportion of ammonium and nitrate in the fertilizer, is central for the environmental effects. In the final production steps smaller amounts of emissions to water of nitrogen and phosphorus are generated (Davis & Haglund 1999). Environmental impacts from production of artificial fertilizer, $\underline{S}_{PMF}$ are estimated as follows:

$$\underline{S}_{PMF} = x_{AMF} \times \underline{\varepsilon}_{PMF} \qquad \text{(eq. 13)}$$

where $\underline{\varepsilon}_{PMF}$ is for each fertilizer a specific vector containing emissions, (kg air emissions of CO_2, N_2O, NO_x, SO_X, HCl, and kg emissions to water of N and P) and energy use (MJ primary energy) per kg fertilizer for production of mineral fertilizer. The variable x_{AMF} is the amount of applied fertilizer (kg) per hectare and year. Data for environmental impacts for mineral fertilizer production were taken from an LCI-inventory of fertilizer production (Davis & Haglund 1999), see Appendix A.3. where emission and energy use for production of some artificial fertilizer is presented per kg fertilizer.

For the fertilizer year 1998/99, 500 000 tonnes of the following artificial fertilizers were sold and distributed in Sweden.

Table 10. Artificial fertilizers sold during the year 1998/99 (Interview Sven Strömberg).

'Swedish commodity name'/ English name	Tonnes
'Kalksalpeter', 15.5% N/ Calcium Nitrate (CN)	130 000
'Axan'/Svavelsalpeter 27% N/ (Ammonium Nitrate fertilizer with Sulphur)	101 000
Kalksalpeter/Svavel, 15.2% N/ Calcium Nitrate with Sulphur	98 000
'Ammoniumnitrat', 35% N/ Ammonium Nitrate (AN)	76 000
'Kalkammonsalpeter', 27.6% N/ Calcium Ammonium Nitrate (CAN)	65 000
'NPK 20-4-8', 20% N/ a complex fertiliser	57 000

As can be seen in Table 10, calcium nitrate (*Kalksalpeter*) is the most frequently used fertilizer in Sweden. Unfortunately emissions from production data for calcium nitrate are not available, due to difficulties in allocating environmental loads between different fertilizer products. Calcium nitrate is made as a by-product during production of other artificial fertilizers. Therefore use of another calcium ammonium nitrate fertilizer (*Suprasalpeter*) was assumed in this study.

Depending on the system boundary of the intended study, environmental load (or part of the environmental load) from storage and application of organic fertilizer can be allocated either to grain production or to the livestock system. The procedure for calculation of emissions from the organic fertilizer production system is described in Appendix B.5.

Seed production

Purchase of seed is a considerable cost for the farmer but the nutrient inflow from seed is often of minor importance. It is first when the seed rate is large compared to the yield that the environmental costs are noteworthy. The seed rates used varied from 8 kg/ha for rapeseed, up to 249 kg/ha for spring wheat (AGRIWISE 2002). Seed can also be taken from self-production on the farm.

Emissions and resource use for seed production were assumed to be the same per area basis as for the crop production on the farm. There may be extra pesticide use for seed production and more nitrogen may also be applied in seed production if increasing the nitrogen application rate generates a higher economic return for seed production, but those two additional contributions would together probably be so small as to be negligible. Consequently, the environmental impacts from seed production, $\underline{S}_{Seed}$ were estimated as a percentage of total crop impact depending on seed rate:

$$\underline{S}_{Seed} = \left(x_S \div x_Y\right) \times \underline{S}_{Crop} \qquad \text{(eq. 14)}$$

where $\underline{S}_{Crop}$ is a vector giving the emissions and energy use calculated using the SALSA arable model for a crop per hectare, x_{Seed} is the seed rate and x_Y is the yield for the crop per hectare and year.

Emissions during production of energy carrier

Emissions and energy use for production and distribution of the energy carrier (electricity, oil, natural gas and diesel) are estimated as follows:

$$\underline{S}_{\Pr iE} = En_E * \underline{\varepsilon}_{Ep}$$ (eq. 15)

$$\underline{S}_{\Pr iO} = En_O * \underline{\varepsilon}_{Op}$$ (eq. 16)

$$\underline{S}_{\Pr iG} = En_G * \underline{\varepsilon}_{Gp}$$ (eq. 17)

$$\underline{S}_{\Pr iD} = En_D * \underline{\varepsilon}_{Dp}$$ (eq. 18)

where En_D is energy derived from diesel fuel (MJ/ha and year), En_E is the energy derived from electricity (MJ/ha and year), En_G is energy derived from natural gas (MJ/ha and year) and En_O is energy derived from oil (MJ/ha and year). $\underline{\varepsilon}_{Dp}$ is the emission vector for the production of diesel, (kg, MJ/ha and year), $\underline{\varepsilon}_{Ep}$ is the emission vector for the production of electricity (kg, MJ/ha and year), $\underline{\varepsilon}_{Gp}$ is the emission vector for the production of natural gas (kg, MJ/ha and year) and $\underline{\varepsilon}_{Op}$ is the emission vector for the production of oil (kg, MJ/ha and year). All energy values are given as lower heating value.[11]

Recalculation to primary energy

A method to facilitate comparison of energy use from different energy carriers is to recalculate all energy use to primary energy use. Here primary energy refers to the total energy use on the farm and energy use for production and distribution of the energy carrier. For electricity production efficiency losses during energy conversion and grid losses are also included. See Appendix A.6. for description of how the conversion indices for primary energy have been calculated.

Primary energy use En_{PriD}, En_{PriE}, En_{PriG}, En_{PriO} is calculated as follows:

$$En_{\Pr iD} = En_D * \Pi_{\Pr iD}$$ (eq. 19)

$$En_{\Pr iE} = En_E * \Pi_{2-\Pr iE}$$ (eq. 20)

$$En_{\Pr iG} = En_G * \Pi_{\Pr iG}$$ (eq. 21)

[11] Lower heating value is the effective energy value, the energy per kg dry matter, which differs from the higher heating value, also called calorimetric heating value, where the energy for vaporisation of water is also included.

$$En_{\Pr io} = En_O * \Pi_{\Pr iO} \quad \text{(eq. 22)}$$

where En_E is energy derived from electricity (MJ/ha & year), En_G is the energy derived from natural gases (MJ/ha & year), En_D is energy derived from diesel fuel (MJ/ha & year) and En_O is energy derived from oil (MJ/ha & year). The primary energy conver factors for diesel, electricity, natural gas and oil are Π_{PriD} (1.06), $\Pi_{2\text{-}PriE}$ (2.2 Swedish average electricity mix), Π_{PriG} (1.07) and Π_{PriO} (1.05).

The total primary energy use on the farm *Primary EnergyUse* $_{Farm}$ is then calculated as follows:

$$\Pr imaryEnergyUseFarm = En_{\Pr iO} + En_{\Pr iG} + En_{\Pr iE} + En_{\Pr iD} \quad \text{(eq. 23)}$$

The proportion of non-renewable primary energy use is also presented. Diesel, oil and natural gas are all fossil fuels. A Swedish average electricity mix is produced with 44% nuclear power with an efficiency of 33%, this gives a primary fossil energy factor of 74% for the energy carrier electricity (see Appendix A.6).

The total primary non-renewable energy use on the farm *Fos. Primary EnergyUse* $_{Farm}$ is then calculated as follows:

$$Fos.\Pr imaryEnergyUse_{Farm} = En_{\Pr iO} * \Pi_{\Pr iO-Fo} + En_{\Pr iG} * \Pi_{\Pr iG-Fo} + En_{\Pr iE} * \Pi_{2-\Pr iE-Fo} + En_{\Pr iD} * \Pi_{\Pr iD-Fo}$$

(eq. 24)

where $\Pi_{PriO\text{-}Fo}$, $\Pi_{PriG\text{-}F}$, $\Pi_{2\text{-}PriE\text{-}Fo}$, $\Pi_{PriD\text{-}Fo}$ are the fractions of the fossil primary energy carriers oil, natural gas, electricity and diesel (see Appendix A.6).

Production of RME from rapeseed oil

The rapeseed was grown on the farm and the rapeseed oil was assumed to be extracted mechanically in a small-scale plant on the farm, a hole cylinder oil expeller with an efficiency of 68%. The rapeseed oil was then manufactured to RME using methanol. Emissions and resource use for manufacture of the rapeseed oil to RME were set according to Bernesson *et al.* (2003). Figures are given in Appendix A.7. The total environmental load and energy use for RME production, $\underline{S}_{RME}$, is calculated as follows:

$$\underline{S}_{RME} = \underline{S}_{CropRS} + \underline{S}_{RSpre} + \underline{S}_{Methanol} + \underline{S}_{RSEster} \qquad \text{(eq. 25)}$$

where $\underline{S}_{CropRS}$ is the environmental load and energy use for production of rapeseed oil on the farm, $\underline{S}_{RSpre}$ is the extraction of the rapeseed to rapeseed oil, $\underline{S}_{Methanol}$ is the production and transportation of methanol and $\underline{S}_{RSEster}$ is the energy use for the transesterification.

4.3.3. Fertilising and N-import

Fertilising

The nitrogen application rate used on the farm is a key factor affecting the crop yield, the environmental load and energy use. There are two options for the fertilizer application rates: they can either be set as is done on a specific farm or they can be estimated according to the Swedish Board of Agriculture's (SJV) manual (Jordbruksverket 1997-2002). In the SJV manual recommended fertilizer application rates are given for different crops. The SJV level is also used as background information to decide whether the fertilizer application rate used on a farm is appropriate or not, due to the fact that N application levels higher than the proposed level will increase the N-leaching. See section on N-leaching.

The N application level proposed by SJV is a result of an optimisation where both prices of fertilizer and product as well as yield responses for different N application rates have been taken into account (see Appendix A.1. for Yield response functions and Appendix B.7. for the optimising equation for fertilising). The N application rate is then adjusted to the potential yield on a specific farm, due to climate and site conditions. For example if the expected yield is decreased by 1 ton/ha and year, the N application rate should be decreased by 20 kg/ha and year. Other sources of nitrogen such as N mineralisation from the soil or animal manure application are then considered and the mineral application rate is assumed to fill the remaining part of the crop's need. The net mineralisation of N was assumed to be the same as that given in the SJV guidelines (Jordbruksverket 1997). The recommendations are based on nitrate fertilizers and if ammonium nitrate is used the nitrogen application rate should be 10-15% higher because of the lower efficiency of use for those fertilizers (Jordbruksverket 2002). A suitable P and K fertilizer level is calculated from the crop's need compared to the soil's P and K status.

The N application level $x_{F(N)}$ (kg N/ha and year) is then calculated as follows:

$$x_{F(N)} = (\varphi x_y + \mu) \qquad \text{(eq. 26)}$$

and the fertilizer level x_F (kg/ha and year) is calculated as follows:

$$x_F = x_{F(N)} \div \eta \qquad \text{(eq. 27)}$$

where φ and μ are crop-specific constants in the linear equation for nitrogen application due to yield level, (Jordbruksverket 2002), x_y is the crop yield (kg/ha and year) and η is the nitrogen content in the fertilizer (%).

Fertilizes can be applied on four occasions in the SALSA arable model; autumn, spring, early summer and late summer. Application of fertilizer (kg/ha and year) for one crop in one cropping season is then the sum of the four applications. The inflow of N, P, K and Cd to the soil, applied on an area basis for one crop $\underline{i}$ (kg/ha), is then estimated from the fertilizer's content of different substances and the application rates as follows:

$$\underline{i} = x_F \times \underline{f} \qquad \text{(eq. 28)}$$

where $\underline{f}$ is a vector containing information on total N, NH_4-N, NO_3-N, organic-N, P, K, S, Cd and dry matter for a set of artificial and organic fertilizers (%) and x_F is the amount of fertilizer used (kg/ha and year).

Emissions during fertilizer application

Emissions of ammonia (NH_3) after application of organic nitrogen fertilizers are a problem of great concern in agriculture. The most important factors for ammonia emissions from fertilizers during spreading are the nitrogen content, fertilizer characteristics and climate and soil conditions (van der Molen *et al.* 1989). The Swedish Institute of Agriculture and Engineering (www.jti.se) has conducted several ammonia emission experiments for organic and mineral fertilizer application in the field, using a field measurement method developed by Svensson (1994). From those field experiments, emission factors related to the ammonia content in organic fertilizer have been calculated for several types of spreading equipment and for applications in winter, spring, early summer, summer, early autumn and late autumn (Karlsson & Rodhe 2002). Emissions of ammonia during application of organic fertilizers S_{AOF} and mineral fertilizers S_{AMF} are calculated as follows:

$$S_{AOF} = x_{OF} \times \alpha_{OF} \times \varepsilon_{AOF} \qquad \text{(eq. 29)}$$

$$S_{AMF} = x_{MF} \times \alpha_{MF} \times \varepsilon_{AMF} \qquad \text{(eq. 30)}$$

where x_{OF} and x_{MF} the amount of organic and mineral fertilizer applied per hectare (kg/ha and year), a_{OF} is the ammonium content in the organic fertilizer (%), a_{OF} is the ammonium content in the mineral fertilizer, ε_{AOF} is an nitrogen emissions factor for application of organic fertilizer per total amount of applied nitrogen ($_{AOF}$) for different equipment and spreading times (%) (Appendix A.4.) and ε_{AMF} is a nitrogen emission factor for application of mineral fertilizer ($_{AMF}$) per total amount of applied nitrogen (%).

Ammonia emission from mineral fertilizer spreading compared to organic fertilizer spreading is very low, and the emission factor was set to 0.15% of applied nitrogen per hectare and year in accordance with a field experiment (Svensson *et al.* 1999).

4.3.4. Machine operations and transport

Arable farmers spend many hours on machine operations for soil preparation, fertilising, pesticide control, harvest and transport of products from field to farm and purchaser. For tractor work occupies 5.7 hours/ha and year and harvesting 2.2 hours/ha and year, while the corresponding tractor work for oilseed crops is 9.6 hours/ha and year, with 1.7 hours/ha and year for harvesting of the oilseed crop (AGRIWISE 2002). Fuel and man-hours are considerable costs for the farmer and the use of fossil energy is also an environmental issue because of the finite nature of fossil fuel and because of the contribution of fossil fuels to the greenhouse effect by CO_2-emissions, to eutrophication by NOx-emissions and to acidification by NOx- and SOx-emissions. The farmer's use of diesel in litres was converted to MJ by dividing by the conversion factor 35.4 MJ/litre.[12]

Data on diesel consumption per operation were taken from farms engaged in the project "Farming in Balance" (Interview Lars Törner). Data on number of field passes per operation for different crops were taken from the previously mentioned farm data or from a Swedish economic advice programme (AGRIWISE 2002).

The use of fuel u_{Fu} per hectare for different machine operations and transport on the farm is calculated for each crop as follows:

[12] The lower heating value, *i.e.* the energy released when 1 l diesel is totally combusted. Standard diesel ("winter" diesel in Sweden) has an energy content of 42.8 MJ/kg and density of 0.826 kg/l (Hansson & Mattson 1999).

$$u_{Fu_{(c,n)}} = x_{Fu(n)} \times No_{(c,n)} \quad (31)$$

where $x_{Fu\ (n)}$ is the operation-specific fuel (diesel or other fuel) consumption per hectare (MJ/ha and year), where the index *c* denotes a crop and *n* denotes an operation, and $No_{(c,\ n)}$ is the number of passes of a specific operation for a crop. There is a considerable variation in the numbers of tillage operations, sprayings and fertilising for different crops but harvesting and ploughing are usually carried out just once for each crop.

Exhaust emissions from the machine operations on the farm were calculated using emission factors for NO_X, CO_2, CH_4, N_2O and SO_2 (Hansson & Mattson 1999, Uppenberg 2001 del II). The exhaust emissions of CO_2 and SO_X are mainly determined by the content of carbon and sulphur in the fuel, whereas the formation of NO_X emissions mainly depends on the reactive conditions during the fuel combustion and is thus affected by different tractor operations. The NO_X formation in the cylinder is high when the temperature and pressure are high (Heywood 1988), *i.e.* when the power used for an operation is high, for example at ploughing. Emissions of CH_4, N_2O are probably also operation-dependent, but due to lack of data an average value for heavy vehicles are used in the model (Uppenberg *et al.* 2001), see also Appendix A.8. Biofuel can be chosen as fuel for tractor driving and drying/heating, and in that case, exhaust CO_2 emissions are set to zero and the remaining emissions as for diesel fuel and fuel oil, respectively. The derived exhaust emissions $\underline{S}_{Fu(1-n)}$ per hectare for different machine operations and transport (*1-n*) on the farm are calculated for each crop as follows:

$$\underline{S}_{Fu(c,n)} = u_{Fu_{(c,n)}} \times \underline{\varepsilon}_{Fu(n)} \quad \text{(eq. 32)}$$

where $u_{Fu(n)}$ is the use of fuel for each crop (MJ/ha and year) and $\underline{\varepsilon}_{Fu(n)}$ is the emission vector (kg/MJ and year) for different machine operations, see Appendix A.8.

4.3.5. Drier and press

The dry matter content in grain during harvest depends on weather conditions before and at harvest. For water contents over 15% for cereals and 8% for oilseed crops, the grain needs to be dried to maintain storage quality. The average water content in fresh grain is 20% for winter wheat, 19% for barley and 15% for spring oilseeds (Fältforskningenheten 2002), see Appendix B.2. Fossil fuel is used for generating heat to the drier and electricity is used for the fan. (Farmers can also deliver undried grain to the purchaser but then they cannot take advantage of the best prices. To get rapeseed oil and rapeseed cake, the grain needs to be pressed. A small screw oil press used on the farms is assumed and used for calculations in the SALSA model. The yield rate for this kind of small press is 30% for rapeseed oil and 72% for rapeseed cake as a percentage of the harvested wet oil crop (Bernesson *et al.* 2003). A larger press where chemical extraction is also used achieves higher oil/cake yield rates.

The drier and press sub-model calculates the energy use and energy use derived emissions during drying of harvested grain, and in the case of rapeseed also during pressing of the seed to rapeseed oil and rapeseed cake. The amount of water that needs to be dried off is computed as the difference between the water content at harvest and the desired water content after drying. Both the drier and the press use fuel oil for heating and Swedish average electricity for electrical processes. For the drier the default fuel consumption value in this study was set to 4.7 MJ/kg removed water and electricity use to 0.34 MJ/kg removed water [13] (Interview Lars Elfversson). In the press, 0.09 MJ fuel/kg dried rapeseed (8% water content) was used for heating and 0.33 MJ electricity/kg rapeseed (8% water content) for pressing (Bernesson 1999). In scenarios where biofuels are used, the fuel oil can be replaced by rapeseed oil.

Water content to be dried off, w, is calculated as follows:

$$w = (x_{Y1} \times \gamma_h) - (x_{y2} \times \gamma_r) \qquad \text{(eq. 33)}$$

where x_{y1} is the yield during harvest, x_{y2} is the yield ready to deliver to the purchaser, γ_h is the water content during harvest and γ_r is the water content when the crop is ready for storage or to be delivered to the purchaser.

The drier's use of electricity En_{d-E} and oil En_{d-O} is calculated as follows:

$$En_{d-E} = w * d_E \qquad \text{(eq. 34)}$$

$$En_{d-o} = w * d_o \qquad \text{(eq. 35)}$$

[13] 0.109 kg diesel/kg vaporized water (Interview Lars Elfverson 1999).

where d_E is the electricity use per MJ water and d_O is the oil use per MJ water.

Emissions and energy use for the drier $\underline{S}_{dry}$ is calculated as follows:

$$\underline{S}_{dry} = \underline{En}_{d-E} + (En_{d-O} \times \underline{\varepsilon}_O) \qquad \text{(eq. 36)}$$

where $\underline{En}_{d-E}$ is the electricity use needed for drying, En_{d-O} is the oil use needed for drying and $\underline{\varepsilon}_O$ is the emission vector for combustion of oil (kg, MJ/ha and year).

For pressing of rapeseed grain to oil and cake products with a small farm press, electricity is used. The energy use for the press S_{RSpre} is calculated as follows:

$$S_{RSpre} = x_{y2} \times d_{pre} \qquad \text{(eq. 37)}$$

where x_{y2} is the amount of dried oil crop and d_{pre} is the energy use for pressing (MJ/kg yield).

4.3.6. SOIL sub-model

The flow between the soil and plant is the core system for crop production, Figure 10. The N application rate *(flow number 1)* is the factor that the farmer completely controls by himself. Other processes such as leaching and denitrification are events that the farmer does not affect directly but indirectly through management practices.

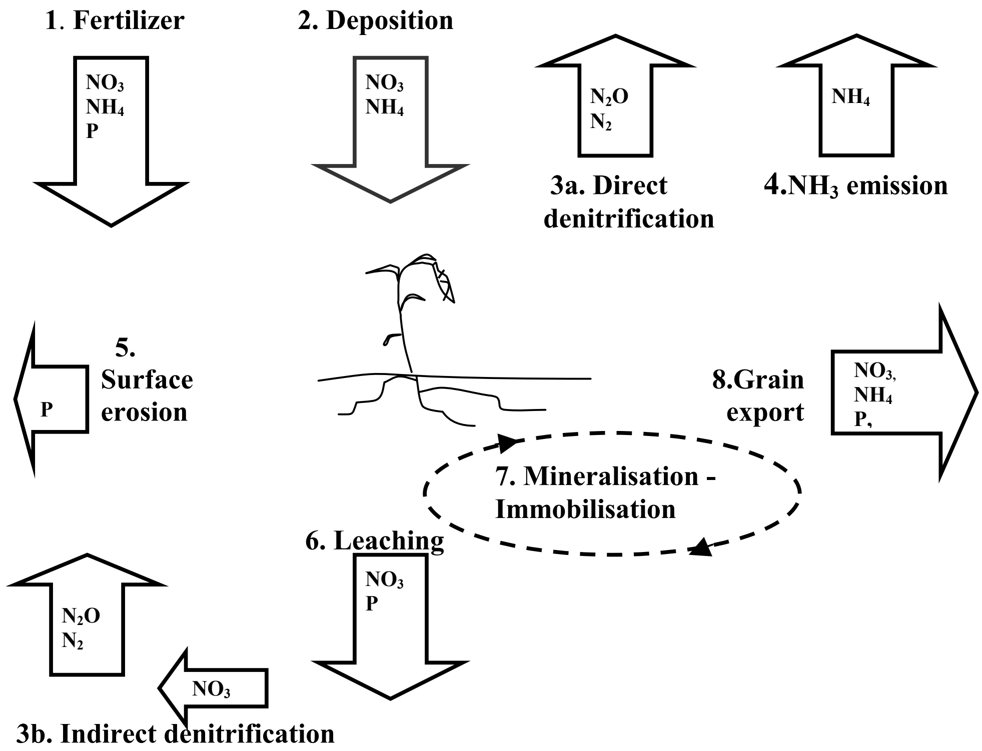


Figure 10. Flows of N and P in the soil-plant system estimated in the study. The nitrogen fertilizer level controls yield level and affects other soil processes.

The arrows in Figure 10 show the yield (*flow number 8*), N and Cd deposition (*flow number 2*), nitrous oxide (N_2O) emissions (*flow number 3a*) from agricultural fields, indirect N_2O emissions via N in the recipient (*flow number 3b*), ammonia emissions from plant residues or plants during ripening and senescence (*flow number 4*), surface erosion of P (*flow number 5*), N and P leaching from the soil (*flow number 6)* and net mineralisation of N (*flow number 7*).

The total emissions from the soil $\underline{S}_{soil}$ is calculated as follows:

$$\underline{S_{soil}} = \underline{l_{Dir-N2O}, l_{Ntot}, l_{Ptot}} \qquad \text{(eq. 38)}$$

where the emissions from the soil considered in the model are NO_3 leaching to water bodies $\underline{l}_{Ntot}$, P leaching via drainage water and as surface losses $\underline{l}_{Ptot}$ and N_2O emissions to air $\underline{l}_{Dir\text{-}N2O}$.

Nitrogen leaching from farmland

Nitrogen leaching from farmland is of great concern since it causes eutrophication in the surrounding seas (the Baltic Sea, Skagerrak, Kattegat), and for some areas in Sweden, especially in the south, the nitrate concentrations in groundwater have been alarmingly high. Of total anthropogenic nitrogen losses to seas, 49% originated from agricultural land during the period 1985-1999 (TRK 2003). Soil texture, precipitation and management practice are the main factors that control the amount of N leaching from land. Jansson *et al.* (1999) showed an increase in nitrogen leaching with nitrogen found in harvest. The same pattern of the nitrogen leaching increasing when excess nitrogen is applied has been found in field trials. However there is probably a decrease in nitrogen leaching when there is a nitrogen deficit in the soil (Interview Gunnar Torstensson). This fact was included in the model by using a variable giving the effect of nitrogen leaching according to excess or deficit nitrogen application rates compared to recommended.

The SALSA arable model consists of two nitrate leaching models, one old used in this study called **the farm model** and one new presented in this report and used in later studies called **STANK in mind leaching model**.

The **farm model** ($l_{FarmNtot}$) is a rough, rule-of-thumb model, developed for advising farmers how different management practices affect N-leaching. Firstly it is based on basic N-leaching figures assumed after empirical studies of N-leaching from Swedish farmland depending on site and management (Hoffman *et al.* 1999), see Appendix A.13. The basic N-leaching is then complemented by management factors and by assumptions on the effect of excess or lower applications of N compared to the recommended. The new model **STANK in mind leaching model,** ($l_{STANKNtot}$) is a refined and improved version of the farm model, and is described in Appendix A.14.

The nitrate leaching (NO_3-N) per hectare and year ($l_{FarmNtot}$) according to the farm model is calculated as follows:

$$l_{Farm\,Ntot} = (\beta * \rho * \tau) + (x_{AOF} * \lambda_{NOF}) + l_{NE} - l_{NA} \qquad \text{(eq. 39)}$$

where β is the background leaching set according to two districts, three soil types and three precipitation ranges, ϱ is a crop index that increases the risk for leaching after oilseed crops, potatoes and peas, and τ is an index for time of tillage where tillage of grass has an index of 1.5 to 2, which increases the leaching, whereas spring tillage, winter rye sown in autumn and an untilled ley have indices of 0.5 to 0.9. The variable x_{OF} is application of manure (ton dm/ha and year) and λ_{NOF} is kg extra N leached/ton dm organic fertilizer applied for district, soil type and precipitation. The variable l_{NE} is the increased N leaching arising from excess N applications and l_{NA} is avoided N leaching resulting from lower applications than recommended (kg N/ha year). All values are given in Appendix A.13.

The amount of N leaching when nitrogen is applied in excess (l_{NE}) is estimated for clay and loamy soils from equation 40 and for sandy and humus soils from equation 41.

$$l_{NE} = 0.15 * (x_e - 0.05) \quad \text{(eq. 40)}$$

$$l_{NE} = 0.0057 * x_e^2 + 0.08 * x_e + 0.4571 \quad \text{(eq. 41)}$$

The excess (x_e) nitrogen application rate (kg/ha and year) in this study was estimated from the actual use compared to a fodder crop's requirement according to the Swedish Board of Agriculture (SJV) in Jordbruksverket (1997). (*Equation 40 is only valid for* $x_e \geq 0.05$.) Note that it is a result of an optimization where both prices and yield responses for different N application rates are included. The figures used in the equation are assumptions made after discussion with an expert (Interview Gunnar Torstensson). This positive correlation between excess amount of applied mineral fertilizer and increase in leaching was also shown by Jansson *et al.* (1999).

The avoided N leaching in kg/ha and year due to lower applications (l_{NA}) was assumed to be half the effect of excess application of N presented in equation 42 for clay and loamy soils and equation 43 for sandy and humus soils:

$$l_{NA} = 0.5 * (0.15 * (x_d - 0.05)) \quad \text{(eq. 42)}$$

$$l_{NA} = 0.5 * (0.0057 * x_d^2 + 0.08 * x_d + 0.4571) \quad \text{(eq. 43)}$$

where deficient (x_d) nitrogen application rate compared to the optimum was estimated from the actual use compared to a fodder crop's requirement according to the Swedish Board of Agriculture (SJV) in kg/ha and year (Jordbruksverket 1997). (*Equation 42 is only valid for* $x_d \geq 0.05$.) The assumption that the effect of lower N application than recommended is half that of N excess was made after discussion with an expert (Interview Gunnar Torstensson).

Note that this N-leaching model aims for a rough assumption of the N-flow fate and other nitrogen flows such as di-nitrogen emissions from the soil, and immobilisation of N in the soil is not included in the calculations.

Phosphorus leaching

Phosphorus is one of the main elements controlling algal production in aquatic ecosystems (Djodjic *et al.* 2002). Phosphorus is lost from farmland via surface runoff, erosion and via drainage water through the soil profile. Factors important for P losses through the soil profile include soil texture, water flow and amount of free P in the soil water. Surface runoff depends mostly on the slope of the field and the precipitation. P losses via drainage water vary greatly, from 0.5 kg up to 10 kg/ha and year and large losses occur episodically. Field trials have shown that surface runoff occurs often during two-three days a year. (Interview Faruk Djodjic) The P in surface runoff is particle bound phosphorus but the drainage losses are mostly free P directly available for plants or organisms. Soils that have received high application rates of manure resulting in high P contents or soils where organic fertilizer is applied unevenly account for most of the P losses from arable farmland (Naturvårdsverket 1997).

Phosphorus application to farmland is regulated indirectly by the numbers of animals permitted on a farm due to available farmland for application of manure (SJVFS 1999:79). The general recommendation from the Swedish Board of Agriculture is that P should be applied in the same amount as is exported with the yield (Jordbruksverket 2003). However the application rate of organic manure is regulated due to the nitrogen content in the manure (SJVFS 1999:79) so if the animal is fed with a surplus of P there will probably be a surplus of P applied to the soil.

Site-specific conditions and management practices have been shown to be important factors for the amount of phosphorus losses. Data on phosphorus leaching from a number of small catchments in Sweden were obtained from the Swedish environmental programme "Typområde på jordbruksmark"

(Carlsson *et al.* 2000). Long-term average net losses from arable land were estimated through source apportionment and values between 0 to 2.2 kg of phosphorus per hectare were estimated. Two tables of phosphorus losses data are presented in Appendix A.12., one giving the total emissions per hectare and one giving surface and drainage losses per hectare and year.

The net phosphorus emission from farmland l_{Ptot} is estimated as follows (kg total P/ha):

$$l_{Ptot} = \sigma_{\mathrm{I,j}} + \delta_{\mathrm{I,j}} + \lambda_{\mathrm{P}} * \left(\sigma_{\mathrm{I,j}} + \delta_{\mathrm{I,j}}\right) \qquad \text{(eq. 44)}$$

where $\sigma_{I,j}$ is the surface losses and $\delta_{I,j}$ the drainage losses (kg total P/ha and year) for different areas *i* and three types of soils *j* in Sweden, see Appendix A.12. However it is difficult to distinguish whether the P found in a water body originates from surface or drainage flow, so data are not available for all areas. The term λ_P in eq. 44 is a P loss factor for excess P applications (%) due to bad management practice. It is a rough factor to indicate the fact that a surplus of P in the soil after an uneven or unbalanced fertilising strategy will probably increase the P losses from farmland.

Nitrous oxide-emissions from soil and water bodies

Nitrous oxide (N_2O) emissions from agricultural fields were calculated according to the Intergovernmental Panel on Climate Change (IPCC) method (IPCC 2001b). The **direct N_2O emissions** from the soil ($l_{Dir\text{-}N2O}$) in kg N/ha and year are assumed to be a proportion of the total input of nitrogen to soil and are calculated as follows:

$$l_{Dir-N2O} = \varepsilon_{DirS} * \sum \left(((x_{MF} * \eta_{MF}) - S_{FM}) + ((x_{OF} * \eta_{OF}) - S_{OF}) + x_{Nfix} + x_{C(R)} \right) \text{(eq. 45)}$$

where x_{MF} is the amount of mineral fertilizer applied to soil (kg fertilizer/ha and year), η_{MF} is nitrogen content in the mineral fertilizer (%), S_{MF} is NH_4-N emission during mineral fertiliser application (kg total N/ha and year), x_{OF} is amount of organic fertilizer applied to soil (kg manure/ha and year), η_{OF} is nitrogen content in the manure (%), S_{OF} is NH_4-N emission during manure application (kg total N/ha and year), x_{Nfix} is amount of nitrogen fixed by N-fixing crop (kg total N/ha and year), $x_{C(R)}$ is amount of nitrogen in crop residues returned to soils (kg total N/ha and year) and ε_{DirS} is emission factor for emissions of N_2O-N from N inputs (%).

The emission factor (ε_{DirS}) used was 1.25%, *i.e.* 0.0125 kg N_2O-N was produced per kg N input to soil (IPCC 2001b). Nitrogen fixation is described in Appendix A.9. Loss of nitrous oxide due to cultivation of organic soils, which is also included in the IPCC method, was not considered in this model.

Indirect nitrous oxide emissions from water bodies and from air emissions occurring as a result of nitrogen pollution of agricultural origin $l_{InDir\text{-}N2O}$ were calculated according to methodology (IPCC 2001b). The N_2O emissions were calculated as a proportion of the nitrate (NO_3) leaching to water bodies and as a proportion of ammonia (NH_3) emissions to air from plants and during fertilizer application. The emission vector of indirect nitrous oxide emissions from the recipient S_{rec} consists of only one figure for $N_2O\text{-}N$.

$$S_{rec} = l_{InDir-N2O} \qquad \text{(eq. 46)}$$

The following equation was used for calculation of indirect emissions of nitrous oxide emissions, $l_{InDir\text{-}N2O}$, in kg N/ha and year originating from agricultural nitrogen pollution:

$$l_{InDir-N2O} = \left((S_{Cair} + S_{OF} + S_{MF}) * \varepsilon_{InDirA}\right) + \left(l_{Ntot} * \varepsilon_{InDirW}\right) \qquad \text{(eq. 47)}$$

where S_{OF} is ammonia volatilisation during application of organic fertilizer (kg NH_4-N /ha and year), S_{MF} is ammonia volatilisation during application of mineral fertilizer (kg NH_4-N/ha and year), S_{Cair} is nitrogen emissions to air from plants (kg NH_4-N/ha and year)and its subsequent atmospheric deposition as NO_x and NH_4 (kg N/ha and year), l_{Ntot} is nitrogen leaching from soil (kg N/ha and year), ε_{InDirA} is an emission factor for estimating indirect emissions of N_2O from nitrogen lost to air (%) and ε_{InDirW} is an emission factor for estimating indirect emissions of N_2O from nitrogen lost as leaching to water bodies (%).

ε_{InDirA} was set to 1%, *i.e.* 0.01 kg N_2O-N was produced per kg N emitted to air, and ε_{InDirW} was set to 2,5%, *i.e.* 0.025 kg N_2O-N was produced per kg N leached.

4.3.7. PLANT sub-model

Depending on the purpose of the study, the yield is either a set value or a function of N-application rate, pest and weed control level and/or soil compaction in the plant sub-model. In addition, the "Plant sub-model" also calculates direct emissions of ammonia from the crop and exported nutrients and cadmium in the crop. In this case study, the yield was estimated as an influence of N application rate and pest and weed control level.

Yield

Since the resulting environmental load and energy use from a simulation is divided by the yield of each crop, the size of the yield has a major influence on the final result. In model applications where the yield is calculated as a function of production factors, the effect of these is central. The production factors included in the yield model are: nitrogen application in fertilizers, soil compaction level and level of pesticide use. The information on soil status regarding nitrogen content and soil compaction is forwarded to the following year, allowing the model to reflect this dynamic interaction.

The yield of the studied crop (x_{y3}) in kg/ha and year was calculated from the following effecting variables (in this study the effect of soil compaction was excluded):

$$x_{y3} = x_{y2} \times C_{eff} \times P_{eff} \qquad \text{(eq. 48)}$$

where: x_{y2} is the yield due to the N application rate (kg N/ha and year), C_{eff} is a reduction factor due to the previous year's soil compaction (%) and P_{eff} is a reduction factor due to avoided pesticide use (%).

The yield response function was calculated from a large number of Swedish field studies that have investigated the yield due to N application rates. (Lantbruksstyrelsen 1990, Frö- och Oljeväxtodlarna 1983-1994, Jordbruks-verket 1993, Mattson and Kjellquist 1992, and Interview Lennart Mattson).

The yield response functions follow this pattern:

$$x_{y2} = \left(\xi_1 + (\xi_2 \times x_{F(N)}) + (\xi_3 \times (x_{F(N)})^2) + (\xi_4 \times (x_{F(N)})^3)\right) \qquad \text{(eq. 49)}$$

The functions reflect the average picture for Sweden. The constants ξ_1, ξ_2, ξ_3, ξ_4, are empirically determined crop-specific constants. The crop-specific functions are presented in Appendix A.1 (Yield response to nitrogen applications). In this case study, the yield response functions were used in the simulations for three application rates of N; normal, 20% below and 20%

above normal application rates. The differing ability of some crops to respond in terms of yield to different N application rates is shown in Figure 11.

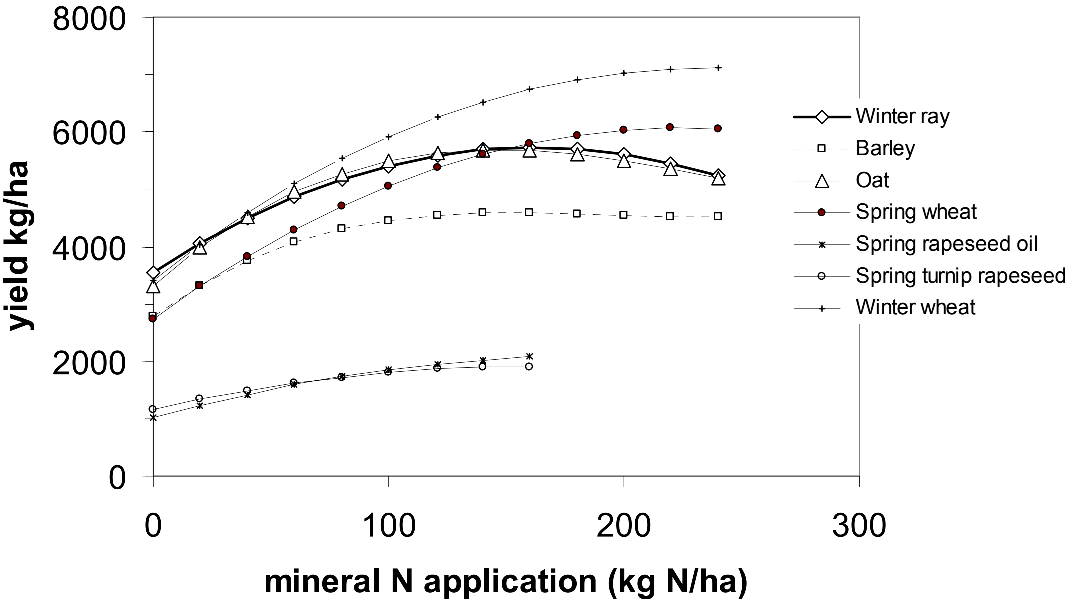


Figure 11. Yield of spring barley, winter wheat, spring wheat, spring oats, (15% water content), and spring oilseed rape and turnip rape (9% water content), as a function of N application rates. The functions reflect the average picture for Sweden.

Soil compaction impact on yield

One choice in the SALSA model is to calculate the previous year's soil compaction as a percentage yield reduction affecting the following crop (C_{eff}). The model used in SALSA was developed by Arvidsson & Håkansson (1991). The equations in the model are mainly based on statistical analysis of a large number of field trials where the degree of compactness of the plough layer was compared with the relative yield.

Compactions in the topsoil (0-25 cm deep) are reparable during tillage and freezing/thawing processes in soil during the winter season but subsoil (25-40 cm deep) compaction is permanent (Håkansson 1994). The permanent impact in the subsoil was also calculated as a separate impact category "Soil production capacity destruction". Soil compaction in lower layers was not included, since the influence is significant lower. The soil compaction model is described in Appendix A.11.

Pesticide level effects on yield

The impact of pesticide dose on yield can be simulated in the SALSA model. Three alternatives are available; no dose, half dose or the manufacturer's recommended dose. The yield regulation factor P_{eff} (%) due to dose use was obtained from an expert group's assessment of the yield consequences of applying half the recommended dose or no chemical control at all (Jordbruksverket 2002). This is a short-term assessment and long-term effects of diseases, insect attack and increases in weed pressure or changes due to other crop rotations in such a system are not included in the figures. The average use of pesticides as kg active substance per hectare for weed-killer x_{PeW}, fungicides x_{PeF} and for insecticides x_{PeI}, is given in Appendix A.2. The yield regulation factors $P_{eff}\ dose\ level_{(1\text{-}2)},\ crop_{(1\text{-}7)}$ were obtained from Table 11.

Table 11. Percentage yield reduction for different crops when none or half of the recommended crop protection spray dose was used compared to the full dose (Jordbruksverket 2002).

Crop no	Crop	P_{eff} Half dose, %	P_{eff} No spraying,%
1	Bread grain	7	30
2	Feed grain	7	30
3	Oilseed crops	7	42.5
4	Protein crops	7	30
5	Sugarbeet	7 [a]	30
6	Potatoes	8 [a]	35
7	Ley	3	3

a Note: Assumed value derived from the effect of no spraying.

NH_3 emissions from plants

Ammonia is volatilised from plants during ripening and senescence of the crop. The emissions from cereals crops are scarcely recognizable compared to other sources if manure is used on the farm or if ley is harvested. Holtan-Hartwig and Bøckman (1994) assumed the ammonia emission from cereal plants to be 1.5 kg NH_3-N per hectare and year and Schjoerring (2001) showed that crop foliage was a net source of NH_3 to the atmosphere, with NH_3 emissions on a seasonal basis between 1 and 5 kg NH_3-N/ha. NH_3

emissions might increase with increasing N concentration in leaves, *i.e.* that the N application rate affects the amount of emitted NH_3-N, but that fact is not considered in the model due to its limited influence compared to other sources.

The ammonia emission from plants S_{Cair} can either be set to the average value presented above (which was done in this study) or modified to crop yield and calculated as follows:

$$S_{Cair} = \varepsilon_C * x_{y2} \qquad \text{(eq. 50)}$$

where ε_C is an emission factor specific for cereal crops, peas and grass/clover giving the nitrogen emissions to air from plants in % (kg NH_4-N/ha and year) and x_{y2} is the yield in kg/ha and year. The emission of 1.5 kg NH_3/ha was calibrated to cereals with a yield of 6000 kg/ha and year.

Nutrients in harvest

For bread grain production, the protein quality is of great importance, while for feed grain production the energy value is a very important criterion. It is also important to have a low concentration of Cd in cereals because of its toxic effect on humans. The nutrient calculation of the crop is aimed for quality studies of the crop production. It can also be used for calculation of inflow and outflow of substances for farm substance balance accounting. The content of exported substances of N, P, K and Cd with harvest $\underline{c}$, is calculated as follows:

$$\underline{c} = x_y * \underline{\omega}_c \qquad \text{(eq. 51)}$$

where $\underline{\omega}_C$ is a vector for each crops that gives the content of N, P, K and Cd in the crop (%) (STANK database, Cd from other report) and x_Y is the yield in kg/ha.

4.3.8. Pesticide use as kg active substance per hectare and year

Risk assessment for pesticides is one of the most difficult parts of LCA (Mattsson 1999). Because of the lack of complete ecotoxicological and human toxicological data, and also due to difficulties in carrying out a comprehensive risk assessment, the pesticide use is presented as quantitative use in kg active substance at a farm. An inventory of the pesticide use on the case farm was carried out and statistical data were also presented. The average kg active substance use of weed-killer x_{PeW}, fungicide x_{PeF} and insecticide x_{PeI}, for treated arable Swedish farmland is presented in Appendix A.2.

4.3.9. Environmental impact categories

The environmental impact assessment (characterisation of the substances into different environmental impact categories) was performed using the following impact categories:

O Ecological effects: Global warming
Eutrophication of water (from N and P)
Acidification,
O Resources: Energy (fossil origin and electricity)
Land use (cultivated area/year on the farm)

Substances that lead to global warming were multiplied with GWP index. The GWP index is built on the ability of the compound to absorb IR radiation and the lifetime of the substance in the atmosphere. Gases that have a potential effect on global warming are N_2O, CO_2 and CH_4. Nitrous oxide is mostly emitted from soil and during mineral fertilizer production. Fossil carbon dioxide originates from machine operations while methane is emitted from manure storage tanks. The weighting factors according to IPCC (IPCC 2001a) for different greenhouse gases are listed in Table 12. The weighting factors differ with horizon time and in this study a perspective of 100 years was chosen. In a report by Naturvårdsverket (1991) the time perspective of 100 years is proposed to make it possible to avert threatened serious effects, because that time horizon shows the worst case scenario. Environmental loadings are given in functional units as CO_2-equivalents/kg product according to LCA practice (Nordic guidelines).

All flows which give rise to eutrophication; nitrate leaching from soil, phosphorus runoff or leaching from soil and NOx-emission from tractor operations are weighted due to their potential impact and given as O_2-equivalents. O_2-equivalents refer to the oxygen needed to degrade the eutrophication substances in water bodies. The weighting factor used for estimating of the potential impact to eutrophication was obtained from Nordic Guidelines (Lindfors *et al.* 1995) (see Table 12). Different aquatic systems are limited by different nutrients, nitrogen or phosphorus and have different sensitivity towards eutrophication. Which of these substances is actually involved in the eutrophication depends on the site. To make the results more general, the eutrophication maximum-scenario was used, which means that both P and N were included as potential affecting substances (Lindfors *et al.* 1995).

The acidification impact was calculated using the maximum scenario approach suggested by Finnveden *et al.* (1992). The effect is the amount of protons released in terrestrial systems. In the maximum scenario, nitrogen as NO_x and NH_3 is assumed to contribute to acidification together with SO_2 and HCl. The acidifying effects occur during nitrogen leaching, so the final contribution from nitrogen depends on the amount of nitrogen that is leached. For acidification, a choice can be made in the scenario settings between a full acidifying effect in the recipient or a 15% acidifying effect (due to the fact that 15% is assumed to leach out into the recipient in Scandinavia) (Grennfelt *et al.* 1994). In this study the maximum scenario was assumed, which meant that all nitrogen had the potential to contribute to the acidifying effect in the recipient. The equivalency factors used in this study for acidification were taken from Lindfors *et al.* (1995).

These equivalency factors probably give an overestimation of the importance of nitrogen relative to sulphur because of the assimilation of nitrogen by ecosystems and in later studies site-generic factors are used (Udo de Haes *et al.* 2002).

Table 12. Classification of substances into impact categories and equivalency factors used in the model, resulting in the equivalence vectors.

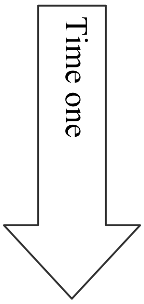
Impact category	Environmental effects or resource use	O_2-eqv/kg factor. Maxi-scenario [a]	CO_2-eqv/kg factor. 100 years horizon [b]	SO_2-eqv/kg factor. Maxi-scenario [a]
Eutrophication W_{eutro}, O_2-eqv/kg	NO_3 to water	4.4	-	-
	P to water	140	-	-
	Ammonium (NH_3)	16	-	-
	Nitric oxides (NOX)	6	-	-
Global warming, W_{GWP} CO_2-eqv/kg	Carbon dioxide (CO_2)	-	1	-
	Nitrous oxide (N_2O)	-	296	-
	Methane (CH_4)	-	23	-
Acidification, W_{acid} SO_2-eqv/kg	Ammonium (NH_3)	-	-	1.88
	Sulphuric oxides (SO_2)	-	-	1.0
	NOx	-	-	0.7
	Hypochloric acid (HCl)	-	-	0.88

Reference; Lindfors *et al.* 1995

a) Reference; IPCC 2001a

Temporal assignments to different crops

The SALSA arable model can be used for analysis of a single crop's growth during one year, or for several crops in a crop rotation during several years. When the environmental effect of an individual crop is considered, there is a need to assign some processes to the causing crop instead of separating the effects of different crops by calendar year alone. Machine operations performed after harvest were allocated to the following crop as seedbed preparation, whereas nutrient leaching during autumn after harvest was allocated to the current year's crop. The benefit of avoided nutrient leaching obtained from a catch crop or a winter crop that absorbs the nitrogen released during autumn was allocated to the catch crop or winter crop. Farming activities are shown in chronological order in Figure 12, with a broken line to show how environmental loads were allocated between the crops.



Crop 1

Activities:
Soil preparation
Sowing
Fertilising
Crop protection
Harvest

Burdens to allocate:
Burdens from machinery work
Nitrogen leaching from N-rich residues from spring oilseed crops

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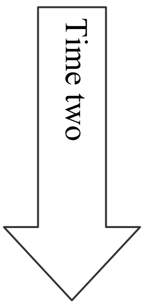

Crop 2

Activities:
Soil preparation
Sowing
Fertilising
Crop protection
Harvest

Burdens to allocate:
Burdens from machinery work
Prevented N leaching due to winter rye sowing
Nitrogen leaching after winter rye

Figure 12. Environmental burdens span calendar years during the farming activities but the impact is allocated to the crop causing the effect. Crop 1 is a spring oilseed crop, and Crop 2 is winter rye.

An optional in the SALSA arable model is to calculate the effect of soil compaction as a yield decrease of a following crop. The lower yield of the following crop increases its environmental load per kg product. This extra environmental burden was appointed to the crop responsible for the soil compaction.

Data handling in SALSA arable

The large amount of substance and energy data for every activity and crop required a structured data treatment and a clear activity plan. Therefore the computer model was constructed in MATLAB-SIMULINK software (MathWorks 2000), in which parameters could be organised in vectors and matrices in MATLAB, and activities could be organised in SIMULINK's graphical interface.

The main tensor consisted of a three-dimensional grid where columns contained information on quantities of substances (H_2O, total N, NH_3, NH_4 NO_3, N_2O, organically bound N, P, K, SO_2, CO_2 of fossil origin and bio origin, CH_4, Cd, Zn) and energy use, and rows represented activity-related emissions (production of input materials, farm activities and soil/plant processes). The third dimension was reserved for time, and organised the substance-activity grid for each simulated year, normally representing each crop in a nine-year crop sequence. Results could be withdrawn from the matrix either as the sum over a full crop rotation or in the form of separate years/crops. Post-simulation calculations and further interpretations of the substance flow data could be performed after each simulation.

The graphical interface of SIMULINK enabled the complex farm system to be viewed as interacting sub-models in a hierarchical structure, which facilitated the comprehension of the system's structure and behaviour**,** Figure 13. New sub-models can also easily be incorporated within the model framework. The specific parameters needed for each scenario simulation were organised in initiation files, and universal parameters of the model were loaded from a reference library.

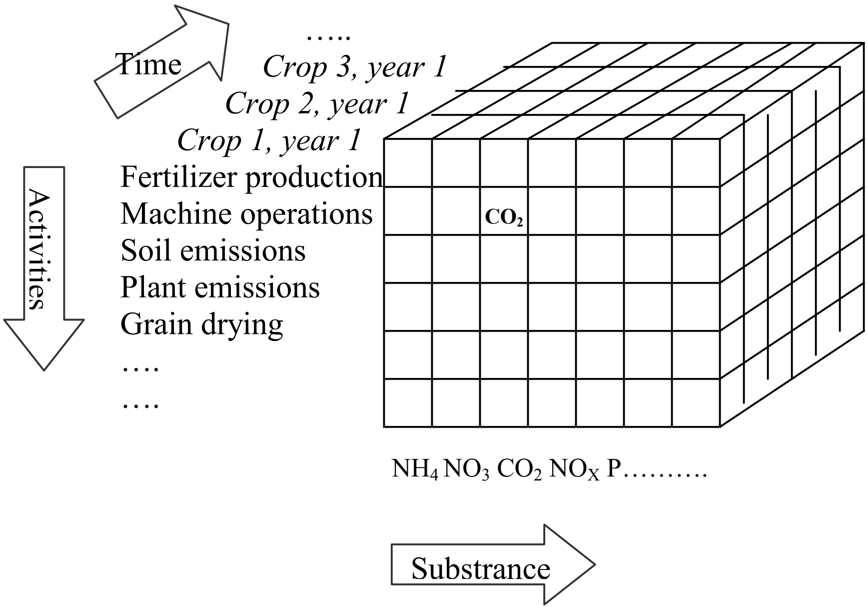

Figure 13. A graphical presentation of how variables and parameters in the SALSA arable model were organised in a three-dimensional matrix structure.

4.3.10. Output data from SALSA arable simulation

Data on yield, which are results from SALSA simulations, are presented in Table 13. The crop yield is calculated as a function of N application rates. Three levels of N application rates were used: A normal N application rate assumed to be the SJV proposed application rate (Jordbruksverket 1998), with an extra 12% due to represent common practice (Kihlberg 2002). The two other alternatives were a 20% lower and a 20% higher N application rate than the assumed normal level. The 20% lower alternative was spread as mineral fertiliser and slurry.

Table 13. The crop yields obtained for the three different N application rates used in the simulations: normal application rate[14] +/- 20%.

Crop	Yield, Norm application rates kg/ha	Yield, 20% lesser application rates kg/ha	Yield, 20% over Norm application rates kg/ha
Oilseed rape	1 896	1 775	1 990
Spring wheat	5 608	5 266	5 826
Spring barley	4 368	4 197	4 483
Winter wheat after cereal	6 250	5 895	6 611
Oats	5 336	5 094	5 511
Winter rye	5 011	4 780	5 209
Fallow	0	0	0
Winter wheat after fallow	6 306	5 920	6 577
Turnip rape	1 836	1 758	1 886

4.4. Communication between SALSA mind and SALSA arable model and some technical descriptions

Environmental loads and yield for the farm production for all alternatives are estimated by simulation with the SALSA arable model. The results of the simulation create a matrix with specific results for each crop and each environmental alternative. The SALSA mind model creates the alternative for different choices from the knowledge of yield, environmental load and price picture. The SALSA mind and SALSA arable model communicate via the integrated model.

The programming language used in the integrated model is C++ and the programme contains 1 600 rows. The programme has an object-orientated structure with ten classes, *e.g.* farmer, farm, parcel, crop, crop rotation. The class named 'farmer' has four sub-classes, one for each decision model. Each sub-class has a unique version of the combi-choice method, which is called for each parcel every year. Here the crop is chosen together with a specific combination of amounts of fertilizer and pesticide, and type of fuel.

The class called 'crop_spec' summarizes all characteristics of a certain crop (*e.g.* costs related to different phases of the cultivation, effects of using

[14] Normal application is set to the Swedish Board of Agricultures advice.

fertilizers and pesticides, price per kilo yield, subsidies, etc). Yield and environmental loadings are calculated in the method named 'gross_growth', which is called in two different ways and in two different situations:

1) During the planning phase when the farmer considers the perceivable profitability of different allocation choices. Approximate values are used in order to reflect the knowledge of the farmer (SALSA mind).
2) During the summation of the final results when calculated values from SALSA arable are used.

In the model, each parcel has a particular crop sequence with different starting crops. In this way all parcels are in different phases of the crop sequence. In the beginning of the simulation the crop choice is randomly selected and depending on the random crop type, different outcomes are obtained. This is particularly the case when using parcels of varying size. Consequently, the outcomes of the different years vary considerably, which makes it inappropriate to carry out annual comparisons. Therefore, the experiments have been designed to cover a ten-year period, during which the parcels go through approximately two crop rotations. Ten replications of each experiment (*i.e.* different random crop types but the same configuration in all other respects) were carried out.

5. MODEL RESULTS AND DISCUSSION

5.1. Simulation results

This section contains the results of the integrated simulation model. The main results are shown in Table 14, which covers eight variables regarded as important for answering the questions posed at the outset of the study. Along with profit, which is the net between income and cost, there are yield and four variables related to environmental loadings – the greenhouse effect GWP (kg CO_2-equivalents), eutrophication EUTR (kg O_2-equivalents), acidification ACID (kg SO_X-equivalents) and energy use (MJ primary energy use). All variables presented in Table 14 summarize the whole production of a farm for one year. For each combination of decision model and level of environmental loading, ranking and amounts are shown.

5.2. Economic impacts

As regards economic aspects of the simulation, organic farming appeared to be more profitable than conventional farming. Irrespective of decision model, organic producers obtained significantly higher profits, which is illustrated by their top ranking positions. Among the conventional farming category, it was the farm with restricted environmental concerns that gained the most. It turned out that conventional farmers trying to minimize environmental loadings were those who did worst – some of them show zero results or even losses. The reasons behind these patterns are to be found in higher prices for organic products (See Table 1) and additional financial support via the common agricultural policy (CAP) to organic producers. The environmental subsidies are nearly twice as high as subsidies for conventional farming. The outcome of the comparison between the conventional farmers with dissimilar environmental concerns is related to differences in yield. Refraining from pesticide use and using less fertilizer obviously have a negative impact on yield as compared to a situation when high doses of pesticides and fertilizers are used. The extra costs related to applying these additives are very much counterbalanced by the larger yield and income they generate.

The clear difference in levels of profit between organic farming and conventional farming, shown in Figure 14, indicates that structural factors such as subsidies and prices are more significant than decision models that represent farmers' various levels of knowledge. For a single farmer, prices and subsidies are virtually impossible to change. The business is too small to have any influence on market prices, and political decisions shaping the design and amount of subsidies are taken far away.

Table 14. Simulation results regarding the farm production. Bold text refers to ranking in the interval 1-24 of each variable across decision model and accepted environmental loading. Normal text shows variable amounts.
Best ranking is marked with a circle.

Decision model	Accepted environmental loadings	Profit, (SEK)	Yield, (kg)	GWP CO_2-equ., (kg)	EUTR. O_2-equ., (kg)	ACID. SO_X-equ., (kg)	Primary energy, (MJ)
Purely rational	Organic prod. (KRAV)	**1** 505’	**21** 371’	**2** 199’	**22** 92’	**24** 5 258	**1** 657’
‘-‘	Limited loadings	**16** 17’	**18** 413’	**16** 243’	**1** 50’	**1** 510	**9** 1 096’
‘-‘	Little loadings	**9** 115’	**7** 560’	**13** 239’	**21** 86’	**20** 3 531	**19** 1 275’
‘-‘	Medium loadings	**7** 149’	**4** 602’	**18** 252’	**19** 80’	**16** 2 796	**22** 1 358’
‘-‘	Much loadings	**6** 178’	**2** 629’	**23** 307’	**10** 67’	**4** 998	**24** 1 558’
‘-‘	Unlimited loadings	**5** 228’	**1** 664’	**24** 345’	**7** 64’	**2** 609	**23** 1 429’
Bounded rational	Organic prod. (KRAV)	**2** 422’	**17** 417’	**4** 207’	**23** 96’	**22** 5 005	**3** 953’
‘-‘	Limited loadings	**20** -8’	**16** 429’	**10** 230’	**8** 65’	**9** 1 914	**8** 1 092’
‘-‘	Little loadings	**15** 29’	**11** 492’	**14** 239’	**18** 79’	**18** 2 938	**17** 1 222’
‘-‘	Medium loadings	**12** 72’	**8** 545’	**17** 244’	**15** 73’	**15** 2 439	**15** 1 197’
‘-‘	Much loadings	**10** 104’	**5** 585’	**20** 259’	**14** 73’	**13** 2 201	**18** 1 229’
‘-‘	Unlimited loadings	**8** 131’	**3** 611’	**22** 291’	**3** 62’	**3** 921	**22** 1 208’
Incremental	Organic prod. (KRAV)	**3** 413’	**19** 407’	**6** 212’	**24** 99’	**23** 5 023	**6** 1 060’
‘-‘1	Limited loadings	**21** -12’	**14** 432’	**8** 229’	**12** 68’	**12** 2 141	**11** 1 125’
‘-‘	Little loadings	**18** 11’	**12** 470’	**11** 233’	**17** 78’	**19** 2 952	**13** 1 158’
‘-‘	Medium loadings	**14** 40’	**10** 512’	**12** 237’	**16** 77’	**17** 2 810	**16** 1 216’
‘-‘	Much loadings	**13** 68’	**9** 538’	**19** 257’	**13** 69’	**11** 2 027	**14** 1 184
‘-‘	Unlimited loadings	**11** 93’	**6** 570’	**21** 282’	**9** 67’	**5** 1 374	**21** 1 337’
Garbage Can (random)	Organic prod. (KRAV)	**4** 356’	**24** 335’	**1** 182’	**20** 85’	**21** 4 418	**2** 839’
‘-‘	Limited loadings	**24** -71’	**23** 335’	**3** 206’	**5** 62’	**8** 1 904	**5** 1 045’
‘-‘	Little loadings	**23** -45’	**22** 371’	**5** 209’	**11** 67’	**14** 2 388	**4** 1 036’
‘-‘	Medium loadings	**22** -17’	**20** 404’	**7** 220’	**6** 64’	**10** 1 958	**7** 1 081’
‘-‘	Much loadings	**19** 0.4’	**15** 429’	**9** 229’	**4** 62’	**7** 1 717	**10** 1 098’
‘-‘	Unlimited loadings	**17** 13’	**13** 443’	**15** 240’	**2** 60’	**6** 1 422	**12** 1 127’

However, the farmer can improve his skills and ability to make better choices by learning from advisers, colleagues, and other sources. If the bounded rationality decision model represents the real life farmer and the pure rationality decision model corresponds to an ideal "super" farmer endowed with all information needed for maximizing profit, the difference between these two farmers across levels of accepted environmental loadings may indicate the potential for what could be accomplished by changed individual behaviour. It seems clear that the farmer's potential to improve his economic situation by making "better" production-related choices is much more confined as compared to specializing in organic production. The importance of public spending on farming via subsidies is in this respect too extensive. The economic potential of improved production-related choices are most likely less than those related to the differences between the subsidies provided to conventional and organic farmers. Differences in crop prices also play a role in this context. Consequently, the economic success of the arable producer is very much affected by policy-making in Sweden and in the European Union.

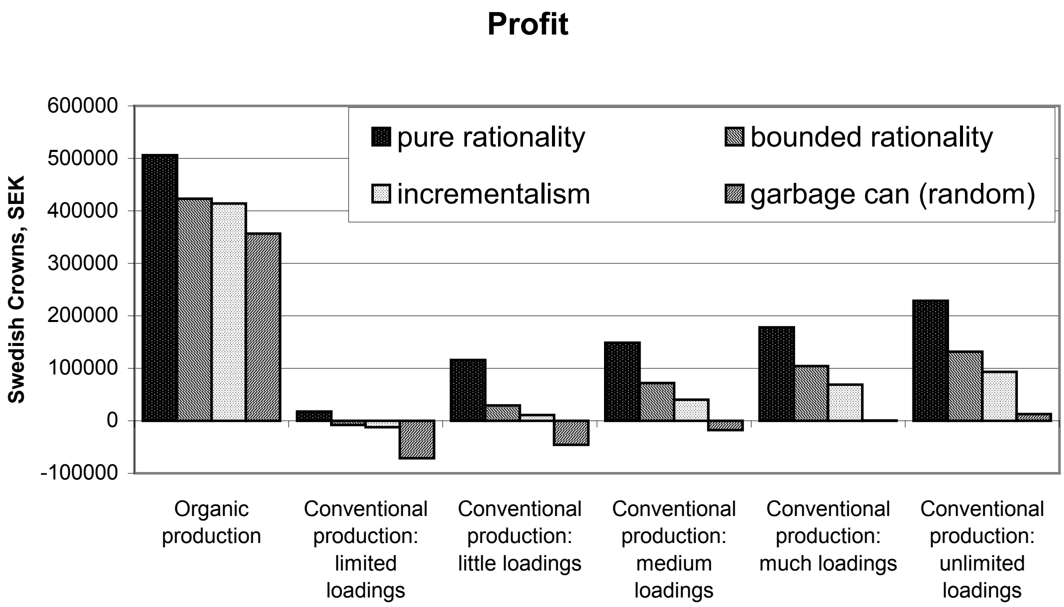

Figure 14. Profit across decision model and acceptance of environmental loadings.

When looking at the environmental variables it turns out that there was no clear-cut divide between organic and conventional farming. Organic farming did not out-perform conventional farming in all respects. On the contrary, organic farming seemed to cause eutrophication and acidification to a higher extent than conventional farming. This result can be attributed to the fact that emissions from slurry spreading were included in the organic alternative. However, the chosen system boundary, within which emissions from slurry spreading are included, only pertains to the organic alternative. This is a choice that for different reasons can be questioned (see below).

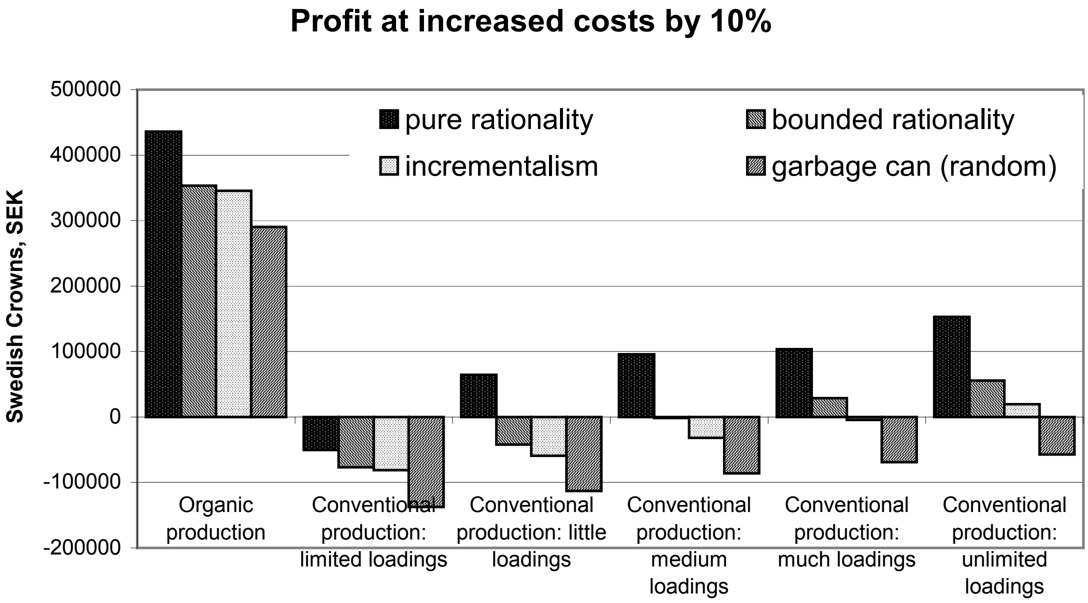

Figure 15. Profit at increased costs by 10%.

In an open market economy the farmer is exposed to changes in prices of products needed for production (*e.g.* fuel, seed, fertilizer) and changes in prices of products for sale. Figure 15 illustrates the consequences of increasing costs by 10% (general increase across all inputs). It can be noticed that the favourable figures for organic farming are a result of relatively higher incomes and relatively lower costs. These differences are, on the one hand, due to higher subsidies and prices for produced products, and on the other hand, due to absent costs for pesticides. A general increase in costs of, for example, 10% tends to affect conventional farming more negatively. These farmers can choose between facing poor profitability or accepting higher levels of environmental loading, which particularly lead to increased emissions of greenhouse gases and energy consumption. When looking more closely at the costs of the agricultural business (excluding wages and taxes) it turns out that expenditures for machinery (40%), fuel and lubrication (20%), and machinery maintenance (12%) are the largest costs. The costs for fertilizers/pesticides and drying crop amount to 10% and 12%, respectively. This variation suggests that the agricultural business is sensitive to where the increased costs emerge. Obviously, the modelled differences between organic and conventional farming mentioned above show various magnitudes depending on whether the 10% increase takes place in, for example, machinery costs or costs for fertilizer/pesticides.

For reasons related to changes in demand, relative prices of different crops can alter. For example, if spring wheat prices increase, the model farmer will try to increase cultivation of this crop. The magnitude of change in cultivation is related to the applied decision models, which have different rules for diverging from the crop sequence. Nevertheless, in this situation the model farmer will rearrange the mix of crops in order to enhance business income. The tables in Appendix C1-C3 show some examples of crop choices according to decision model in combination with levels of accepted environmental loadings.

5.3. Environmental impacts

The positive effect on business income may, however, have a disadvantageous effect on the environment. Table 15 shows the environmental loadings of seven different crops per hectare for the base alternative, i.e. normal application of nitrogen fertiliser, full dose of pesticides and ordinary fuel was assumed. In the event of the model farmer choosing to cultivate spring wheat instead of rye, there will be a 48% increase in the emission of greenhouse gases, 4% more eutrophication, 36% more acidification, and 42% more energy used per hectare. Generally, rye, barley and oats generate less emission per hectare than the two oilseed crops and wheat. However, in Sweden rye is a less frequently cultivated crop that is mostly used for bread production, but the other four crops – winter wheat, spring wheat, spring barley and spring oats – can in principle replace each other in a feed mix. At least that is what we have assumed in this study. Examples of energy content from a feed table give the following energy content for three cereals: oats 11.7 MJ/kg dm, barley 13.2 MJ/kg dm and wheat 14.1 MJ/kg dm (Interview Agneta Strandäng). Wheat is used as a feed ingredient as well as for human consumption. If farmers produce wheat with high protein content, and it fulfils the bakery's quality criteria, they receive a higher price. Neither the quality perspective nor the dynamics in demand for the products are included in this study, which should be kept in mind when interpreting the results.

When studying emissions and energy use from a production perspective, a yield decrease is less favourable from an environmental point of view for crops with low yield per hectare. This is due to the fact that some of the emissions are background emissions, such as nitrogen and phosphorus leaching from the soil. Another example of an effect that does not vary with yield to any large extent is machinery operations, because the number of

Table 15. Simulation results showing environmental and energy variables per hectare for seven crops (normal applications of mineral nitrogen fertiliser, full dose of pesticides and ordinary fuel was assumed). Bold text refers to ranking of each variable across the crops and normal text shows emissions and energy use per hectare.

Crop	GWP CO_2-equ., (kg/ha)	EUTR. O_2-equ., (kg/ha)	ACID. SO_X-equ., (kg/ha)	Primary energy, (MJ/ha)	Yield (kg/ha)[a]
Rye	**1**	**2**	**1**	**1**	**4**
	1 641	376	3.3	7 445	4 960
Barley	**2**	**3**	**3**	**3**	**5**
	1 837	386	3.7	8 187	4 324
Oats	**3**	**1**	**2**	**2**	**3**
	1 898	362	3.6	7 848	5 283
Spring oilseed rape	**4**	**6**	**4**	**4**	**6**
	2 013	415	3.7	8 392	1 877
Spring turnip rape	**5**	**7**	**5**	**5**	**7**
	2 029	417	3.9	8 634	1 818
Winter wheat	**6**	**5**	**6**	**7**	**1**
	2 335	395	4.2	10 587	6 216
Spring wheat	**7**	**4**	**7**	**6**	**2**
	2 429	391	4.5	10 544	5 551

a) 15% water content for cereals and 8% for oilseed crops.

sowing, fertilizing, tillage and crop protection operations is the same irrespective of yield.

There is an ongoing discussion about how to evaluate the environmental load and energy use of crops, and whether these factors should be calculated per area or per kilogram product. The area perspective is more topical if most of the farmer's income is gained from area subsidies. Moreover the area perspective is interesting when different sensitivities in sites are to be compared. For example nitrogen leaching from farmland is much more serious from farms close to the see than from farms situated at in inlands. But on the other hand crops are cultivated for a purpose and then the kilogram perspective is more appropriate. Considering that products are grown for the purpose of being feed, food, energy source or an industry product, the kilogram perspective is adequate. In this case the amount of the product is essential. The best-worst crop ranking differs when environmental load and energy use is presented as kg CO_2-, SO_X-, O_2-equivalents, and MJ per kg product (Table 16). As regards the kilogram perspective, the four crops –

winter wheat, spring wheat, spring barley and spring oats – have a similar function in a feed mix and therefore they can be compared. The two oilseed crops can be compared in between. Winter wheat gets a much better ranking in the kilogram perspective as compared to the area perspective because of the high capacity of the winter wheat crop to respond with yield to nitrogen rates. The amount of winter wheat obtained is about 30% higher than spring barley and 20% higher than spring wheat. The difference in yield is the main explanation for the new ranking list of the crops. From the kilogram perspective, spring oilseed rape turns out to be a more environmentally friendly crop than spring turnip rape, although the difference is very low.

Table 16. Simulation results given per kg product of the three environmental and energy variables for the seven crops (normal applications of mineral nitrogen fertiliser, full dose of pesticides and ordinary fuel was assumed).. Bold text refers to ranking of each variable across the crops and normal text shows emissions and energy use per product.

Crop	GWP CO_2-equ., (kg/kg)	EUTR. O_2-equ., (kg/kg)	ACID. SO_X-equ., (kg/kg)	Primary energy, (MJ/kg)	Yield (kg/ha)[a]
Rye	**1**	**4**	**1**	**2**	**4**
	0.331	0.076	0.00067	1.501	4 960
Barley	**4**	**5**	**5**	**4**	**5**
	0.425	0.089	0.00085	1.893	4 324
Oats	**2**	**2**	**2**	**1**	**3**
	0.359	0.069	0.00068	1.485	5 283
Spring oilseed rape	**6**	**6**	**6**	**6**	**6**
	1.072	0.221	0.00195	4.470	1 877
Spring turnip rape	**7**	**7**	**7**	**7**	**7**
	1.116	0.229	0.00212	4.750	1 818
Winter wheat	**3**	**1**	**3**	**3**	**1**
	0.376	0.064	0.00068	1.703	6 216
Spring wheat	**5**	**3**	**4**	**5**	**2**
	0.437	0.070	0.00081	1.899	5 551

a) 15% water content for cereals and 8% for oilseed crops.

There is not a clear conclusion to be drawn on the crop ranking from either the area perspective or the kilogram perspective. The purpose of the study should guide which perspective should be most suitable. One may also have in mind that crops are part of a crop rotation. Even if a crop is bad from an environmental point of view, a change of crops in an unvarying crop rotation can overcome these negative effects. Another more suitable yardstick could be the total effect from a whole crop rotation or from a whole feedmix.

Environmental loadings per kilo produced product are exemplified by results from simulation of barley. Emissions of substance emissions for different activities within the production chain are presented in Figures 16 to 20. Results of global warming potential per substance and per activity or process during the production chain are presented in Figure 16. The two largest sources are the N_2O-emissions from land and from mineral fertiliser production. Nitrous oxide emission from land is the overall largest source but also probably the most uncertain and variable figure. The IPPC method used for estimating the N_2O-emission from land is not very exact and the variation regarding soil types and climate is high. Nevertheless, if these figures show the real situation the N_2O-emission from land areas is a real risk, and this indicates the need for more investigations in that area. It is during the manufacture of nitric acid (which is used in the production of ammonium nitrate, calcium nitrate and potassium nitrate) that nitrous oxide and nitrogen oxides are emitted (Davis & Haglund 1999). Using a filter during the production could reduce this emission. Unexpectedly, the carbon dioxide emissions from machinery operations were a smaller contributor than the nitrous oxide emissions. The extra machinery operations of inter-harrowing in the organic alternative did not make any large changes to the overall results. The indirect nitrous oxide emission from water bodies is a notable source but is also an uncertain figure because the emission is a result of the estimated nitrogen leakage into the recipient.

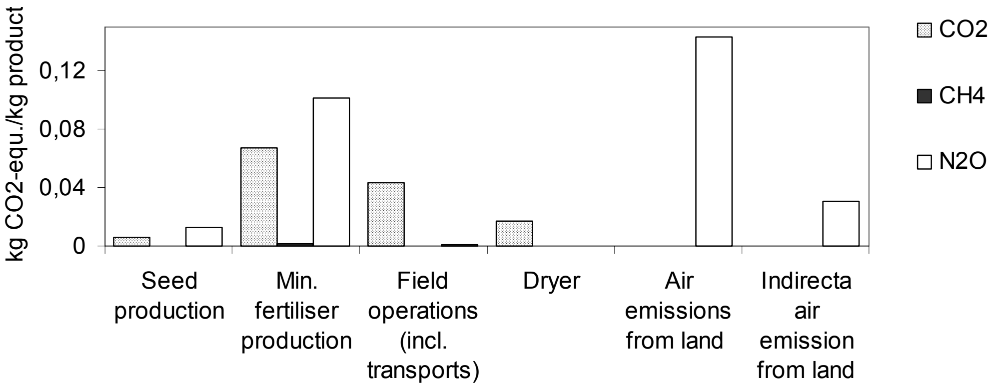

Figure 16. Simulated global warming potential (CO_2-equivalents/kg barley) per substance and per activity or process during the production chain of barley. Normal rates of mineral fertilizer, recommended pesticide dose and ordinary diesel fuel were assumed.

The acidification sources are shown in Figure 17 for mineral fertiliser and in Figure 18 for organic fertiliser. When organic fertiliser is used, the ammonia emission during slurry spreading is the overall largest contributor (Figure 18), and there is no acidification originating from the mineral fertiliser production from that system. However, this choice of system boundary of only including the ammonia emissions in the organic system can be questioned when the conventional and organic production are compared. This is discussed more in a later section. Ammonia emission can also vary a lot due to climate and spreading technique. The second largest source when organic fertiliser is used but the largest source when mineral fertiliser is used is ammonia emissions from plants. Here, it would have been interesting to compare the emissions from cultivated plants with emission from natural ecosystems.

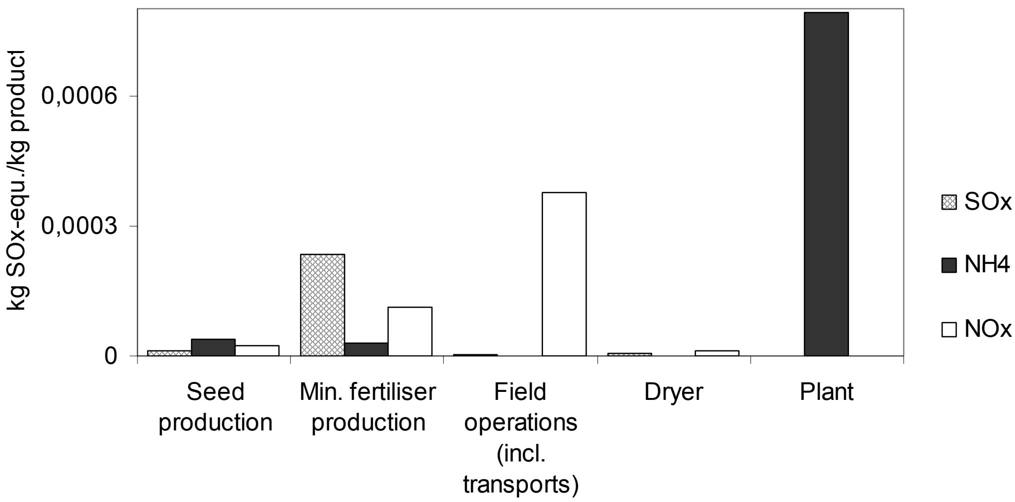

Figure 17. Simulated acidification potential (SO_x -equivalents/kg barley) per substance and per activity or process during the production chain of barley. Normal rates of mineral fertilizer, recommended pesticide dose and ordinary diesel fuel were assumed.

Eutrophication was calculated as a max-scenario, *i.e.* both nitrate and phosphorus were considered as contributing to eutrophication (Figure 19). Leaching from land represented most of the leaching. As can be seen, the nitrate leaching is slightly higher than phosphorus leaching, but the actual effect depends on where the leaching occurs. Generally, seas are most sensitive to nitrate leaching and lakes to phosphorus.

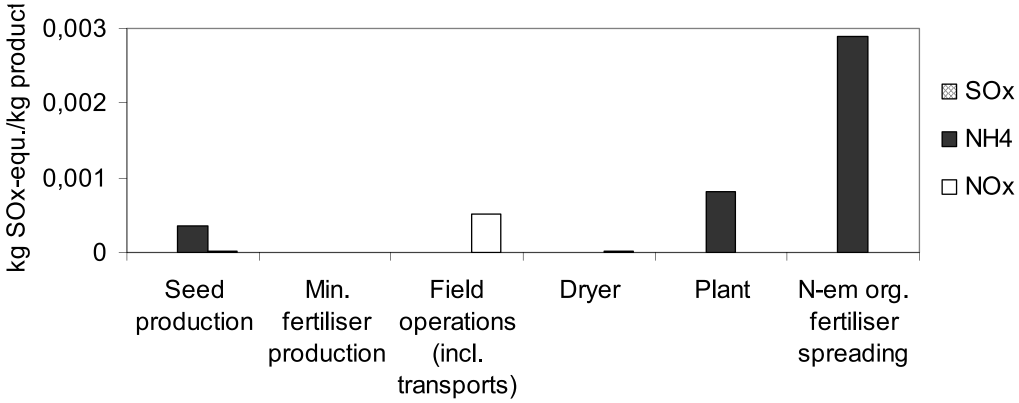

Figure 18. Simulated acidification potential (SO_x-equivalents/kg barley) per substance and per activity or process during the production chain of barley. A fertilisation rate of 80% of normal nitrogen fertilisation rate applied as slurry, recommended pesticide dose and ordinary diesel fuel were assumed.

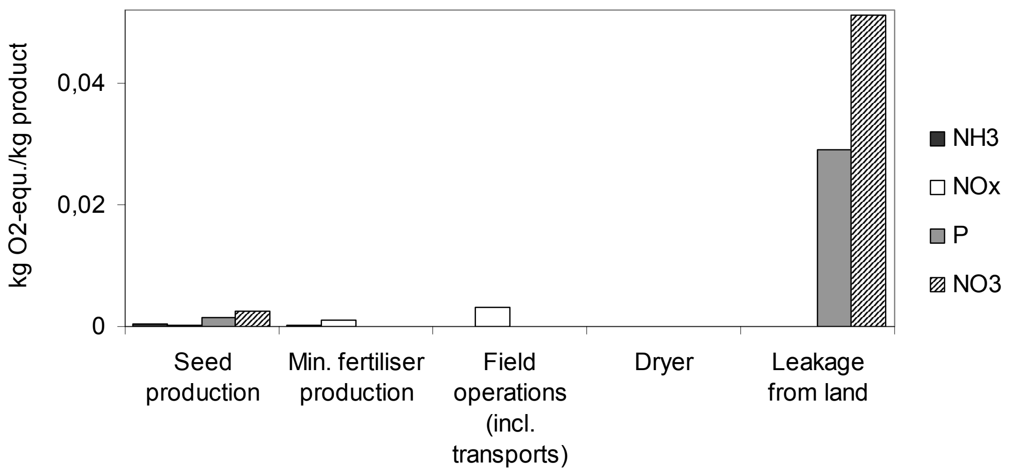

Figure 19. Simulated leaching potential (O_2 -equivalents/kg barley) per eutrophication substance and per activity or process during the production chain of barley. Normal rates of mineral fertilizer, recommended pesticide dose and ordinary diesel fuel were assumed.

Regarding primary energy use, the results showed that the production of mineral fertilizers was the largest energy user, followed by field operations, drying of grain and finally seed production (Figure 20). In reality, energy use for drying varies remarkably due to weather conditions during harvest. In this study average water content was assumed.

One of the environmentally friendly alternatives we used for the simulations included the use of RME fuel for machinery and grain drying. RME is a refined product from rapeseed oil, which can be used as fuel in an ordinary engine. The use of a bio-produced product instead of diesel fuel implies that fossil fuel can be replaced and carbon dioxide emissions avoided. However, as shown in Figure 21, the use of RME generates even higher fossil carbon dioxide emissions. This is explained by the production of artificial fertilizer, which is a process where large amounts of energy are used. This also pertains to primary energy use shown in Appendix C5. Another important source for CO_2-equivalents is N_2O-emissions from the soil originating from the rapeseed production.

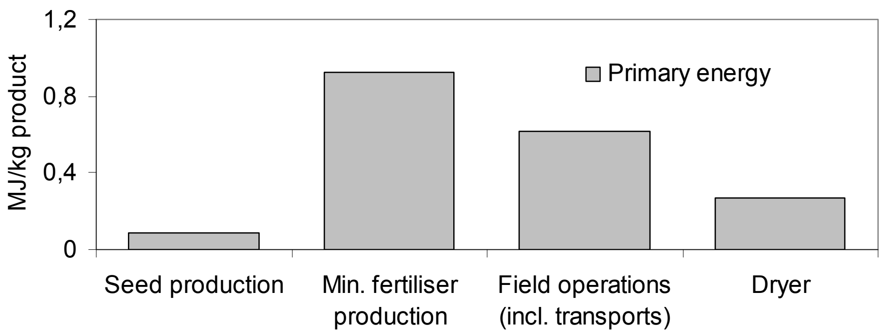

Figure 20. Simulated primary energy use (MJ/kg barley) per activity or process during the production chain of barley. Normal rates of mineral fertilizer, recommended pesticide dose and ordinary diesel fuel were assumed.

The rapeseed crop also responds weakly to nitrogen fertilisation and much of the nitrogen is used for the tap-root. However, in terms of crop rotation this is beneficial to the following crop, which produces more yield compared *e.g.* to a cereal crop after another cereal crop. In addition, the emissions of eutrophication substances are higher for all the RME alternatives (Appendix C5). This is a result of the larger area used for the production of rapeseed. A similar pattern is found for SO_X-emissions and primary energy use, which are higher for the RME-alternatives (Appendix C5).

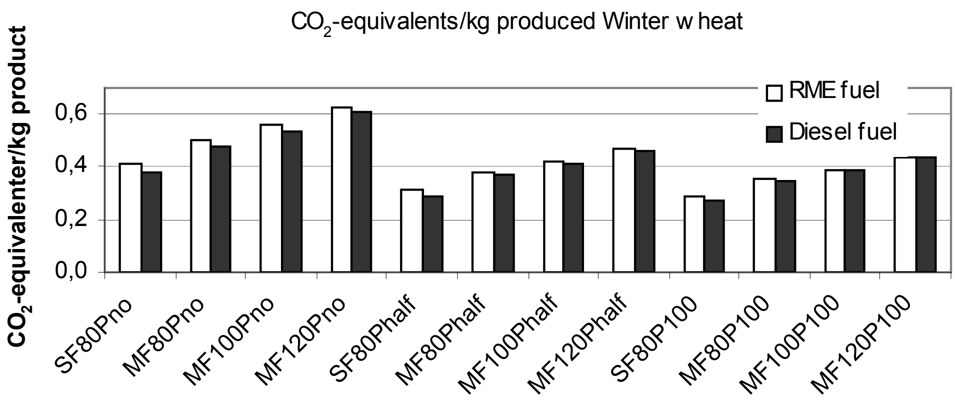

Figure 21. Environmental simulation results for winter wheat (kg CO_2-equivalent/kg product) for sixteen variables of management choice. SF is slurry fertilizer; MF is mineral fertilizer; 80,100 and 120 % are the three nitrogen fertilising strategies; and Pno, Phalf and P100 refer to the percentage of pesticide used.

5.4. Decision pattern of the simulations

Some examples of the decision patterns of the simulations are shown in Appendix C.1.-C.3. A general observation is that the simulated decisions follow logical patterns. The rational decision farmer chooses the best economic alternatives and the farmer working on pure chance generates least economic return. The bounded rational and the incremental farmers' decisions are between the two extremes. The rational farmer chooses the most profitable crop approximately three times more often than the bounded rational farmer and about ten times more often than the incremental farmer. The inertia of two latter alternatives to new decisions can be observed because they adhere to the given crop rotations about four times as often as the rational farmer (Appendix C.1.) The result of the punishment mechanism triggered by monoculture cultivation can be seen in Appendix C.3. The rational economic optimizer never chooses a crop too often, despite a better price for some of the crops in comparison to the incremental, and the bounded rational farmer chooses a crop with a good price even if it brings less yield. The farmer operating on chance does not follow a crop rotation at all and will therefore be substantially punished with reduced yield. Given the crop prices and yield reductions assumed, the results of the simulation model suggest that it is beneficial to the farmer to adhere to the pre-specified crop rotations.

Concerning the choice of management, the 80% N application rate is a frequently used alternative for farmers who at least have a slight interest in reducing environmental loads (from m1 to m4). Only the strictly rational farmer with restricted environmental concerns chooses the alternative characterised by 120% nitrogen application rate, full pesticide dose and no biofuel.

Surprisingly, the rational and most economically-orientated farmer never chose barley in the crop rotation. This can be explained by the fact that the background data were obtained from a real farm which had proportionately high diesel consumption for barley and also by the fact that barley has a low price and a low yield. Another unexpected result was the frequent choice of oilseed crops compared to what is grown in reality by farmers. The choice of the simulated farmer clearly depends on good prices for oilseed crops.

5.5. Impacts of the choice of system boundaries

The critical issue in making comparisons between conventional and organic production for an arable farm is to choose suitable system boundaries so an adequate comparison can be made. The difficulty is how to compare the use of organic fertilizer with mineral fertiliser. What is the production cost for organic fertilisers and is the organic fertiliser a resource or a waste? When this study was designed the boundary was set to include activities at the farm gate plus some of the production cost for resources such as mineral fertilisers. For the organic system only emissions from slurry spreading were included and impacts during storage of organic fertiliser were left outside the system boundary. This choice of system boundary is similar to a farm accounting budget methodology where the inflow and outflow of the farm is investigated and the share of different parts is the main focus[15].

In the results presented in Table 14, the organic alternative contributed more to the effect categories acidification and eutrophication due to ammonia emissions during slurry spreading, but lesser to the global warming category due to no use of mineral fertiliser. The organic system had an advantage concerning global warming emissions because the upstream production cost of slurry for mineral fertiliser was excluded from the main study.

Moreover, the conventional system was favoured because it did not include emissions from production and use of organic manure despite the fact that most of the grain production is used for animal feed..

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[15] Tillman (2000) made a distinction between LCA studies with a retrospective or accounting perspective and a prospective perspective, where the consequence of an alternative production is investigated.

Regarding a comparison between the organic and conventional systems, a change-orientated approach would have been more adequate. The slurry did not simply materialise from nowhere and consequently slurry production costs need to be included. Manure is not a nitrogen source on its own but more of an 'intermediate' product, with its source from either mineral fertilizer, mineralization from previous fertilising or from a nitrogen fixation crop. In this study the slurry was assumed to be bought from a conventional pig farm in the immediate neighbourhood, so the nitrogen originated from mineral fertilisers. Then the production costs for an upstream nitrogen mineral fertilizer use in the animal system need to be allocated between the livestock production (meat) and the manure. A physical allocation is one way to distinguish between the products, while another is economic allocation. Results of different system boundary settings from this change-orientated perspective are shown in Table 17 and a figure showing different parts possible to include or exclude in the organic production system are presented in Appendix B.4. In Table 17 the four environmental effects global warming potential, eutrophication, acidification and primary energy use are presented per kg produced winter wheat. The calculation methods used for calculation of the two allocation factors are given in Appendix B.5. Losses during storage and spreading of slurry should be either included or excluded for both conventional and organic system since there is no difference in the total emissions of ammonia to the environment between the systems. Differences in ammonia emissions depend more on the choice of slurry management technique than on whether an organic or conventional system is used.

The conclusion that can be drawn from this discussion is that there is no obvious system boundary to be set regarding slurry use in the organic production when organic and conventional production is compared.

The fourth alternative in Table 17, where the upstream mineral fertiliser production was included and physical allocation methodology was chosen, resulted in even more mineral fertiliser production costs for the organic alternative than the conventional. The physical allocation led to 58% of the mineral fertiliser production cost allocated to the slurry. The economic allocation resulted in only 0.6% of the mineral fertiliser production cost being allocated to the slurry due to the low economic value of slurry compared to pig meat, the fifth alternative in Table 17. This perspective assigns nearly no value to the slurry and no production costs are allocated to slurry, which makes slurry a free resource. One may argue that the organic fertilizer has a higher economic value for an organic farmer than a conventional farmer because of the deficit of nitrogen in the organic alternative and because of the higher prices of organic fertilizer. However, even if the cost of organic fertilizer were ten times higher, it would only lead to marginal changes in the economic allocation factor.

Table 17. Environmental impacts comparing organic and conventional production with different system boundaries (kg equivalents or primary energy per kg produced winter wheat). Both alternatives are with 80% N fertilising application rates but as mineral fertilizer in the conventional production and as pig slurry for the organic alternative.

		Slurry spreading	Upstream mineral fertilizer production in the animal system	GWP CO_2-equ., (kg/kg)	EUTR. O_2-equ., (kg/kg)	ACID. SO_X-equ., (kg/kg)	Primary energy, (MJ/kg)
1.	Organic production [16]	Included	Excluded	0.27	0.120	0.0081	0.99
2.	Organic production [17]	Excluded	Excluded	0.27	0.065	0.0018	0.99
3.	Conventional production [18]	Excluded	Excluded	0.35	0.063	0.0018	1.60
4.	Organic production [19]	Excluded	Included, Physical allocation	0.52	0.067	0.0023	2.30
5.	Organic production [20]	Excluded	Included, Economic allocation	0.27	0.065	0.0018	1.00

Another theoretical alternative is that organic fertilizer is produced in surplus and the use of it as fertilizer leads to avoided use of mineral fertilizer. However this is a far-fetched alternative because of the fact that animal density on a farm is restricted due to available spreading land area and slurry spreading is regulated by legislation. Neither of the methods is satisfactory and a more comprehensive comparison requires an expanded system boundary, including parts of the animal production system.

[16] The system border used in the main study, pig slurry was applied with 80% of recommended nitrogen fertiliser application rates.
[17] An alternative system border for the organic production where slurry storage was excluded.
[18] The system border used in the main study, where mineral fertiliser is applied with 80% of recommended nitrogen fertiliser application rates.
[19] An alternative system border for the organic alternative where upstream production of mineral fertiliser was included and physical allocation was used.
[20] An alternative system border for the organic alternative where upstream production of mineral fertiliser was included and economic allocation was used.

Another objection to a general conclusion from the comparison between organic and conventional production is that a frequently used nitrogen source in organic production is green manure, which is not studied here. The use of green manure crops alters the crop rotation and the pressure from weeds, insect attacks and diseases. In addition, the use of land is also changed. For example, if arable land is a limited resource and more land is released when land is used for intensive production with high yields, the released land can be used for energy production that can maybe replace other fossil energy sources.

5.6. Concluding remarks

The ongoing discussion within the European Union on reforming the common agricultural policy may lead to substantial cuts in subsidies such as the area subsidies and different environmental subsidies. The expansion of the Union to include countries in Eastern Europe together with a growing public opinion indicating dissatisfaction with major expenditure on agricultural policies opens up the possibility of radical shifts in structure and subsidy levels. Cutting subsidies by, for example, 50% implies a profit reduction for the conventional farmer amounting to approximately 130 000 SEK, which would make conventional farming run at a loss. In absolute numbers, the organic farmer would lose circa 250 000 SEK, which is more than his conventional colleague. Despite this substantial loss, the organic farmer would still make a profit amounting to approximately 200 000 SEK before tax. In conclusion, it turns out that the conventional farmer is more exposed to dramatic reductions in subsidies than the organic farmer.

From the results presented so far it might be concluded that the answer to the many of today's problems would be to have a large-scale conversion to organic production. However, it is unclear if the advantages would remain in the event of all farmers converting to organic production. Although the interest among consumers for organically produced products is relatively high, large consumer groups are still focusing on low prices. It is doubtful if a massive increase in the supply of organic products would be met by demand at the same high prices. From this point of view it could be argued that organic production is still a niche market.

Another aspect is related to the international competition within the organic segment. Several organic products are produced and manufactured in foreign countries. Foreign trade clearly makes it possible to increase exports, which could be an important factor when trying to make farming more profitable. International trade with organic products is by itself rather ambiguous because it is based on long-distance transport. The transport sector and agriculture are two major contributors of harmful substances to the environment, and little seems to be gained if reductions of emissions in one sector are counterbalanced by growth in the other. One way of coping with this problem would be to argue that the negative effects of transport should be included when determining which products be given the organic label. Such a strategy would probably benefit regionally produced goods, and would provide an opportunity for more farmers to convert to organic production. In turn, such a development could make the Swedish agricultural sector more sustainable for the future, and reduce the pace of farm closures.

However, from a global point of view the development sketched out above includes some problematical features. It would most likely bring higher rates of duty on agricultural goods produced further away, notably in developing countries. Poor countries whose economies to a large extent rely upon exports of primary sector products to developed countries, such as those within the European Union, would suffer heavily from such policies. Generally, the bottom line is who gains from a policy aiming at eliminating world market prices – is it the European consumer, is it the European farmer, or is it the farmer outside EU? Indeed there are different answers to this question, but it has been recognized for a long time that all parts benefit from producing goods and services for which they have comparative advantages. The comparative advantage of a country or a region is dynamic and changes over time. These changes are interrelated to the continuous restructuring of the economy, which is the basis for a sustained welfare state. Swedish trade and industry is very different today compared to the situation fifty years ago – some sectors have declined whereas others have grown. The agricultural sector is no exception. The recently recognized profitability decline in Swedish farming, despite import restrictions into the EU and substantial subsidies, indicates that there are structural problems. It is uncertain if these problems originate from differences in fuel taxes or other selective taxes (*e.g.* taxes on fertilizers) between EU-countries or whether they are more profound. In order to alter this development, consumers will have to change their behaviour and more frequently select more expensive domestic products. Whether consumers are prepared to do this is an open question, as is their willingness to allocate more money to agricultural subsidies.

It is difficult to say what will come out of this restructuring process and what farming will look like in the future. In the public debate there seems to be a consensus about the importance of open landscapes. To many people the open landscape possesses many positive qualities that they want to maintain, and the invasion of woodland is something unappealing. Keeping the open landscape will probably be demanded in the future. In spite of the problems farmers are facing today, the potential of a successful future should also be stressed. Some of the most important ingredients in such a recipe could be a deepened focus on environmentally friendly production, increased specialisation in high-quality products, continued efficiency improvements and openness towards agricultural diversification.

Some of the main conclusions to be drawn from this study are:

- The development of the integrated simulation model demonstrates the possibility of operationally integrating research from the social sciences and the natural sciences.

- The economic potential of making "better" production-related choices as a conventional farmer are much less than the gains from converting to organic production, all else being equal.

- From an economic point of view, the farmer can choose between two relatively sustainable strategies: either he can specialise in organic production or he can continue with conventional cultivation and use large amounts of pesticides and fertilisers. The worst strategy is to combine conventional cultivation with minimal use of pesticides and fertilisers.

- The results from simulations of the integrated model show that political changes regarding subsidies have a major influence on the farm economy.

- The choice of system boundary is most important for feed production simulations. When comparing the conventional and organic feed production systems, the system boundary needs to be expanded to also include livestock production and upstream inflow of nitrogen.

- The choice of using RME instead of ordinary diesel does not diminish the environmental impact, which is a consequence of the emissions occurring during the production of artificial fertiliser.

- Given the crop prices and yield reductions applied, the results of the simulation model suggest that it is beneficial to the farmer to adhere to the pre-specified crop rotations.

- The use of nitrogen is a key factor affecting both yield and all environmental impact categories. Several authors have pointed out that more nitrogen than the recommended level is applied, and this study showed similar results for a rational farmer with no environmental awareness choosing the highest level of both nitrogen and pesticides. This can be explained by the fact that the cost to the farmer of nitrogen and pesticides only amounts to 10% of the farm's cost and a small yield increase is economically beneficial. In order to get a more sustainable agricultural production, society needs to support and stimulate production to be more environmentally friendly.

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APPENDIX A. SALSA ARABLE FUNCTIONS & VARIABLES

Appendix A.1. Yield response to nitrogen applications (x_y)

Yield response functions used in this study for winter wheat, spring wheat, spring barley, rye, oats and spring rapeseed **are marked with bold text**.

Table A..1 Yield response functions due to N-application rates, used in the SALSA arable model for calculations of the yield (x_y). The variable ($x_{F(N)}$) is applied nitrogen as kg total nitrogen per hectare and year.

Crop	Yield function	Ref
Spring barley	**$2778+(30.47*x_{F(N)}\ (1))-(0.1658*x_{F(N)}\ \hat{}2)+(0.000288*x_{F(N)}\ \hat{}3)$**	**a)**
Oats	**$3311+(37.07*x_{F(N)})-(0.1741*x_{F(N)}\ \hat{}2)+(0.000218*x_{F(N)}\ \hat{}3)$**	**a)**
Winter wheat	**$3407+32.85*x_{F(N)}-0.08047*x_{F(N)}\ \hat{}2+0.0000331*x_{F(N)}\ \hat{}3$**	**b)**
Winter rye	**$3542+(27.03*x_{F(N)})-(0.0833*x_{F(N)}\ \hat{}2)$**	
Spring wheat	**$2740+(29.84*x_{F(N)})-(0.0669*x_{F(N)}\ \hat{}2)$**	**c)**
Spring oilseed rape, grain yield	**$1027.5+(11.087*x_{F(N)})-(0.0283*x_{F(N)}\ \hat{}2)$**	**d)**
Spring oilseed rape, oil yield	$456.72+(4.9063*x_{F(N)})-(0.0146*x_{F(N)}\ \hat{}2)$	d)
Spring turnip rape, grain yield	$1162+(9.468*x_{F(N)})-(0.03*x_{F(N)}\ \hat{}2)$	d)
Spring turnip rape, oil yield	$487.37+(3.835*x_{F(N)})-(0.0138*x_{F(N)}\ \hat{}2)$	d)
Potatoes, washed, main fraction 30-70 mm, research field Ångermanland	$17100+(0.12*x_{F(N)})-(0.000540*x_{F(N)}\ \hat{}2)$	e)
Triticale	$3754+(56.02*x_{F(N)})-(0.2311*x_{F(N}\ \hat{}2)$	c)
Sugarbeet	$33500+(0.09*x_{F(N)})-(0.000139*x_{F(N}\ \hat{}2)$	c)
Grass-ley 2 harvest	$4000+(46.6*x_{F(N)})-(0.09*x_{F(N}\ \hat{}2)$	a)
Grass-ley 3 harvest	$3290+(33.8*x_{F(N)})-(0.046*x_{F(N}\ \hat{}2)$	a)
Mixed ley 60% clover 2 harvest	$8100+(13.25*x_{F(N)})-(0.0315*x_{F(N}\ \hat{}2)$	a)
Mixed ley 60% clover 3 harvest	$6900+(13.06*x_{F(N)})-(0.0173*x_{F(N}\ \hat{}2)$	a)

a) Jordbruksverket, 1993
b) Mattson & Kjellquist, 1992

c) Interview; Lennart Mattson, 6 August 2002
d) calculated from research data (Frö & Oljveväxtodlarna 1983-1995)
e) Interview; Lennart Mattson, 21 May 2002

Comments:
Cereal yield is given for 15% water content, oilseed crop yield is given for 9% water content, and forage yield is given as dry matter. The functions are valid only in the interval 0-200 kg N/ha. There are no functions given for nitrogen fixation crops since the yield does not depend on the nitrogen application rate for those crops.

APPENDIX A.2. Average pesticide use (x_{Pe})

In this study, data from the case farm on kg active substance pesticide per hectare were used.

Table. A.2.1 Average use of pesticide; herbicide x_{PeW}, fungicide x_{PeF}, and insecticide x_{PeI}, on Swedish treated land, kg active substance per hectare (Jordbruksverket 2002). These are optional data to be used in the SALSA arable model simulations to calculate the use of active substance.

Crop	Herbicide x_{PeW}	Fungicide x_{PeF}	Insecticide x_{PeI}	Total x_{Pe}
Winter wheat	0.54	0.32	0.02	0.88
Rye	0.57	0.27	0.01	0.85
Triticale	0.54	0.27	0.03	0.84
Winter barley	0.73	0.37		1.10
Spring wheat	0.54	0.32	0.04	0.90
Spring barley	0.50	0.30	0.09	0.89
Oats	0.41	0.35	0.04	0.80
Cereal mixture	0.40	-	-	0.40
Leys for hay making	-	-	-	-
Leys for grazing	-	-	-	-
Leys for seed production	-	-	-	-
Green fodder	-	-	-	-
Peas for cooking and feed	1.03	-	0.07	1.40
Processing peas	0.78	-	0.07	0.85
White beans	-	-	-	-
Potatoes for human consumption	0.84	3.83	0.13	4.80
Potatoes for starch processing	0.96	2.71	0.25	3.92
Sugar beet	3.09	-	0.05	3.14
Winter oilseed rape	0.84	0.57	0.01	1.42
Winter turnip rape	-	-	-	-
Spring oilseed rape	0.48	-	0.01	0.49
Spring turnip rape	0.42	-	0.01	0.43
Linseed	0.13	-	-	0.13

Comments:
There has been a decrease in the amount of chemicals used, principally herbicides, during recent years. This change can be explained by the increased use of low-dose agents, sulphonlyurea compounds, a decrease in cultivated area land and the decrease in herbicide use.

APPENDIX A3. Emissions during production of artificial fertilizer (ε_{PMF})

Data for environmental impacts of mineral fertilizer production were taken from an LCI-inventory of fertilizer production (Davis and Haglund 1999), emission and energy use for production of the fertilizer are presented per kg fertilizer. *Suprasalpeter,* an ammonium nitrate fertiliser, was used in this study (marked in bold letters).

Table A.3.1 Emissions and energy use during production of different artificial fertilizers giving the emission vector ε_{PMF}. Figures given as MJ and g emissions per kg fertilizer.

	Energy (MJ) e)	NOX (g)	NH_3 (g)	NO_3-N (g) to water	N_2O (g)	P (g) to water	CO_2 (g)	SO_2 (g)	CH_4 (g)	HCl (g)
Hydro NP Svavel 27-5[a]	12.3	2.1	0.2	0.1	4.6	$1.9*10^{-3}$	903	3.1	0.92	0.0065
Supra-salpeter[b]	**12.7**	**1.5**	**0.2**	**0.1**	**5.6**	$\mathbf{9.2*10^{-7}}$	**903**	**1.3**	**0.86**	**0.065**
Hydro NPK 17-4-13 Svavel[c]	9.2	1.4	0.1	0.07	3.1	$1.6*10^{-3}$	669	2.5	0.68	0.041
MAP[d]	10.8	4.7	0.1	0.046	0.076	$6.8*10^{-6}$	893	10	1.2	0.033

a) 27% N, 4.8% P. 3% S (1 kg), produced by Hydro Agri AB, Köping
b) 27.6% N, calcium ammonium nitrate (1 kg), produced by Hydro Agri AB, Köping
c) 17% N, 4% P, 13% K, 3% S (1 kg), produced by Hydro Agri AB, Köping
d) Monoammonium phosphate, 11% N, 52% P_2O_5, (1 kg), West European average data
e) Data for extraction of natural gas are included in the data.

APPENDIX A.4. Emissions during spreading of organic fertilizers (ε_{AOF})

In this study, use of the band-spreading technique placing the slurry in the crops in June was assumed (marked with bold text), which results in an emission factor of 7%.

Table A.4.1. Ammonia emissions from applications of organic fertilizers, ε_{AOF}. Ammonia emissions are given as a percentage of the total ammonium-nitrogen content in the organic fertilizer (Karlsson & Rodhe 2002).

Season	Spreading technique	Incorporations in soil or not	Manure [a] %	Urine %	**Slurry %**
Spring/winter	Broadcasting	Application on ground frost	20	40	30
"	Band spreading		-	30	20
Spring	Broadcasting	Direct inc.	15	8	10
"	"	Inc. after 4 hours	33	14	15
"	"	Inc. After 5-24 hours	50	20	20
"	"	Spreading in ley	70	35	40
"	"	Spreading in cereal	-	11	20
"	Band spreading	Direct inc.	-	7	5
"	"	Inc. after 4 hours	-	14	8
"	"	Inc. After 5-24 hours	-	20	10
"	"	Spreading in ley	-	25	30
"	"	Spreading in cereal	-	10	15
"	Shallow injection	Spreading in ley	-	8	15
Early summer-summer	Broadcasting	Spreading in ley	90	60	70
"	"	Spreading in cereal	-	10	20
"	Band spreading	Spreading in ley	-	40	50
"	**Band spreading**	**Spreading in cereal**	-	10	**7**
"	Shallow injection	Spreading in ley	-	15	30
Early autumn	Broadcasting	Direct inc.	20	15	5
"	"	Inc. after 4 hours	35	23	18
"	"	Inc. After 5-24 hours	50	30	30
"	"	No inc.	70	45	70
"	Band spreader	Direct inc.	-	10	3
"	"	Inc. after 4 hours	-	18	9
"	"	Inc. After 5-24 hours	-	25	15
"	"	No inc.	-	30	40
Late autumn	Broadcasting	Direct inc.	10	10	5
"	"	Inc. after 4 hours	15	15	8
"	"	Inc. After 5-24 hours	20	20	10
"	"	No inc.	30	25	30
"	Band spreader	Direct inc.	-	4	3
"	"	Inc. after 4 hours	-	11	4
"	"	Inc. After 5-24 hours	-	18	5
"	"	No inc.	-	25	15

a) valid also for deep litter, semi-solid manure and sewage sludge

APPENDIX A.5. Emissions during production of energy carriers (ε_D, ε_E, ε_G, ε_O)

Table A.5.1. Emissions for production of the energy carrier; diesel ε_D, Swedish average electricity ε_E, natural gas ε_G and oil ε_O. Figures given as mg per MJ fuel.

	NOX (mg/MJ)	NH_3 (mg /MJ)	N_2O (mg/MJ)	CO_2 (mg/ MJ)	SO_2 (mg/MJ)	CH_4 (mg/MJ)	N (aq) mg/MJ	P (aq) mg/MJ
ε_D [a]	31			3500	19	2.0	0.07	0.01
ε_O	0.025 e-6 [a]	0.17e-12	0.044e-9 [b]	590000 [b]	0.010e-6			
ε_E [a]	15	0.22	0.71	7842	13	0.049e-6		
ε_G [c]	-	-	-	-	-	-	-	-

a) Uppenberg *et al.* (2001), part 2.
b) Uppenberg *et al.* (1999)
c) Lack of data, emissions included already in the production of N fertilizers.

APPENDIX A.6. Primary energy factors ($\Pi_{2\text{-}PriE}$, Π_{PriD}, Π_{PriO} Π_{PriG})

Primary energy factors for Swedish and Brazilian production of electricity are given in Table A.6.1 (the conversion factor for Swedish average electricity mix used in this study is marked with bold text). The calculations on which Table A.6.1 is based are presented in Table A.6.2 and in the equations below.

Table A.6.1. The primary energy production factors, $\Pi_{2\text{-}PriE}$, for Swedish and Brazilian electricity mixes.

	Swedish electricity mix	Brazilian electricity mix
Primary energy factor $\Pi_{2\text{-}PriE}$	**2.2**	1.1
Share of fossil primary energy $\Pi_{2\text{-}PriE\text{-}Fo}$	74%	6%

Table A.6.2. Swedish and Brazilian electricity mixes *Sha*, energy efficiency losses *Eff* , losses during production/distribution λ_{ElPrCo} and grid losses λ_{ElGr} for production of electricity.

	Brazilian electricity mix[a], *Sha* %	Swedish electricity mix[b], *Sha* %	Efficiency[c], *Eff* %	El.prod Costs, λ_{ElPrCo} %	Grid losses, λ_{ElGr} %	Comments
Hydro power	95	48.2	100	0.37 [b]	9 [d]	-
Nuclear power	0.65	44.3	33[e]	6 [b]	9 [d]	fossil
Wind power	1.7	0.23	100	2.9 [b]	9 [d]	-
CHP, oil	2.65	1.33	60	3.2 [b]	9 [d]	fossil
CHP, coal	0	2.43	60	3.2 [b]	9 [d]	fossil
CHP, natural gas	0	0.47	60	3.2 [b]	9 [d]	fossil
CHP, biofuel	0	2.81	60	3.2 [b]	9 [d]	-
Cold condensing oil	-	0.2	40	3.2 [b]	9 [d]	fossil

a) Sattari (2002)
b) Swedish average electricity mix, Uppenberg *et al.* (2001), Parts I and II, average value is assumed for CHP plant production costs
c) Arnäs *et al.* (1997)
d) Vattenfall (2001)
e) The total mass of uranium is assumed to be a potential energy source to make it possible to compare nuclear power with other energy carriers. This is a rough simplification and it is not either clear logically to compare energy and mass. Indeed this simplification was chosen to indicate that nuclear power leads to wastes of radioactivity.

The production of the energy carrier electricity in the power plant $\Pi_{1\text{-}PriE}$ is calculated as follows:

$$\Pi_{1\text{-}PriE} = ((Sha_{Hydro} * Eff_{Hydro}) + (Sha_{Nuclear} * Eff_{Nuclear}) + (Sha_{Wind} * Eff_{Wind}) (Sha_{CHP} * Eff_{CHP}) (Sha_{Cond} * Eff_{Cond})) \quad \text{(eq. A.6.1)}$$

where Sha_{Hydro} is the amount of hydro power, $Sha_{Nuclear}$ is the amount of nuclear power, Sha_{Wind} is the amount of windpower, Sha_{CHP} is the amount of CHP power and Sha_{Cond} is the amount of cold condensing oil in the electricity mix and Eff_{Hydro} , $Eff_{Nuclear}$, Eff_{Wind}, Eff_{CHP}, Eff_{Cond} is the efficiency during the production considering production losses during the energy conversion. For figures see

Table **A.6.2**.

The factor for the total primary electricity energy use $\Pi_{2\text{-}PriE}$ is calculated as follows (where the production and distribution losses are considered):

$$\Pi_{2\text{-}PriE} = \Pi_{1\text{-}PriE} + \Pi_{1\text{-}PriE} (\lambda_{ElGr} * \lambda_{ElPrCo}) \qquad (A.6.2)$$

where the λ_{ElPrCo} is production and distribution costs for generating electricity, and λ_{ElGr} is energy losses from the grid from the transferring from the power plant to the energy user. For figures see Table A.6.2.

Table A.6.3. The primary energy production factors; for diesel Π_{PriD}, for Π_{PriO} oil and for natural gas Π_{PriG} (Uppenberg *et al.* 2001, Parts I and II) and the share of fossil energy use.

	Diesel	Oil	Natural gas
Primary energy factors Π_{PriD}, Π_{PriO}, Π_{PriG}	1.06	1.05	1.07
Share of fossil primary energy $\Pi_{PriD\text{-}Fo}$, $\Pi_{PriO\text{-}Fo}$, $\Pi_{PriG\text{-}Fo}$	100%	100%	100%

APPENDIX A.7. RME production ($\underline{S}_{RME}$)

Emissions and energy use for RME production were taken from a paper by Bernesson *et al.* (2003). Only air bound eutrophication substances were consindered in that investigation. Physical allocation was used. If economic allocation is chosen the total energy use for the whole production chain is 20% higher.

Table A.7.1. Emissions and energy use for RME production (Bernesson *et al.* 2003).

Production factors	GWP (g CO_2-eq/Mj_{fuel})	Acidification (mg SO_2-eq/ Mj_{fuel})	Eutrophication (mg O_2-eq/ Mj_{fuel})	Input energy [a] (kJ/MJ_{fuel})
Electricity, oil extraction, $\underline{S}_{RSpre}$	0.1	0	0	31
Production of methanol and catalyst, KOH, $\underline{S}_{Methanol}$	1.1	2	14	37
Electricity, transesterfication, $\underline{S}_{RSEster}$	0.2	0	0	32
Production of rapeseed [b] $\underline{S}_{CropRS}$	*38.8*	*233*	*1800*	*190*
RME prod/total [c]	*4%*	*0.8%*	*0.8%*	*35%*

a) Primary energy use, including production, transportation and efficiency during electricity production.
b) Production of rapeseed also from Bernesson *et al.* (2003). For the case study presented in this report production data from SALSA simulations were used.
c) The share of RME production compared to total emissions and energy also including production of rapeseed at the farm.

APPENDIX A.8. Exhaust emissions during machine operations ($\varepsilon_{FU(n)}$)

The vector $\varepsilon_{FU(n)}$ consists of emissions of CO_2, NOX, SOX, CH_4 and N_2O per MJ for different operations (n), Table A.8.1 and Table A.8.2. There are operations-specific data available for CO_2 and NOX. Those substances are included in the EU-regulation from 1998 for exhaust emissions from working machines but the data on CH_4 N_2O and SOX are only available per MJ used fuel (Hansson & Mattsson 1999, Lindgren *et al.* 2002).

Table A.8.1. Emissions of CO_2 CH_4, N_2O and SO_X for tractor operations and stationary combustion (part of the substances in the vector $\varepsilon_{FU(n)}$).

Type of combustion	Emissions (g/MJ)			
	CO_2	CH_4	N_2O	SOx
All tractor operations [a, b]	73	0.006	0.003	0.0016
Stationary combustion (drying, and heating before pressing) [a, c]	75	0.001	0.0005	0.030

a) Uppenberg *et al.* (2001)
b) Approximated to be the same as for heavy vehicles.
c) Approximated to be the same as for a domestic heater.

Table A.8.2. Emissions of CO_2 CH_4, N_2O and SO_X during drying of grain.

Type of combustion	Emissions (g/MJ)					
	CO_2	NOX	NH3/NH-4	CH_4	N_2O	SOx
Drying of grain	73	0.070e-6	0.0001e-6	0.001e-6	0.0005e-6	0.030e-6

Table A.8.3. Emissions of NOx per MJ diesel fuel for different tractor operations (NOx has a specific place in the vector $\varepsilon_{FU(n)}$).

Tractor operations	NO_X (g/MJ)
Disc cultivation	0.75[a]
Rolling; straw baling	0.82[b]
Harrowing; grain transport; straw transport[c]; slurry transport[d]	0.90[a]
Combined sowing and mineral fertilising	0.92[b]
Direct drilling	0.93[b]
Conventional sowing; pesticide spraying; mineral fertilising	0.95[a]
Ploughing; grain harvesting[c], sugar beet harvesting[e]	0.99[a]

[a] Hansson & Mattson (1999)
[b] Norén *et al.* (1999)
[c] Approximated to be the same as the previous activity, due to lack of data (this could be a slight overestimation since the harvester works on same rev count during the whole operation.
[d] Approximated to be the same as the ploughing, due to lack of data.

APPENDIX A.9. Nitrogen fixation (x_{Nfix})

There were no N fixation crops in the present study, but an N fixation sub-model is available in the SALSA arable model. The amount of N fixation in leys with grass and clover was estimated according to clover percentage, yield and N application rate (Fagerberg & Salomon 1992). Linear equations were created from the table values presented in Fagerberg & Salomon (1995). The variable x_{Nfix} is the nitrogen fixed to the leaves and the variable x_y is the yield in dry matter. For leguminous plants, nitrogen fixation is given as a percentage of the yield. For example, a pea crop with a yield of 3130 kg, (average Swedish yield for 2002 (SCB 2003)) fixes 103 kg N in above-ground crop parts (Jordbruksverket 2001).

Table A.9.1. Equations to calculate the nitrogen fixed in leaves for different percentages of clover and when 0-30 kg N is applied per hectare.

Clover, %	Fixation in leaves
10%	$x_{Nfix} = 0.0036\ x_y + 7.2439$
20%	$x_{Nfix} = 0.0065\ x_y + 14.488$
30%	$x_{Nfix} = 0.0092\ x_y + 20.878$
40%	$x_{Nfix} = 0.0116\ x_y + 25.634$
50%	$x_{Nfix} = 0.0135\ x_y + 24.512$
60%	$x_{Nfix} = 0.0179\ x_y + 23.293$
70%	$x_{Nfix} = 0.0166\ x_y + 23.463$
80%	$x_{Nfix} = 0.0179\ x_y + 23.293$
90%	$x_{Nfix} = 0.0191\ x_y + 22.951$

Table A.9.2. Equations to calculate the nitrogen fixed in leaves for different percentages of clover and when 30-90 kg N is applied per hectare.

Clover, %	Fixation in leaves
10%	$x_{Nfix} = 0.0023\ x_y + 16.024$
20%	$x_{Nfix} = 0.0046\ x_y + 21.463$
30%	$x_{Nfix} = 0.0068\ x_y + 26.122$
40%	$x_{Nfix} = 0.0089\ x_y + 30.854$
50%	$x_{Nfix} = 0.0103\ x_y + 31.024$
60%	$x_{Nfix} = 0.0116\ x_y + 30.244$
70%	$x_{Nfix} = 0.0133\ x_y + 30.585$
80%	$x_{Nfix} = 0.0142\ x_y + 29.098$
90%	$x_{Nfix} = 0.0144\ x_y + 28.756$

Table A.9.3. Equations to calculate the nitrogen fixed in leaves for different percentages of clover and when 90-120 kg N is applied per hectare.

Clover, %	Fixation in leaves
10%	$x_{Nfix} = 0.0016\, x_y + 24.244$
20%	$x_{Nfix} = 0.0032\, x_y + 27.878$
30%	$x_{Nfix} = 0.0048\, x_y + 32.122$
40%	$x_{Nfix} = 0.0064\, x_y + 35.756$
50%	$x_{Nfix} = 0.0077\, x_y + 35.366$
60%	$x_{Nfix} = 0.0089\, x_y + 36.049$
70%	$x_{Nfix} = 0.0102\, x_y + 35.659$
80%	$x_{Nfix} = 0.0106\, x_y + 33.024$
90%	$x_{Nfix} = 0.0106\, x_y + 30.463$

Table A.9.4. Equations to calculate the nitrogen fixed in leaves for different percentages of clover and when 120-180 kg N is applied per hectare.

Clover, %	Fixation in leaves
10%	$x_{Nfix} = 0.0016\, x_y + 24.244$
20%	$x_{Nfix} = 0.0032\, x_y + 27.878$
30%	$x_{Nfix} = 0.0048\, x_y + 32.122$
40%	$x_{Nfix} = 0.0064\, x_y + 35.756$
50%	$x_{Nfix} = 0.0077\, x_y + 35.366$
60%	$x_{Nfix} = 0.0089\, x_y + 36.049$
70%	$x_{Nfix} = 0.0102\, x_y + 35.659$
80%	$x_{Nfix} = 0.0106\, x_y + 33.024$
90%	$x_{Nfix} = 0.0106\, x_y + 30.463$

APPENDIX A.10. SJV manual for fertilising using good agricultural practice

The actual nitrogen application on the farm is compared to the Swedish Board of Agriculture's recommendations in order to decide whether the N actual application rate is a higher amount x_e or a lower amount x_d than recommended.

Table A.10.1. Nitrogen application rate $x_{F(N)}$ using good agricultural practice, according to yield in ton/ha and economic optimum, recommendations from the Swedish Board of Agriculture (Jordbruksverket 2002). This figures are used for linear equations, which are used in the SALSA model to calculate the N application rates for different yields.

Crop	1.5	2	2.5	3	4	5	6	7	8	9
Wheat						115	130	155	195	
Spring wheat					110	130	150	170		
Barley, oats					70	90	110	130		
Rye					65	85	105	125	145	
Triticale, winter barley					70	90	110	130	150	170
Grass ley, 2 cuts/year							135	155	175	
Grass ley, 3 cuts/year							170	195	220	245
Grass-clover ley, 20% clover, 2 cuts/year							100	115	130	
Grass-clover ley, 20% clover, 3 cuts/year							130	145	165	185
Spring oilseed crops	85	100	115	130						
Winter oilseed crops			100	115	145					

There is similar recommendation for phosphorus and potassium depending on soil status. (Jordbruksverket 2002).

APPENDIX A.11. Soil compaction model (C_{eff})

Effects from soil compaction were not included in the present model, but they are included in the SALSA arable model.

The crop yield losses C_{eff} (% reduced yield) caused by machinery-induced soil compaction in topsoil (0-25 cm deep, y_{top}) and subsoil (25-40 cm deep, y_{sub}) were calculated using the model developed by Arvidsson & Håkansson (1991) and are calculated as follows:

$$c_{eff} = y_{top} + y_{sub}$$
(eq. A.11.1)

Crop yield losses caused by topsoil compaction y_{top} (0-25 cm deep) were calculated as follows:

$$y_{top} = \Gamma * 0.0000154\ (t_{top} + t_{back} + t_{trailer})$$ (eq. A.11.2)

where Γ is the clay content (%) and t_{top}, t_{back} and $t_{trailer}$ are front- back- and trailer wheel traffic intensity calculated as Mgkm/ha.

The traffic intensity t_{top} in (Mgkm/ha) was calculated as follows:

$$t_{top} = \Psi * 10 * (\Delta) \ / \ \Theta * (\log10(\Pi) - 1.2 * (\gamma_S * 0.2625 - 0.056) * PassesNo$$

(eq. A.11.3)

where Ψ is machine weight for the back and front axles (tons/axle), Δ is affected area (percentage) (Interview Johan Arvidsson) (for ploughing 0.5 is subtracted from this value due to the fact that one side of the tractor runs in the furrow directly), Θ is working width of the equipment (m), Π is pressure in the back and front tyres (kPa), γ_S is soil moisture, rated on a subjective scale from 1 (very dry) to 5 (very moist) and $x_{no}(1\text{-}n)$ is number of passes for individual field operations (number).

The estimation is made for the main area; compaction of headlands is not included here. The equation is based on the assumption that tracks from the same field operations never cross each other, and tracks from different operations are randomly distributed in relation to each other. The weight of a semi-mounted implement such as a manure spreader is partly transformed to the tractor.

Subsoil compaction y_{sub} is calculated in a similar way as for topsoil, except that the axle pressure leads only to compaction when the load is larger than 4 tons, the soil water content is higher than 2 and the yield reduction is independent of the soil type (Arvidsson 1992).

APPENDIX A.12. Phosphorus losses (L_{Ptot})

There are two data sets available for phosphorus losses from farm land, one where surface and drainage losses are presented separately and one giving an average figure for both.

In this study, surface P leaching was set to the maximum figure of 0.5 and the drainage losses were set to 0.35 (marked with bold text in Table A.12.1).

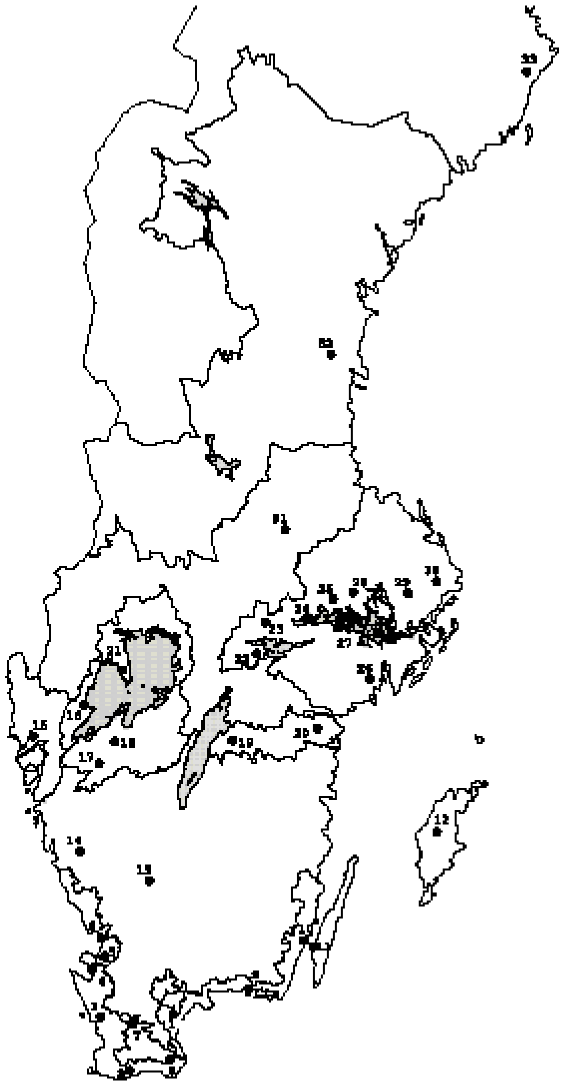
Table A.12.1. Surface σ and drainage δ phosphorus losses (kg/ha and year) from Swedish fields for three areas *i* and for six types of soils *j* (Naturvårdsverket 1997).

Areas in Sweden *j*	Soil type *j*	Surface water average TotP	Surface water average PO_4-P	Surface water Max TotP	Surface water Max PO_4-P	Drainage water average TotP	Drainage water average PO_4-P	Drainage water Max TotP	Drainage water Max PO_4-P
South[a]	Med. to heavy clay					0.59	0.38	1.51	1.51
	Glacial till/light clay					0.19	0.10	0.36	0.23
	Fine/very fine sand					0.80	0.66	2.61	2.49
Centre[b]	Med. clay/heavy clay	0.42	0.26	0.80	**0.50**	**0.35**	0.19	3.42	1.44
	Fine/very fine sand					0.09	0.05	0.50	0.07
	Peat soil					0.47	0.31	0.92	0.69
North[c]	Silt					0.03	0.01	0.07	0.02
	Glacial till/light clay					0.13	0.08	0.33	0.14
	Fine/very fine sand	0.59	0.39	1.51	1.14	0.03	0.01	0.08	0.02

a) County; M, L, N)
b) County; R, E, C, D, S, T
c) County; W, Z, AC

Table A.12.2. Estimated field phosphorus losses (L_{Ptot}) from type districts 2000/2001 and long-term average values (kg/ha) (Carlsson *et al.* 2002).

Type districts	2000/2001 N-tot	2000/2001 P-tot	Long term average N-tot	Long term average P tot	No years
Gärds Köpinge	20	0.00	27	0.01	12
Vemmenhög	20	0.14	24	0.30	12
Asmundtorp	19	0.09	23	0.24	6
Förslöv	24	0.36	31	0.57	11
Gullbrannabäcken	26	0.34	26	0.55	9
Menlösabäcken	46	0.32	52	0.42	12
Medel Gss	***26***	***0.21***	***31***	***0.35***	
Snogeröd	43	0.41	40	0.53	16
Smedstorp	36	0.08	48	0.33	7
Heabybäcken	24	0.25	21	0.30	7
Barlingbo	18	0.10	17	0.07	11
Medel Gmb	***30***	***0.21***	***32***	***0.31***	
Draftingebäcken	21	0.29	22	0.22	6
Öxnevallabäcken	40	0.53	49	1.32	7
Vikenbäcken	26	2.09	21	1.17	7
Medel Gsk	29	***1.0***	***31***	***0.90***	
Järnsbäcken	26	1.13	25	0.67	7
Fåglabäcken	22	0.55	19	0.21	12
Uveredsbäcken	30	2.45	21	0.75	12
Marstad	24	0.13	15	0.07	12
Gisselöå	12	1.32	8	0.58	12
Medel Gns	23	***1.12***	***18***	***0.46***	
Averstadån	28	1.25	20	0.79	6
Husön	91	1.38	40	0.08	6
Vällbäcken	21	4.27	12	1.50	6
Fiholm	23	3.70	14	1.16	7
Frögärdebäcken	25	2.02	17	0.72	7
Långtora	16	0.99	10	0.45	6
Skepptuna	22	0.67	12	0.32	8
Lohärad	31	0.40	20	0.36	7
Mässingsboån	18	2.16	12	0.54	11
Medel Ssk & Ss	31	***1.87***	***17***	***0.65***	



No.	Type districts	County
1	Gärds Köpinge	LM
2	Vemmenhög	LM
3	Asmundtorp	LM
4	Förslöv	LM
5	Menlösabäcken	N
6	Gullbrannabäcken	N
7	Snogeröd	LM
8	Smedstorp	LM
9	Heabybäcken	K
10	Ljungbylundsbäcken	H
11	Klevabäcken	H
12	Barlingbo	I
13	Draftingebäcken	F
14	Öxnevallabäcken	O
15	Vikenbäcken	O
16	Järnsbäcken	O
17	Fåglabäcken	O
18	Uveredsbäcken	O
19	Marstadsbäcken	E
20	Gisselöå	E
21	Averstadån	S
22	Husön	T
23	Vällbäcken	T
24	Fiholm	U
25	Frögärdebäcken	U
26	Hillestabäcken	D
27	Bergshammarsbäcken	D
28	Långtora	C
29	Skepptuna	AB
30	Lohärad	AB
31	Mässingsboån	W
32	Norrbo	X
33	Flarkbäcken	AC

Figure A.12.3. The locations of the investigation fields for type districts (see Table A.12.2 used for estimation of phosphorus from farmland 2000/2001 (Carlsson *et al.* 2002).

APPENDIX A.13. Nitrogen leaching - farm-model, $l_{FarmNtot}$ (β, τ, ϱ, λ_{NOF})

In this study, the background leaching was set to 10 kg N/ha and year (marked with bold text)

Table A.13.1. Background nitrogen leaching β (kg N/ha) from arable land[a] for three soil types and for three precipitation levels (Aronsson & Torstensson 2001).

	Sand & humus soil			Clay-light clay[b]			Clay loam - heavy clay[c]		
	<560 mm/year	560-750 mm/year	>750 mm/year	<560 mm/year	560-750 mm/year	>750 mm/year	<560 mm/year	560-750 mm/year	>750 mm/year
Götaland	25	35	45	17.5	25	32.5	10	15	20
Svealand	15	25	35	10	17.5	25	5	**10**	15

a) These values represent nitrogen leaching on a conventional arable farm, no manure is used and the first autumn tillage is done directly after harvest.
b) 5-25% clay
c) > 25% clay

For the crop index, all cereals were set to the index 1.0 and the spring oilseed crops were set to 1.2 (marked with bold text).

Table A.13.2. Crop index (ϱ) inducing extra leaching (Aronsson & Torstensson 2001).

	Crop index, ρ
Cereals	**1.0**
Winter oilseed crops	1.2
Spring oilseed crops	**1.2**
Ley	1.0
Fallow	1.0
Root crops	1.0
Peas	1.3
Potatoes	1.7

Comments: Sugar beet gives a residual fertilizing effect to the following crop of 25 kg N/ha if the tops are left in the field, otherwise the effect of the preceding crop is 0 kg N/ha (Jordbruksverket 2003).

For tillage index, early tillage was assumed after oats and before winter rye to give a tillage index of 0.9, otherwise the tillage index was assumed to 1.0 (marked with bold text).

Table A.13.3. Tillage index τ inducing extra leaching or avoided leaching (Aronsson & Torstensson 2001).

	Tillage index, Götaland, τ	Tillage index, Svealand, τ
Early tillage[a]	1.0	**1.0**
Early tillage - followed by winter rye	0.9	**0.9**
Late tillage[b]	0.9	1.0
Late tillage and catch crop that is broken up late	0.7	0.8
Late tillage after sowing of a catch crop in autumn	0.8	0.9
Spring tillage	0.7	0.8
Spring tillage	0.5	0.6
Spring tillage - followed by catch crop sown in autumn	0.6	0.8
Ley - undercropping	0.5	0.6
Ley - followed by spring tillage	0.9	0.9
Ley without tillage	0.4	0.5
Grass ley - early tillage	1.5	1.5
Grass ley - early tillage followed by winter rye	1.4	1.4
Grass ley - late tillage[b]	1.2	1
Clover ley - early tillage	2	2
Clover ley - early tillage, followed by winter rye	1.8	1.8
Clover ley - late tillage	1.5	1.3
Fallow	0.6	0.7
Early tillage or chemical control of the fallow	1.2	1.2

a) early means before 15 September
b) late means after 15 September

Table A.13.4. Extra nitrogen leaching λ_{NOF} as kg nitrogen leakage/ha per ton dry matter application of manure per hectare for three soil types and for three precipitation levels (Aronsson & Torstensson 2001).

	Sand & humus soil			Clay-light clay[a]			Clay loam - heavy clay		
	<560 mm/year	560-750 mm/year	>750 mm/year	<560 mm/year	560-750 mm/year	>750 mm/year	<560 mm/year	560-750 mm/year	>750 mm/year
Götaland	1.5	2.25	3.25	1.0	1.75	2.25	0.50	1.25	1.75
Svealand	1.0	1.75	2.25	0.5	1.25	1.75	0.25	**0.75**	1.00

a) 5-25% clay

APPENDIX A.14. Nitrogen leaching – STANK in mind, $l_{STANKNtot}$

Leaching of N (*flow number 6)* depending on site and management was estimated using a Swedish model for predicting leaching to drainage water (Aronsson & Torstensson 2004). The model was constructed by experts from the Division of Water Quality Management at SLU and the Swedish Board of Agriculture to be a tool in advising farmers on good agricultural practice. The 'normal' leaching data were obtained from a project where the SOILNDB model was used to calculate N leaching from Swedish soils [Johnsson *et al.* 1987; Johnsson *et al.* 2002). Important factors related to choice of management considered in the model include: time of tillage, application rate of nitrogen in relation to crop requirements, time and technique for spreading of manure, nitrogen fertilisation and nitrogen uptake in crops during autumn and mineralization from crop residuals. The effects of management were constructed from empirical field data from 15-20 years of field experiments in the south of Sweden, literature data and expert assumptions (Aronsson & Torstensson 2004).

The formula used for quantification of NO_3-N leaching ($L_{STANKNTot}$) from land per hectare was:

$$L_{STANKNTot} = Base_{s,j} + L_{N(T)} + L_{N(MF\&OF)aut} + L_{N(OF)spring} + L_{N(CSowUP)aut} + L_{N(CGrowUP)aut} + L_{N(C\mathrm{Re})} + L_{N(ExcessOrDeficit)}$$

(eq.A.14.1)

where $Base_{s,,j}$ is normal leaching from a cereal crop supplied with mineral fertiliser in appropriate amounts and with normal soil tillage practices, $L_{N(T)}$ is the effect of tillage time, $L_{N(MF\&OF)aut}$ is the effect from nitrogen applied in autumn, $L_{N(OrgF)spring}$ is the effect from organic nitrogen applied in spring, $L_{N(CsownUP)aut}$ is prevented leaching due to crop uptake in autumn, $L_{N(CRe)}$ is the effect from nitrogen released from crop residues and $L_{N(ExcessOrDeficit)}$ is the effect from an excess or inadequate application of nitrogen relative to crop requirements.

The 'normal' leaching is given according to five soil texture classes (types) regarding clay content *(s)* and for communities *(j)*, with values from 289 Swedish communities. The $Base_{s,,j}$ value for the community studied here (Enköping) is 18 kg N/ha for a clay soil with a clay content of 25-40% and 37 kg N/ha for a sandy soil with a clay content of 0-5% clay.

The formula used for quantification of the effect of tillage time $x_{N(T)}$ was as follows:

$$x_{N(T)} = -(1 - Tf_{s,t}) * Base_{s,j}$$

(eq. A.14.2)

where $Tf_{s,t}$ is a tillage factor given for five soil types *(s)* and for nine tillage times *(t)*. The normal tillage time occurs between 10 September and 10 October and is a base alternative with a *Tf*-factor of 1, valid for spring barley and spring rapeseed in this study. For winter wheat the soil needs to be prepared earlier than the normal reference time and therefore the *Tf*-factor of winter wheat is 1.10 for the sandy soil and 1.05 for the clay soil.

The formula used for quantification of the effect from mineralised organic nitrogen from spreading of manure and mineral fertiliser applied in autumn $x_{N(MF\&OF)aut}$ was as follows:

$$x_{N(MF\&OF)aut} = Lf_{s,j} * Cf_j \left(x_{(NH4)aut} * Of_{aut\ z,t} + x_{N(MF)aut} \right)$$

(eq. A.14.3)

where $x_{(NH4)aut}$ is the amount of applied ammonium nitrogen in autumn from manure applications and $x_{N(MF)aut}$ is the amount of mineral nitrogen in artificial fertiliser in autumn, $Of_{aut\ z,t}$ is the percentage of the ammonium in the soil available for N leaching for different manure spreading techniques *(z)* and spreading times *(t)* and $Lf_{s,j}$ is a spatial factor that adjusts the leaching to the actual location according to soil type, precipitation and climate. The *Lf*-factor was assumed to be negatively correlated with clay content and cooler mean temperature than in the reference location but positively correlated with amount of precipitation. Cf_j is a climate factor that adjusts the potential crop growth value according to climate *(j)*.

The formula used for quantification of the effect from mineralised organic nitrogen from spreading of manure during spring and summer $x_{N(OrgF)spring}$ was as follows:

$$x_{N(OrgF)spring} = Lf_{s,j} * Cf_j \left(x_{(orgN)spring} * Of_{spring_{z,t}} * Tf_{s,t} \right) \qquad \text{(eq. A.14.4)}$$

where $x_{(orgN)spring}$ is the amount of organic nitrogen applied in spring and summer and $Of_{spring\ z,t}$ is the maximum amount of that organic nitrogen that can mineralise and then be available for leaching.

The formula used for quantification of the effect of prevented leaching due to crop uptake in autumn $x_{N(CsownUP)aut}$ was as follows:

$$x_{N(CsownUP)aut} = -1 * Lf_{s,j} * Cf_i \left(x_{N(CuptSow)aut,i,j} - Uf_C * x_{N(CuptSow)aut,i,j} \left(x_{(orgN)spring} * Of_{spring_{z,t}} * Tf_{s,t} \right) - \left(x_{(NH4)aut} * Of_{aut\, z,t} \right) \right)$$

(eq. A.14.5)

where $x_{N(CupSow)aut,C}$ is the nitrogen uptake for different plants *(c)* for crops sown in autumn. The winter wheat crop is assumed to take up 20 kg N/ha during the autumn; Uf_C is the crop's potential uptake of released organic nitrogen and winter wheat is assumed to take up 10% of the released organic nitrogen.

The formula used for quantification of the effect from nitrogen released from crop residuals $x_{N(CRe)}$ was as follows:

$$x_{N(C\,\mathrm{Re})} = Lf_{i,j} * Cf_j * x_{N(\mathrm{Re})C}$$

(eq. A.14.6)

where $x_{N(Re)C}$ is the release of nitrogen from crop residues after harvest, only spring rapeseed was assumed to contribute to this factor with an extra nitrogen release of 20 kg N/ha.

The effect from an excess or inadequate application of nitrogen was also calculated. Whether the nitrogen is applied in excess or whether there is a nitrogen deficit in the soil $x_{N(ExcessOrDeficit)}$ relative to crop requirements was calculated as follows:

$$x_{N(ExcessOrDeficit)} = x_{N(Tot)} - x_{N(CropNeed)}$$

(eq. A.14.7)

where $X_{N(Tot)}$ is the net nitrogen input to the soil and $X_{N(CropNeed)}$ is the crop requirement according to the Swedish Board of Agriculture recommended application rate for 2002 for crops of feed quality (Jordbruksverket 2002).

In order to avoid including effects of small differences, the following limit was calculated:

$$x_{N(\mathrm{limit})} = 5\% * x_{N(CropNeed)}$$

(eq. A.14.8)

and if $x_{N(ExcessOrDeficit)} > x_{N(\mathrm{limit})}$

(eq. A.14.9)

then $x_{N(ExcessOrDeficit)} = Lf_{i,j} \left(x_{N(ExcessOrDeficit)} - x_{N(\mathrm{limit})} \right)$ (eq. A.14.10) or if $x_{N(ExcessOrDeficit)} < -5$

(eq. A.14.11)

the value of -5 was used to avoid including effects caused by a small difference.

then $x_{N(ExcessOrDeficit)} = -1 * Lf_{i,j}\left(x_{N(ExcessOrDeficit)} + x_{N(\mathrm{limit})}\right)$ (eq. A.14.12)

otherwise there was no extra leaching or prevented leaching due to management.

The burden from a crop was assigned to the causing crop, even if the leaching or prevented leaching occurred during a following crop season.

APPENDIX B. DATA USED FOR SIMULATION OF THIS CASE STUDY

Appendix B.1. Excess and deficit of N application to the soil (x_d, x_e)

Table B.1.1. Calculated value (kg/ha) for the amount of applied nitrogen in excess x_e and at lower amounts than recommended x_d. The norm application rate was set according to Swedish Board of Agriculture recommendations and from data on the expected yield on the case farm.

Crop	Excess N for normal applications kg/ha	Excess N when over applications x_e kg/ha	Deficit N when under applications x_d kg/ha
Oilseed rape	12	33	10
Spring wheat	13	38	12
Spring barley	9	27	8
Winter wheat after cereal	13	38	11
Oats	9	26	8
Winter rye	7	21	6
Fallow	0	0	0
Winter wheat after fallow	12	34	10
Turnip rape	12	33	10

APPENDIX B.2. Average water content at harvest in Sweden (γ_h)

Table B.2.1. Average water content (%) at harvest γ_h in the Swedish districts B, C, D, and U, calculated from field trials during the period 1995-2002 (Fältforskningsenheten 2003).

Crop	Water content, %
Spring wheat	19.3
Winter wheat	20.0
Oats	17.8
Spring barley	19.0
Winter rye	18.8
Spring oilseed rape	14.7
Spring turnip rape	15.2

APPENDIX B.3. Yield reduction due to monoculture

The reducing effect of a bad preceding crop is assumed after Fogelfors (2001) and Bingefors *et al.* (1978). The main concept is that wheat and barley are the most sensitive crops among cereals. Rye and especially oats can act as a cleaning crops between other more sensitive crops. The repeated monoculturing is assumed to increase by the same figure as the numbers of repeated years. Reasonably, the negative effect of cropping the same crop year after year causes more damage where half or no biocide is used. For the scenarios with half dose biocide and no biocide at all, the reducing yield effect is multiplied by an increasing factor.

Table B.3.1. First year's reducing effect on yield (%) originating from the preceding crop or monoculture[21]

Previous crop	Spring oilseed crop, %	Spring wheat, %	Oats, %	Spring barley, %	Winter rye, %	Winter wheat,%
Spring oilseed crop	**13**					
Spring wheat		**10**	**3**	**10**	**3**	**17**
Oats		**1**	**5**	**1**	**1**	**1**
Spring Barley		**5**	**3**	**5**	**3**	**5**
Winter rye		**3**	**3**	**3**	**5**	**3**
Winter wheat		**10**	**3**	**10**	**3**	**17**

Table B.3.2. Yield reduction (%) due to monoculture in conventional farming.

Numbers of years with monoculture	Spring oilseed crop, %	Spring wheat, %	Oats, %	Spring barley, %	Winter rye, %	Winter wheat, %
Year 1	13	10	5	10	5	17
Year 2	26	20	10	20	10	34
Year 3	39	30	15	30	15	51
Year 4	52	40	20	40	20	68
Year 5	65	50	25	50	25	85

[21] The reducing effect on spring and winter wheat is compared with them being placed at the most favourable place in the crop rotation *i.e.* after fallow or an oilseed crop. The other three cereals are often placed after another cereal but a spring oilseed crop is placed after a cereal.

Table B.3.3. Yield reduction (%) due to monoculture in conventional farming where half the dose of biocide is used.

Numbers of years with monoculture	Spring oilseed crop, %	Spring wheat, %	Oats, %	Spring barley, %	Winter rye, %	Winter wheat, %
Year 1	19	16	12	16	12	23
Year 2	31	26	16	26	16	39
Year 3	43	35	21	35	21	54
Year 4	55	44	26	44	26	70
Year 5	67	54	30	54	30	86

Table B.3.4. Yield reduction (%) due to monoculture in conventional farming where no biocide is used.

Numbers of years with monoculture	Spring oilseed crop, %	Spring wheat, %	Oats, %	Spring barley, %	Winter rye, %	Winter wheat,%
Year 1	50	37	34	37	34	42
Year 2	57	44	37	44	37	54
Year 3	65	51	41	51	41	66
Year 4	72	58	44	58	44	78
Year 5	80	65	48	65	48	90

APPENDIX B.4. Choice of system boundaries in the organic production system

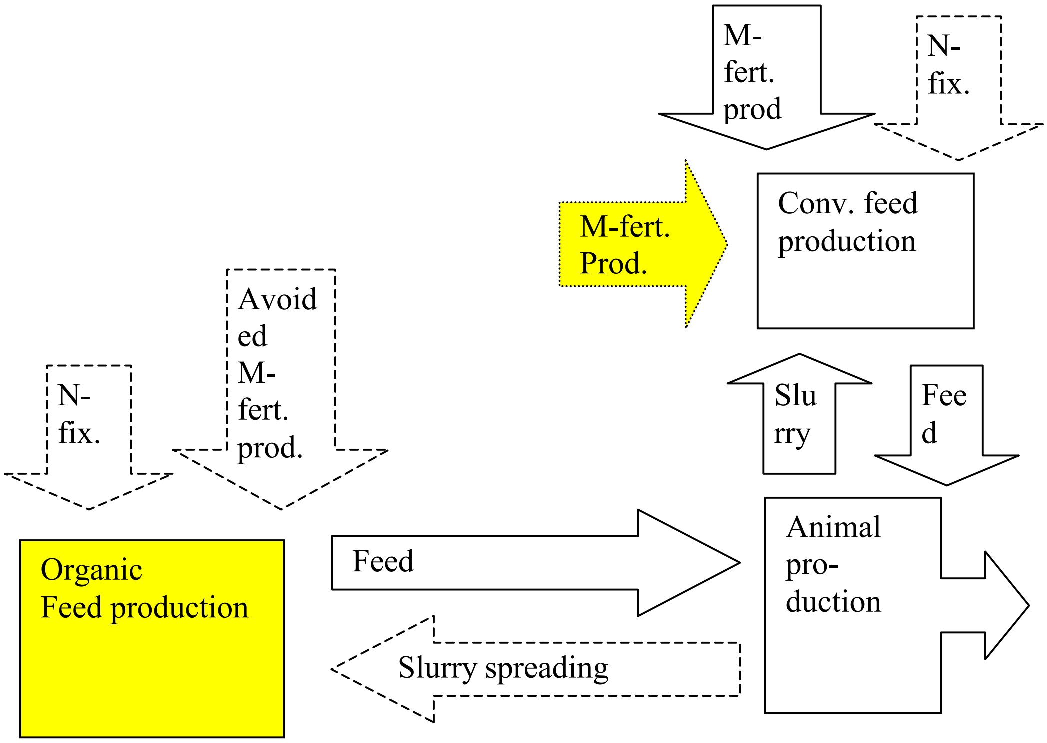


Figure B.4. Choice of system boundary. Activities of the farm production that can be included or excluded in the systems analysis of farm production. Dashed lines indicate possible activities to include depending on the purpose of the study and choice of system boundary.

APPENDIX B.5. Upstream production of mineral fertilizers and allocation factors

Table B.5.1. Physical (A_PS, A_PB) and economic (A_ES, A_EB) allocation factors for pig slurry and pig body delivered from the farm.

	Slurry, % A_PS, A_ES	Pig production, % A_PB, A_EB
Physical allocation	58	42
Economic allocation	0.6	99.4

The need of mineral fertilizer X_{NupAMF} to get 1 kg N in the slurry due to exchange is calculated as follows:

$$X_{NupAMF} = \frac{1}{A_PS} + \frac{A_PB}{(A_PS)^2}$$ (eq. B.5.39)

The physical allocation factors for slurry A_PS and pig body A_PB are calculated as follows:

$$A_PS = \frac{x_{Npig\text{-}slurry}}{X_{Npig\text{-}intake}} = 58\%$$ (eq. B.5.2)

$$A_PB = \frac{x_{Npig\text{-}retention}}{x_{Npig\text{-}intake}} = 42\%$$ (eq. B.5.3)

where the N in excreted slurry, $x_{Npig\text{-}slurry}$ was set to 31.82 g N/day, N retention, $x_{Npig\text{-}retention}$ was set to 22.61 g N/day and the N intake, $x_{Npig\text{-}intake}$ was set to 54.41 g N/day (Canh, 1998). This pig diet included 14.5 % crude protein.

The economic allocation factor for slurry A_ES is calculated as follows:

$$A_ES = \frac{A_PS * Price_{slurry}}{((A_PB * Price_{pigb}) + (A_PS * Price_{slurry}))}$$

(eq. B.5.4)

The economic allocation factor for pig body A_EB is calculated as follows:

$$A_EB = \frac{A_PB * Price_{pigb}}{((A_PB * Price_{pigb}) + (A_PS * Price_{slurry}))} \quad \text{(eq. B.5.5)}$$

where the price for slurry $Price_{slurry}$, was estimated to 0.027 SEK/kg slurry and the price for the pig body was set to 6.86 SEK/ kg pig body delivered from the farm.

The slurry price was assumed to be the same as the price of N, P and K as mineral fertilizer. The ammonia content in the slurry was assumed to have the same fertilizer effect as mineral fertilizers. Data on average ammonia content for pig slurry were used, 3.3 kg NH4-N/ton slurry (Steineck *et al.* 2000). This gave a price of 27 SEK/ton slurry. The price the farmer gets for the whole pig was set to 6.86 SEK/kg pig body, calculated from the deadweight price 9.40 SEK/kg (http://agriprim.com/marknadsinfo/default.asp?kategori 2004-02-02) and slaughter losses of about 28% for slaughter weights of 115-120 kg (Interview Allan Simonsson, 11 February 2004).

APPENDIX B.6. Crop rotation constraint matrix

Practical constraints determine how the crop can be grown each year. Winter crops can only be cropped on land where there is an early harvest. Table B.6.1 shows a matrix of possible crop sequences in a crop rotation due to practical constraints.

Table B.6.1. Crop rotations constraints matrix[22]

Order	Previous crop	SR	SW	OA	SB	RY	ST	WW	OA	FA	WW
1	Spring oilseed rape	0	1	1	1	0	0	0	1	1	0
2	Spring wheat	1	1	1	1	0	1	0	1	1	0
3	Oats	1	1	1	1	1	1	1	1	1	1
4	Spring barley (early)	1	1	1	1	1	1	1	1	1	1
5	Winter rye	1	1	1	1	1	1	1	1	1	1
6	Spring turnip rape	0	1	1	1	1	0	1	1	1	1
7	Winter wheat	1	1	1	1	1	1	1	1	1	1
8	Oats	1	1	1	1	1	1	1	1	1	1
9	Fallow	1	1	1	1	1	1	1	1	1	1
10	Winter wheat	1	1	1	1	1	1	1	1	1	1

APPENDIX B.7. Estimation of optimal N application rates

The optimum N application rate for winter wheat is estimated thus:
Average yield response of winter wheat x_y (in kg grain/ha, at 15% water content) for N application rates is described by the following equation:

$$x_y = 3407+32.85*x_{F(N)} -0.08047*x_{F(N)}^{\ 2}+0.0000331*x_{F(N)}^{\ 3} \qquad \text{(eq. B.7.1)}$$

where $x_{F(N)}$ is the applied mineral N (kg N/ha).

The economic optimum for different nitrogen application rates, the *Profit*, is estimated from the relationship between receipts and costs:

[22] Oilseed crops (Spring oilseed rape and spring turnip rape) are not recommended to be cropped more often than every fifth year, four years between). Not more than 60% winter crops, due to normal machine capacity (de Toro & Hansson 2003) and fallow needs to be minimum of 10% of total area each year to get subsidies. Winter crop (i.e. winter wheat and winter rye) cannot follow after spring wheat or spring oilseed rape, due to the late harvest time.

$$\boldsymbol{Profit\ (N)} = \boldsymbol{Receipts_{TotCrop}} - \boldsymbol{Costs_{Crop}}$$ (eq. B.7.2)

$$\boldsymbol{Receipts_{TotCrop}} = x_y * Net\boldsymbol{Receipts_{kgCrop}}$$ (eq. B.7.3)

$$Net\boldsymbol{Receipts_{kgCrop}} = Receipts_{\boldsymbol{kg}crop} - Expenses_{\boldsymbol{kg}crop}$$ (eq. B.7.4)

where $Net\boldsymbol{Receipts}_{kgcrop}$ is the difference between receipts, $Receipt_{kgcrop}$ (0.95 SEK/kg for dried grain, winter wheat of normal quality 2001) and $Expenses_{\boldsymbol{kg}crop}$ (the cost for PK fertilizer 0.06 SEK/kg grain, harvest, drying and transport 0.14 SEK/kg dried grain). (Interview Bertil Albertsson)

$$\boldsymbol{Costs_{Crop}} = x_{F(N)} * ExpensesN_{fertilizer}$$ (eq. B.7.5)

where $ExpensesN_{fertilizer}$ is the cost per kg N (9.0 SEK/kg N fertilizer to winter wheat) (Interview Bertil Albertsson)

By using equations B.7.1-5, the profit can be expressed as follows:

$$\boldsymbol{Profit\ (N)} = \boldsymbol{Receipts_{TotCrop}} - \boldsymbol{Costs_{Crop}}$$ (eq. B.7.6)

$$= (x_y * Net\boldsymbol{Receipts_{kgCrop}}) - (x_{F(N)} * ExpensesN_{fertilizer}) =$$ (eq. B.7.7)

$$= (3407 + 45.55 * x_{F(N)} - 0.08047 * x_{F(N)}^{2} + 0.0000331 * x_{F(N)}^{3}) * Net\boldsymbol{Receipts_{kgCrop}} - (x_{F(N)} * ExpensesN_{fertilizer})$$ (eq. B.7.8)

$$= 3407\ Net\boldsymbol{Receipts_{kgCrop}} + (45.55\ Net\boldsymbol{Receipts_{kgCrop}} - ExpensesN_{fertilizer}) * x_{F(N)} - 0.08047\ Net\boldsymbol{Receipts_{kgCrop}} * x_{F(N)}^{2} + 0.0000331\ Net\boldsymbol{Receipts_{kgCrop}} * x_{F(N)}^{3}$$ (eq. B.7.9)

The economic optimum N application rate or when the profit is at maximum is when the derivative of the profit is zero *Profit (N)'* = 0, and is found in the interval 0-250 kg N/ha for $x_{F(N)}$ figures.

$$\textbf{\textit{Profit ' (N)}} = 45.55\ Net\textbf{Receipts}_{kgCrop} - ExpensesN_{fertilizer} - 0.16094R^* x_{F(N)} + 0.0000993R^* x_{F(N)}{}^2 = 0$$
(eq. B.7.10)

For $ExpensesN_{fertilizer} = 9$, and $Net\textbf{Receipts}_{kgCrop} = 0.70$ (SEK) (eq. B.7.11)
$x_{F(N)} = 246$ kg N/ha

Nitrogen import $N_{ImportToSoil}$ from sources other than fertilizer is estimated as follows:

$$N_{ImportToSoil} = x_{Nmin} + x_{Nfix} + x_{C(R)} + (x_{Ndep})$$
(eq. B.7.12)

where x_{Nmin} is the mineralization from soil which will be available for plant uptake, x_{Nfix} is the N imported to the soil by N fixation, $x_{C(R)}$ is extra mineralization from crops that leave nutrient-rich residues after harvest in the soil and x_{Ndep} is the amount of N deposition on the soil.

A suitable nitrogen application rate $Nfertilizer_{need}$ is then estimated from:

$$Nfertilizer_{need} = x_{F(N)} - N_{ImportToSoil}$$
(eq. B.7.13)

The N application rate must then be adjusted for the potential yield on the farm due to climate and site conditions. For example if the expected yield is decreased by 1 ton, the application of fertilizer should be decreased by 20 kg/ha (Jordbruksverket 2002).

APPENDIX C. RESULTS

APPENDIX C.1. Decision pattern regarding crop rotation

Table C.1.1. Simulation results showing the pattern of how often farmers adhere to the given crop rotation and how often the most profitable crop is chosen and numbers of choices for using the parcel for fallow. This table shows decisions from the normal scenario with 100% mineral fertilizer, 100% pesticide dose and ordinary diesel used as fuel.

Decision model in combination with levels of accepted environmental loadings	According to crop rotation	Most profitable crop	Fallow
Unlimited loadings, Purely rational (M5rat)	2100	7140	1560
Unlimited loadings, Incremental (M5inc)	8561	619	1620
Unlimited loadings, Bounded rational (M5beg)	7580	1660	1560
Unlimited loadings, Garbage Can (random) (M5ran)	0	0	0
Medium loadings, Purely rational (M3rat)	2100	7140	1560
Medium loadings, Incremental (M3inc)	8468	712	1620
Medium loadings, Bounded rational (M3beg)	7101	2139	1560
Medium loadings, Garbage Can (random), (M3ran)	0	0	0
Limited loadings, Purely rational (M1rat)	1470	7770	1560
Limited loadings, Incremental (M1inc)	8472	708	1620
Limited loadings, Bounded rational (M1beg)	8354	886	1560
Limited loadings, Garbage Can (random) (M1ran)	0	0	0
Organic production, Purely rational (KRAV) (M0rat)	1260	7980	1560
Organic production, Incremental (KRAV) (M0inc)	8455	706	1639
Organic production, Bounded rational, (KRAV) (M0beg)	6017	3223	1560
Organic production, Garbage Can (random) (KRAV) (M0ran)	0	0	0

APPENDIX C.2. Decision pattern regarding frequency of combinations

Table C.2.1. Simulation results showing the pattern of frequency of combinations of the management choices for different decision characteristics and environmental preferences. Management alternatives numbers 1-24 correspond to the alternatives given, accepted environmental loadings. The figures show the numbers of choices per parcel.

Management alternatives, see Table 7	M5 rat	M5 inc	M5 beg	M5 ran	M3 rat	M3 inc	M3 beg	M1 rat	M1 inc	M1 beg	M0 rat	M0 inc	M0 beg
1			58	451			165			886		4391	3401
2		93	1313	443		1394	614		5313	5544		914	2067
3		840	1184	458		818	1366						
4		335	742	444		345	1459						
5		280	262	451		1088	911						
6		886	319	465		412	582						
7		289	394	440	1680	735	757						
8		292	306	473		122	191						
9		303	331	476	4284	898	429						
10		314	91	440	3276	634	637						
11		52	903	431		87	207						
12		271	279	435		78	141						
13		560	68	460		83	899				9240	3856	3772
14		584	329	455		1645	368	9240	3867	2810			
15		317	308	450			172						
16		622	90	444									
17		659	94	463		287	342						
18		859	260	443		554							
19		885	322	457									
20		113	79	478									
21		309	333	420									
22		41	389	465									
23		276		423									
24	9240	93		435									

APPENDIX C.3. Decision pattern regarding frequency of crop choice

Table C.3.1. Simulation results showing the pattern of crop choice frequency for the different decision characteristic and environmental preferences. Numbers 1, 2 and 3 in column for crop rotation mean frequency of repeated crop in a four-year period.

Crop	Frequency of 4 years	M5rat	M5inc	M5beg	M5ran	M0rat	M0inc	M0beg
Fallow		1560	1620	1560	2051	1560	1639	1560
Spring wheat		1740	1621	1558	832	2130	1680	1573
Winter wheat		1680	1236	1449	581	1860	1175	1420
Oats		1560	1442	1401	779	1260	1426	1308
Spring barley			1467	1358	786	60	1462	1298
Rye		1650	1537	1498	615	210	1372	1348
Spring oilseed rape		1440	980	1057	792	1920	1049	1154
Spring turnip rape		1170	518	522	808	1800	677	630
Spring wheat	1		103	63	468		169	101
Winter wheat	1		81	56	258		94	61
Oats	1		9	64	509			39
Rye	1		186	100	258			143
Spring oilseed rape	1			33	442		55	143
Spring turnip rape	1			49	425		2	61
Spring barley	1			30	495			74
Spring wheat	2			1	110			1
Winter wheat	2				41			
Oats	2				100			
Spring barley	2				102			
Rye	2				33			
Spring oilseed rape	2				130			2
Spring rape seed	2			1	118			1
Spring wheat	3				6			
Winter wheat	3				2			
Oats	3				16			
Spring barley	3				5			
Rye	3				1			
Spring oilseed rape	3				20			
Spring turnip rape	3				11			

M5rat= Unlimited loadings, Purely rational
M5inc= Unlimited loadings, Incremental
M5beg= Unlimited loadings, Bounded rational
M5ran= Unlimited loadings, Garbage Can (random)
M0rat= Organic production (KRAV), Purely rational
M0inc= Organic production (KRAV), Incremental
M0beg= Organic production (KRAV), Bounded rational

APPENDIX C.4. Environmental loadings per farm

The following four figures show results from simulation of the integrated model; total contribution from farm production expressed as global warming potential (kg CO_2-equivalents), acidification (kg Sox-equivalents), eutrophication (kg CO_2-equivalents) and primary energy use (MJ).

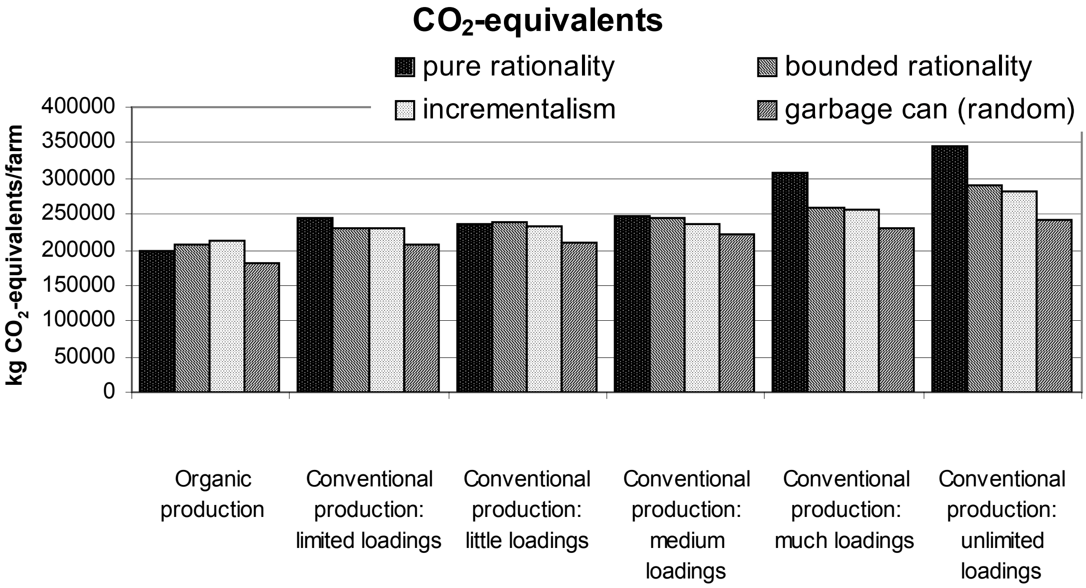


Figure C.4.1. Emissions of CO_2-equivalents across decision models and acceptance of environmental loadings (kg/farm and year).

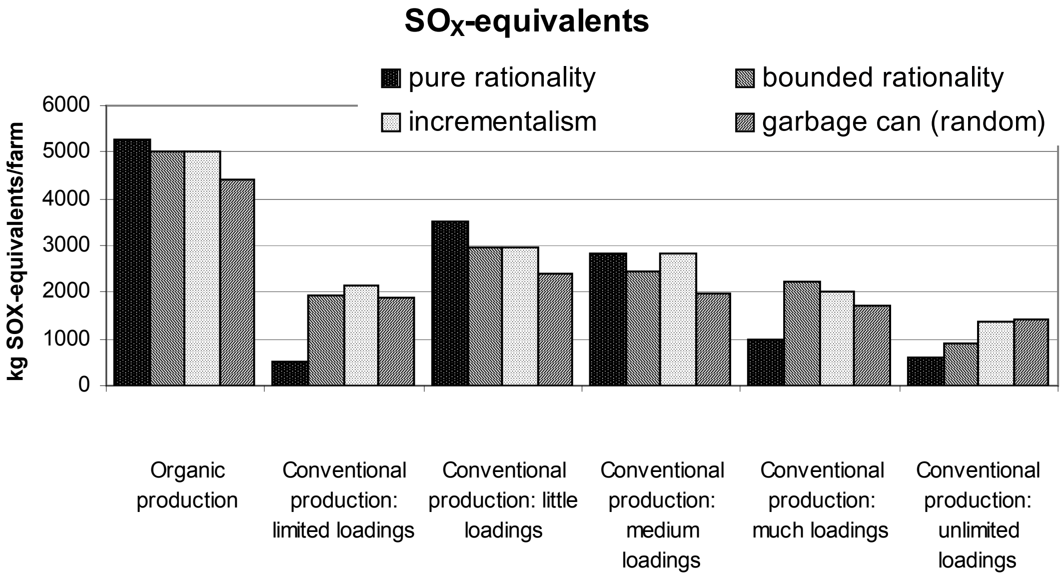


Figure C.4.2. Emissions of SOX-equivalents across decision models and acceptance of environmental loadings (kg/farm and year).

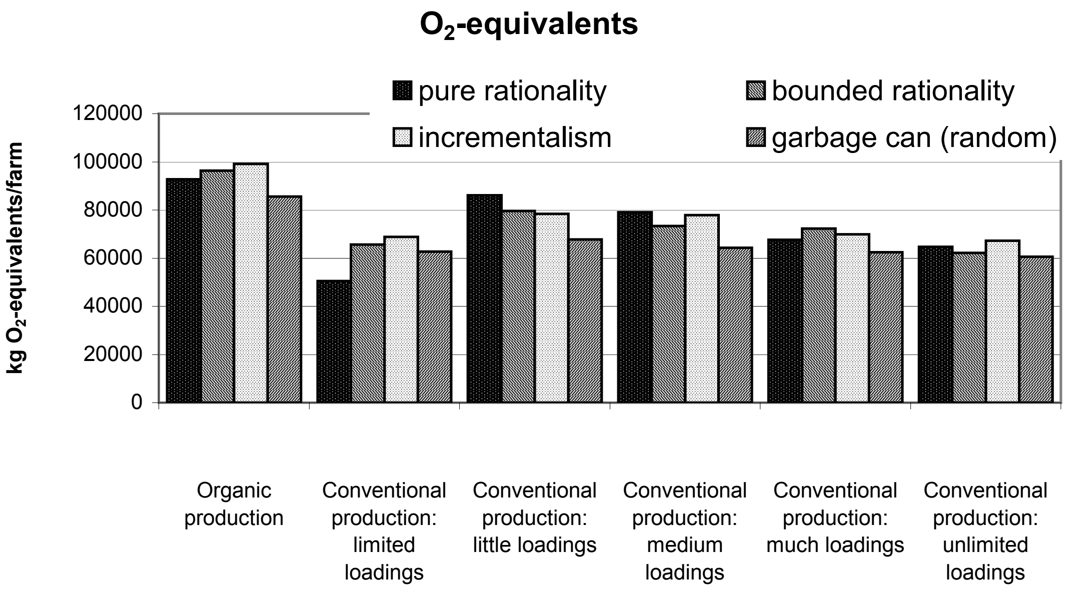


Figure C.4.3. Emissions of O_2-equivalents across decision models and acceptance of environmental loadings (kg/farm and year).

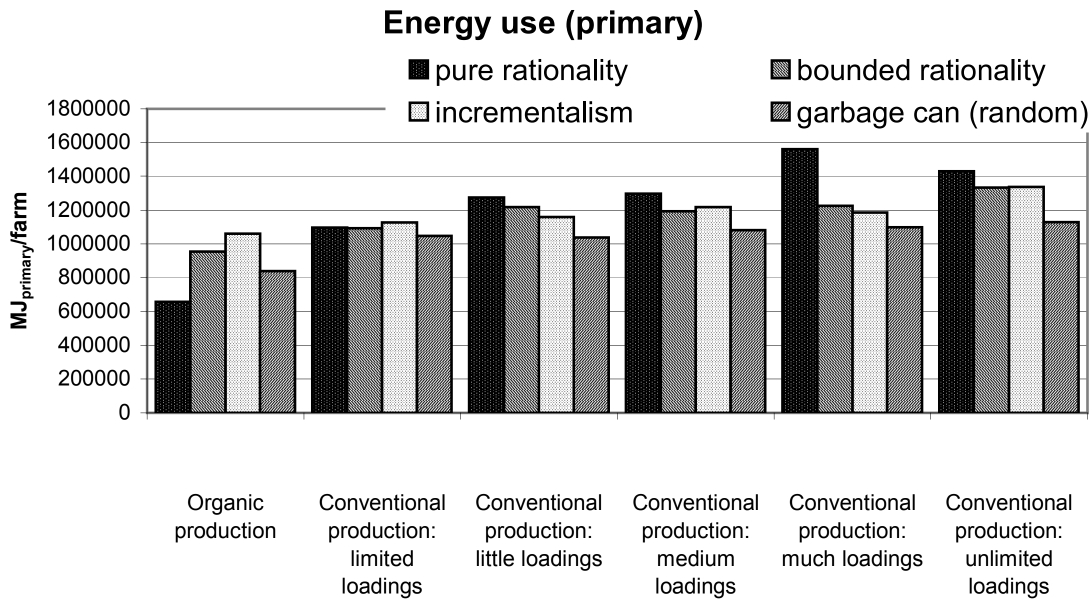


Figure C.4.4. Primary energy use across decision model and acceptance of environmental loadings (kg/farm and year).

APPENDIX C.5. RME compared to diesel

Eutrophication, acidification and primary energy use across the 24-production allocation alternatives (kg O_2-equivalents and SOx-equivalents and MJ/kg winter wheat product).

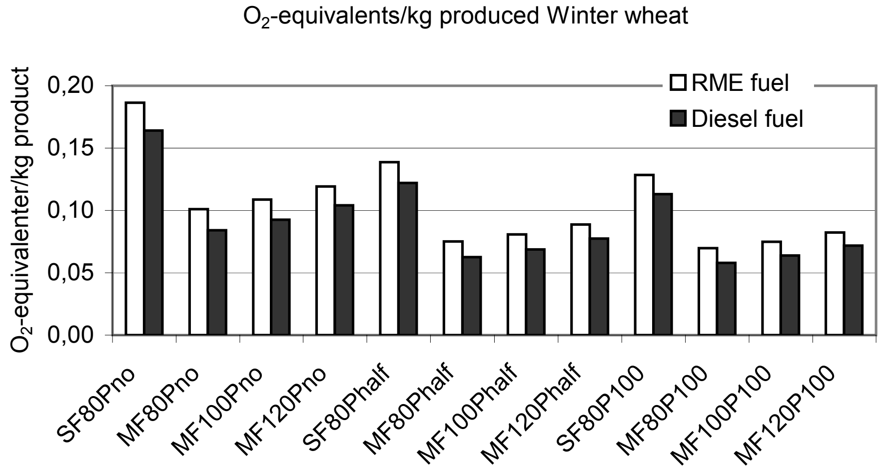


Figure C.5.1. Environmental simulation results for winter wheat, kg O_2-equivalent/kg product, for sixteen variables of management choice. SF is slurry fertilizer, MF is mineral fertilizer, 80,100 and 120 % are the three nitrogen fertilising strategies and Pno, Phalf and P100 refer to the percentage pesticide use.

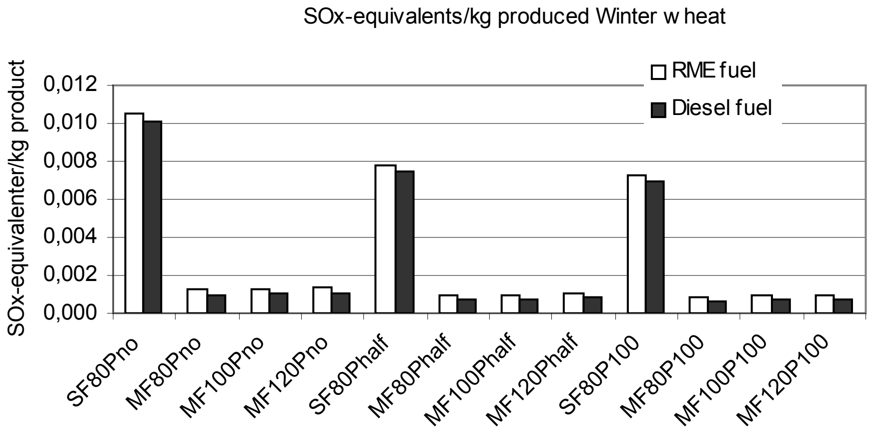


Figure C.5.2. Environmental simulation results for winter wheat, kg SOX-equivalent/kg product, for sixteen variables of management choice. SF is slurry fertilizer, MF is mineral fertilizer, 80, 100 and 120 % are the three nitrogen fertilising strategies and Pno, Phalf and P100 refer to the percentage pesticide use.

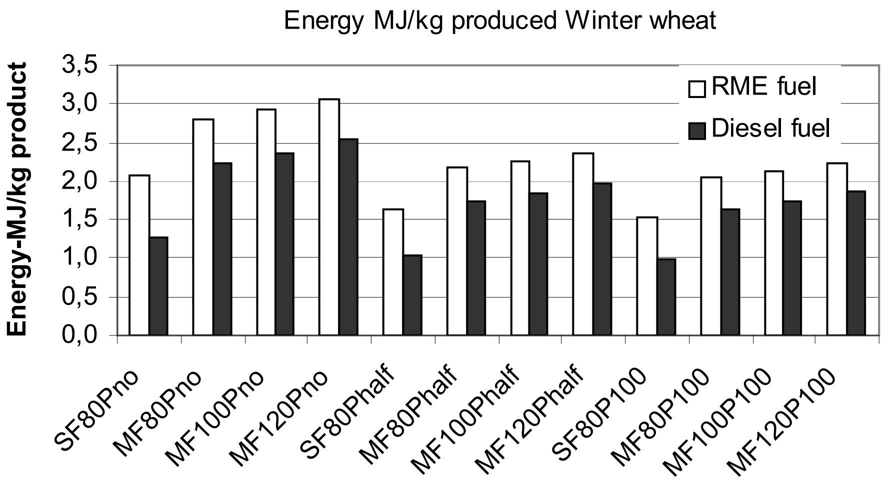


Figure C.5.3. Environmental simulation results for winter wheat, MJ primary energy/kg product, for sixteen variables of management choice. SF is slurry fertilizer, MF is mineral fertilizer, 80,100 and 120 % are the three nitrogen fertilising strategies and Pno, Phalf and P100 refer to the percentage pesticide use.

NOTATIONS

Table N.1. Notations, variables and constants used in SALSA arable model.

	Symbol (latin)	*Description*	*Value*	*Unit*
	A	Area used for growth of a crop		hectare
Assigned	a, b, c, d	Parameters accounting for varying characteristics of different machinery		
Calculated	A_EB	Economic allocation factor for assigning upstream mineral production to pig body	99.4	%
Calculated	A_ES	Economic allocation factor for assigning upstream mineral production to pig slurry	0.6	%
Calculated	A_pB	Physical allocation factor for assigning upstream mineral production to pig body	42	%
Calculated	A_pS	Physical allocation factor for assigning upstream mineral production to pig slurry	58	%
Assigned	$Base_{s,j}$	The base leaching calculated by the STANK in Mind module. $Base_{s,j}$ is set according to soil type *s* and for community *j*.		kg NO_3-N/ha
Calculated	*C*	Content of nutrients in harvest		kg N, P, K, Cd
	CC	Capital costs		
Calculated	c_{eff}	Crop yield loss due to soil compaction from topsoil and subsoil compaction		
Assigned	D	Depreciation per year		
Assigned	d_E	The dryer's electricity use MJ/kg water to be dried	0.34 MJ	MJ
Assigned	d_O	The dryer's oil use MJ/kg water to be dried	4.7 MJ	MJ
Assigned	d_{pre}	Energy use for pressing of oil crops, rapeseed		MJ/kg yield
Assigned	Eff_{Hydro} $Eff_{Nuclear}$, Eff_{Wind}, Eff_{CHP}, Eff_{Cond}	Efficiency of energy conversion during production of electricity		%
Assigned	EL	Economic lifetime		years
Calculated	$En_{d\text{-}E}$	The use of electricity to dry a crop to storage quality		MJ

Calculated	$En_{d\text{-}O}$	The use of oil to dry a crop to storage quality	MJ
Calculated	En_E En_G En_D En_O	Energy use of electricity, natural gas, diesel fuel and oil	MJ/ha
Calculated	En_{PriD}, En_{PriE}, En_{PriG}, En_{PriO}	Primary energy use of electricity, natural gas, diesel fuel and oil	MJ/ha
Assigned	f	The content of total-N, NH_4-N, NO_3-N, organic-N, P, K, S, Cd in fertilizers	%
Assigned	FC	Fuel consumption	Litres/hour
	FLC	Fuel and lubrication costs	
Assigned	FP	Fuel price	Price/litre
Flows	i	Inflow of substances to the soil	kg/ha
Assigned	IC	Interest charge	
Flows	$l_{Dir\text{-}N2O}$	Direct N_2O emissions from the soil	kg N/ha
Flows	$l_{InDir\text{-}N2O}$	Nitrous oxide emissions originating from agricultural nitrogen pollution	kg N/ha
Calculated	l_{NA}	Avoided N leaching according to lower application than recommended	kg N/ha
Calculated	l_{NE}	Extra N leaching according to excess application compared to recommended	kg N/ha
Calculated	$l_{N\text{-}tot}$	Nitrogen leaching from field, $l_{Farm\ N\text{-}tot}$ is the Farm model	kg NO3-N/ ha
Flows	l_{Ptot}	Phosphorus leaching from field	kg tot P/ ha
	$\boldsymbol{L_{N(CRe)}}$	N leaching originating from nitrogen released from crop residues	kg N/ ha
	$\boldsymbol{L_{N(CsownUP)aut}}$	Prevented nitrogen leaching due to crop uptake in autumn	kg N/ ha

	$\boldsymbol{L}_{N(ExcessOrDeficit}$	N leaching or prevented N leaching due to an excess or inadequate application of nitrogen relative to crop requirements.	kg N/ ha
	$\boldsymbol{L}_{N(MF\&OF)aut}$	N leaching effect from nitrogen applied in autumn	kg N/ ha
	$\boldsymbol{L}_{N(OrgF)spring}$	N leaching effect from organic nitrogen applied in spring	kg N/ ha
	$\boldsymbol{L}_{N(T)}$	N leaching effect from tillage time	kg N/ ha
Calculated	$L_{STANKN\text{-}tot}$	Nitrogen leaching from field, the STANK in Mind N leaching sub-model.	kg NO3-N/ ha
	MC	Maintenance costs	
Assigned	$No_{(c,n)}$	Number of passes for individual field operations *n*, for specific crops *c*	number
	$\boldsymbol{Of}_{aut\ z,t}$	The percentage of the ammonium in the soil available for N leaching for different manure spreading techniques (z) and spreading times (t)	%
	$\boldsymbol{Of}_{spring\ z,t}$	The maximum amount of the organic nitrogen spread in spring that can mineralise and be available for leaching	%
Assigned	OT	Operating time	Hours
Assigned	p_{eff}	Crop yield loss due to half or no dose of pesticides	%
	$\boldsymbol{Pf}_{s,j}$	A place factor which adjusts the N leaching to the actual place according to soil type, precipitation and climate.	
Assigned	RV	Replacement value	
Flows	S_{AMF}	Nitrogen emission from volatilization of applied artificial fertilizer	kg NH_4-N/ha
Flows	S_{AOF}	Emission of ammonia during application of organic fertilizers	kg NH_4-N/ha
Calculated	S_{Cair}	Ammonia emissions to air from plants	kg NH_4-N/ha
Assigned	$\underline{S}_{Crop}$	Total emission and energy use for production of a crop on one hectare	kg, MJ/ha
Calculated	$\underline{S}_{dry}$	Emissions and energy use for drying of grain	kg, MJ/ha

Flows	S_{Fuel}	Exhaust emissions from fossil fuel for machine operations	kg, MJ/ha
Assigned	Sha_{CHP}	The share of energy generated from CHP power plant for production of an electricity mix	%
Assigned	Sha_{Cond}	The share of cold condensing oil power plant used for production of an electricity mix	%
Assigned	Sha_{Hydro}	The share of hydro power used for production of an electricity mix	%
Assigned	$Sha_{Nuclear}$	The share of nuclear power used for production of an electricity mix	%
Assigned	Sha_{Wind}	The share of windpower used for production of an electricity mix	%
Calculated	S_{PMF}	Energy use and emissions for production of mineral fertilizer	kg,MJ/ha
Calculated	S_{PriD}	Energy use and emissions for production of the energy carrier diesel fuel	kg, MJ/ha
Calculated	S_{PriE}	Energy use and emissions for production of the energy carrier electricity	kg,MJ/ha
Calculated	S_{PriG}	Energy and emissions for production of the energy carrier natural gas	kg,MJ/ha
Calculated	S_{PriO}	Energy and emissions for production of the energy carrier oil	kg,MJ/ha
Calculated	S_{rec}	Nitrous oxide emissions from the recipients; a proportion of the nitrate (NO_3-N) leaching to water bodies and ammonia (NH_3-N) emissions to air from plants and during fertilizer application.	kg N_2O-N/ha
Calculated	S_{RME}	Emissions and energy use for production of RME	kg, MJ/ha
Calculated	S_{RSpre}	Emissions and energy use for pressing rapeseed oil	kg, MJ/ha
Calculated	S_{Seed}	Total emissions for production of seed used for a crop per hectare	kg, MJ/ha
Calculated	S_{soil}	Soil emissions of NO_3-leaching to water bodies, P-leaching via drainage water and as surface losses and N_2O-emissions to air.	kg P, NO_3-N and N_2O-N/ha
Calculated	t_{back}	Back wheel traffic intensity	Mgkm/ha
	$Tf_{s,t}$	Tillage factor for five soil types (s) and for nine tillage times (t)	

	TIC	Tax and insurance costs	
	TMC	Total annual machinery costs	
Calculated	t_{top}	Front wheel traffic intensity	Mgkm/ha
Calculated	$t_{trailer}$	Trailer wheel traffic intensity	Mgkm/ha
	Uf_C	The crop's potential uptake of released organic nitrogen.	%
Calculated	$u_{Fu(c,n)}$	Fuel use for each machine operation *n* and for each crop *c*	MJ/ha
Flows	w	Water in grain to be dried off	kg/ha
Assigned	$\underline{W}_{Acid}$	Equivalent impact factor for acidification	kg SO_x-equivalents
Assigned	$\underline{W}_{Eutro}$	Equivalent impact factor for eutrophication	kg O_2-equivalents
Assigned	$\underline{W}_{Green}$	Equivalent impact factor for global warming	kg CO_2-equivalents
	$x_{(NH4)aut}$	The amount of applied ammonium nitrogen in autumn from manure application	kg NH_4-N/ ha
	$x_{(orgN)spring}$	The amount of organic nitrogen applied in spring and summer	kg organic -N/ ha
Assigned and/or Calculated	x_{AMF}	Application rate of mineral fertilizers	kg fertilizer/ha
Assigned/ Calculated	x_{AOF}	Application rate of organic fertilizers	kg org. fertilizer/ha
Assigned	$x_{C(R)}$	Amount nitrogen in crop residues returned to soils annually	kg total N/ha
Calculated	x_d	Deficient nitrogen application rate compared to the economic optimum rate according to Swedish Board of Agriculture's recommendations	kg N/ha

Calculated	x_e	N application excess, more than recommended according to Swedish Board of Agriculture economic optimum rate		kg N/ha
Assigned or Calculated	$x_{F(N)}$	Nitrogen fertilizer application rate		kg N/ha
Assigned	$x_{Fu(n)}$	Fuel consumption for one machine operation *n*		MJ/ha
	$x_{N(CropNeed)}$	Crop needs according to the Swedish Board of Agriculture recommended application rate for 2002.		kg N/ha
	$x_{N(CupSow)aut}$	The nitrogen uptake for different plants (c) for crops sown in autumn	For example winter wheat = 20 kg N	kg N/ha
	$x_{N(MF)}$	The amount of mineral nitrogen applied as artificial fertiliser in autumn		kg N/ ha
	$x_{N(Re)C}$	The release of nitrogen from crop residues after harvest.	For spring rapeseed = 20 kg N	kg N/ha
	$xN(Tot)$	The net nitrogen input to the soil		kg N/ha
Assigned	x_{Ndep}	The amount of N deposition kg/ha to the soil		kg total N/ha
	x_{Nfix}	Amount of nitrogen fixed by a N-fixation crop		kg total N/ha
Assigned	x_{Nmin}	Amount of nitrogen mineralised from the soil		kg total N/ha
Assigned	$x_{Npig\text{-}intake}$	Pigs nitrogen intake in feed		g N/day
Assigned	$x_{Npig\text{-}retention}$	Nitrogen retention in pig body		g N/day
Assigned	$x_{Npig\text{-}slurry}$	Nitrogen excretion during pig slurry production		g N/day
Calculated	X_{NupAMF}	Amount of nitrogen from mineral fertilizer to get 1 kg N in pig slurry, upstream mineral fertilizer production		kg N/kg N
Assigned	x_{PeF}	The average use of fungicides for a crop		kg active substance/ ha
Assigned	x_{PeI}	The average use of insecticides for a crop		kg active substance/ ha

Assigned	x_{PeW},	The average use of herbicides for a crop		kg active substance/ ha
Assigned	x_{Seed}	Amount of seed used per hectare	8 -200 kg/ha	kg/ha
Calculated	x_{y1}	Yield during harvest, undried		kg grain/ha
Calculated or Assigned	x_{y2}	Yield at storage quality, dried grain or yield from a specific farm or district		kg grain/ha
Calculated	x_{y3}	Yield at storage quality, affected by soil compaction or/and pesticide level		kg grain/ha
Calculated	y_{sub}	Crop yield reduction due to subsoil compaction		%
Calculated	y_{top}	Crop yield reduction due to topsoil compaction		%

	Symbol (Greek letters)	*Description*	*Value*	*Unit*
	φ	Constant in the N formula to calculate N application rate		
Assigned	Γ	Clay content		%
Assigned	Ψ	Machine weight for the back and front axles		(ton/axle)
Assigned	Δ	Affected area (percentage), (for ploughing 0.5 is subtracted from this value due to the fact that one side of the tractor runs in the furrow directly)		
Assigned	Θ	Working width of the equipment		m
Assigned	Π	Pressure in the back and front tyres		KPa
Assigned	ξ_1, ξ_2, ξ_3, ξ_4,	Crop specific constant in the yield used for calculations of yield according to N application rates		

Assigned	ε_C	Emission factor specific for three groups; cereal crops, peas and grass/clover giving the nitrogen emissions in percentage of the yield to air from plants		%
Assigned	ε_{DirS}	Emission factor giving the N_2O emissions according to total N inputs to the soil	1.25	kg N_2O-N/kg N input
Assigned	λ_{ElGr}	Grid energy losses during the transfer of electricity from the power plant to the energy user	9%	%/MJ
Assigned	λ_{ElPrCo}	Production and distribution costs for generating electricity, expressed in energy	~ 3.2%	%
Assigned	ε_{InDirA}	Emission factor for estimating indirect emissions of N_2O from nitrogen lost to air	1	%
Assigned	ε_{InDirW}	Emission factor for estimating indirect emissions of N_2O from nitrogen lost as leaching	2.5	%
Assigned	η_{MF}	Nitrogen content in mineral fertilizer		%/kg
Assigned	$\underline{\varepsilon}_O$	Emission vector for oil combustion for drying grain		kg, MJ
Assigned	α_{OF}	The ammonium content in organic fertilizer		%
Assigned	η_{OF}	Nitrogen content in manure		%
Assigned	λ_P	P losses due to surplus P- application to the soil	0-20% own assumpti on	%
Assigned	γ_S	Soil moisture, rated on a subjective scale from 1 (very dry) to 5 (very moist).		
	a	Area used for growth of a crop		hectare
Assigned	β	Background leaching per district and for soil type used in the Farm model to calculate N leaching		kg N/ha

Calculated	γ_h	Water content in grain at harvest		%
Assigned	γ_r	Desired water content for grain ready for delivering or storage		%
Assigned	$\delta_{i,j}$	Drainage P loss specific value for a district		kg tot P/ha
Assigned	ε_{AMF}	Nitrogen emission factor for applications of mineral fertilizers		%
Assigned	ε_{AOF}	Nitrogen emission factor for applications of organic fertilizers		%
Assigned	ε_{Dp}	Emission vector for production of diesel		kg, MJ/ha
Assigned	ε_{Ep}	Emission vector for production of electricity		kg, MJ/ha
Assigned	$\varepsilon_{Fu(n)}$	NOX, SOX, CH_4 and N_2O-emission for different machine operations *n*		kg/MJ
Assigned	ε_{Gp}	Emission vector for production of natural gas		kg, MJ/ha
Assigned	ε_{Op}	Emission vector for production of oil		kg, MJ/ha
Assigned	ε_{PMF}	Emissions and energy use for production of artificial fertilizer		kg, MJ/kg
Assigned	η	Nitrogen content in the fertilizer		%
Assigned	λ_{NOF}	kg extra N leached/ton applied organic fertilizer ('Farm model' N-leaching)		kg N/ton dm
Assigned	μ		See Appendix 1	
Calculated	$\Pi_{1\text{-}PriE}$	Production of the energy carrier electricity in the power plant		MJ
Calculated	$\Pi_{2\text{-}PriE}$	Total primary energy for electricity use		%
Assigned	$\Pi_{2\text{-}PriE\text{-}Fo}$	Share of fossil primary energy in electricity mix	74 Sweden, 6 Brazil	%, %
Assigned	Π_{PriD}	Primary energy conversion factor for diesel	1.06	%
Assigned	$\Pi_{PriD\text{-}Fo}$, $\Pi_{PriO\text{-}Fo}$, $\Pi_{PriG\text{-}Fo}$	Share of fossil primary energy for diesel, oil and natural gas	100	%

Assigned	Π_{PriG}	Primary energy conversion factor for natural gas	1.07	%
Assigned	Π_{PriO}	Primary energy conversion factor for oil	1.05	%
Assigned	ϱ	Crop index for increasing or decreasing the N leaching ('Farm model' N-leaching)		
Assigned	$\sigma_{i,j}$	Surface P loss specific value for districts		kg tot P/ha
Assigned	T	Tillage time index, when index >1 the N leaching increases ('Farm model' N-leaching)		
Assigned	ω_C	Crop content of N, P, K and Cd		%

This is FOOD 21

FOOD 21 is an interdisciplinary Research Program dealing with issues of a sustainable food chain, from production to consumption. The most important goals are to provide suggestions for solutions concerning the weak links in Swedish agriculture and food production. The consumers should feel comfortable about food quality and production methods when purchasing food. A set of objectives for sustainability has been developed concerning crop production, animal husbandry, product quality, consumers and producers to encompass research and evaluation of new production methods and means. The Foundation for Strategic Environmental Research, MISTRA, is financing the Program over an eight-year period starting in 1997. Twenty-five doctoral candidates and some 75 senior researchers are involved. The Swedish University of Agricultural Sciences is the centre of activities but research is also conducted at the universities in Gothenburg, Umeå, Lund and Uppsala.

For more information see www-mat21.slu.se

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